CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Despite the advances already made in diagnosing eye diseases, accessing quality eye care services is still a challenge in developing countries. The chronic absence of eye care services in the rural communities in the developing countries and the difficulties encountered by the patients in consulting eye doctors have pushed some patients to seek self-help with its attendant consequences (Merck, 2006). Such self-help often culminates to self-medication. This may include use of un-recommended eye drugs, use of traditional harmful medications and use of other concoctions such as urine, engine oil, honey, sugar, holy water and breast milk. Also, some blinding eye conditions such as glaucoma and central retinal vein occlusion do not leave trace of early warning signs to the patient before they hit. Furthermore, Kurniawan et al.(2014),noted that in reality, poverty stops people in the developing world from consulting an eye doctor regularly. Thus, many patients do not get appropriate treatment for their eye disease until it is too late. Hence, a simple eye disease which could have been treated with appropriate eye glasses or recommended drugs may often propagate to blindness. If there is but a standard place or health kiosk where the patients could get reasonable eye-check attention, the current level of global blindness could have been abated to acceptable level (Serge & Tricia, 2012).Unfortunately, the rural communities are characterized by challenging conditions such as difficult terrain/topography, lack of good road network, lack of adequate electricity supply, lack of good communication facilities, lack of social infra-structure (pipe-born water, accommodation, standard market and leisure centers) (Ntsoane & Oduntan, 2010). These factors have made living in and visiting the rural communities less attractive to the eye care personnel. Consequently, setting up standard eye clinic in these areas is not considered a cost-effective investment. The result is that the distribution of eye clinics and doctors in most developing

countries is skewed towards the urban cities, thereby leaving the eye care services in the rural communities chronically under-served! (Abdull, et al., 2009). It is therefore evident from the aforementioned that the problem is from the health system in practice today in which patients (are forced by circumstances to) consult their doctors only when they are sick. Development of an automated eye diagnostic system which could detect eye diseases in the absence of the eye doctors, could help a lot in provision of un-interrupted and quality eye care services in remote and inaccessible communities.

Several efforts were made by researchers in the past in attempt to developing a self-automated system that could diagnose eye diseases in the absence of eye doctors. The existing models used various expert system methods, with each having one setback or the other such that the diagnostic output are still far outcry from the clinical expectations. Most of these models relied on production rule (rule base) as method of knowledge representation. Using production rule alone has its challenges in representing complex data structure for all possible evidences and their corresponding hypothesis which are often encountered by the domain experts in real life. To get around this challenge, object-oriented data structure had been tried of recent to drive rule base systems. Eye disease diagnosis requires input of symptoms by the patients, but most patients are not very certain about the full characteristics of their symptoms and thereby leaving behind the possibility of uncertainties (Bhupendra, 2016). These uncertainties which are intrinsic in most medical diagnostic systems were managed by the existing systems using mostly Bayesian network, fuzzy logic and Dempster-Shafer methods with sparing use of certainty factor method. Using Bayesian network, fuzzy logic and Dempster-Shafer methods do not give the patient the opportunity to weigh his/her symptoms thereby leaving out uncertainty management which is an intrinsic aspect of expert systems. It is therefore pertinent that development of a diagnostic system that could consider or manage the uncertainties emanating from the patient could improve the diagnostic quality.

Another essential input parameter in the diagnosis of eye conditions is the visual acuity status of the patient (Jesse et al, 2010). The visual acuity expresses the condition of the eye at each point in time. Hence each eye condition/disease has associated visual acuity status. The existing system had applied various methods of visual acuity measurement ranging from Snellen chart analogue to interactive projection system. Unfortunately, the existing system could not integrate the symptom input with the visual acuity status of the patient, thereby exposing diagnostic output to unreliable discrepancies as there is no way the patient's claims are verified.

From the foregoing, it is evident that a reliable eye diagnostic system shall have the ability to consider the visual acuity of the patient, the symptoms and the degree of uncertainties associated with both the symptoms and the diseases. Therefore, the proposed model shall fulfil above expectations by measuring the visual acuity as well as collecting symptoms from the patients with their associated certainty factors, analyze these input values together with the rules supplied by the domain experts and then proffer diagnosis. This could be achieved by designing an expert system model that could use certainty factor as a reasoning tool and rule base for knowledge representation.

1.2 Statement of the Problem

Each eye disease condition affects the functional quality of vision and invariably affects the visual acuity of the patient. Therefore, consideration of the level of visual acuity of a patient and matching this with the symptoms presented by the patients are inseparable determinants in diagnosis of eye diseases,(American_Optometric_Association, 2016). This implies that anefficient eye diagnostic model shouldconsider the visual acuity of the patient(Gary & Jeniffer, 2016). Unfortunately, existing diagnostic models rely mainly on the symptoms, signs and at times laboratory results as supplied by the patients without considering the visual acuity of such patients.The existing automated visual acuity

systemcould only offer diagnosis or measure visual acuity but not both despite the inseparability of the duo in eye diagnosis (Jacobs etal., 2014). Furthermore,grading of symptoms by patients with respect to degrees of uncertainties varies from one patient to another. Hence, if a model was to rely solely on the claims made by the patients, such a model should also allow the expression of the degree of certainty with which the patient has provided each symptom. Most existing models rely on Bayesian network as a method of reasoning but Bayesian model does not evaluate the level of belief or disbelief a patient has but relies on prior probability values supplied by the doctor during knowledge acquisition and thereafter datamines the causal relationship between the disease and symptoms. Existing models also depend on large databases with assumption of complete independencies between coexisting variables (symptoms), an assumption which cannot hold in all cases and which has also affected the range of eye diseases diagnosed, which currently stands at twelve. Therefore, a gap in technology is evident in the existing models and may have created credibility issuesamong the target users (Kragt, 2009) and (Zhang , 2006) as most of the models still wander at experimental level. The existing eye diagnostic system therefore is not designed for small knowledge bases as it uses Bayesian network, does not measure or use visual acuity as a way of verifying or validating patient's claims, does not allow the patient to provide the level of confidence or belief in the information he or she has supplied and does not integrate both diagnostic and visual acuity measurement into a single platform as expected in modern times (Shaun, 2017).

1.3 Aim and Objectives of the Study

The aim is to develop a certainty factor reasoning model for eye disease diagnosis

The specific objectives are to:

a) Present or formulate the certainty factor reasoning model for eye disease diagnosis

b) Analyze and design the certainty factor reasoning based expert system for diagnosis of eye diseases.

c) Develop the certainty factor reasoning based expert system for diagnosis of eye diseases.

d) Evaluate the performance of the proposed system by comparing it with the existing systems.

1.4 Significance of the Study

This study is significant as follow:

a) Doctor's time will be saved since only genuine and serious cases will consult doctors. The spare time could be invested in research, literary work and other clinical activities.

b) The system when implemented will serve as both training and learning tools to the medical students, general practitioners and other paramedics

c) Prompt and early detection of eye diseases by the system could help in reduction of global blindness.

d) Reduction in global blindness will translate to having more able-bodied citizens who could contribute positively to the growth of the economy of the state.

e) The patients could learn disease characteristics with the system and then be on watch-out for early signs and symptoms at first occurrence.

f) The system could serve as ocular first aid advisory in cases of ocular emergencies.

g) Since the system could be located closer to the rural dwellers, it will save the patients the cost and risk of travel to urban cities to seek eye care services

h) It will encourage implementation of certainty factor as a reasoning model in other diagnostic and troubleshooting expert systems

1.5 Scope of the Study

The scope of this work is limited to the expert systems meant for eye disease diagnosis. It covers the diagnosis of eye diseases which could be detected through diagnostic questions and visual acuity assessment only. The expert system is limited to the genre which uses rule base method for knowledge representation, certainty factor method for reasoning under uncertainty and object-oriented analysis and design method for data management.

1.6 Limitations of the Study

a) **Few eye clinics useautomated diagnostic systems**

Only few eye clinics within the study region could afford automated eye diagnostic system while the majority are still using manual approach. Therefore the number of eye clinics available for selection as study centers for the analysis of existing system was limited.

b) **Paucity of data in study area**

Accessing relevant literatures for models which combine both visual acuity measurement and eye diagnosis into a single platform is rare. Consequently, getting adequate literature and data for comparison with the developed model has set a limitation to the extent of this study.

c) **Fear of job competition by the eye doctors**

During the process of knowledge engineering in which the domain experts were approached for release of information on eye disease diagnostic procedures, some eye doctors were skeptical and suspicious of the study as according to the comments made by some of them, if the patients could be testedwithout seeing eye doctor, they may not visit their doctors as frequent as they used to. Therefore, fear of direct or indirect job competition had made the domain experts (eye doctors) become economical with information they provided.

d) Dynamic and variable knowledge base

Eye Medicine is a fast-expanding field in terms of knowledge and way of management of eye conditions. Practices which are considered safe today will tomorrow become obsolete and forbidden. Although the system's knowledge base was built dynamically bearing in mind the nature of this fluctuating information, nevertheless developing expert system under this scenario has made it almost impossible to add the most current information on signs, symptoms, risk factors and treatment plans of eye diseases used in this dissertation.

e) Paucity of resource materials in domain area

The system was designed to measure the visual acuity as well as diagnose eye conditions. The integration of two different eye examination and diagnostic protocols into one system is a rare invention. The systems already available are either visual acuity tester or diagnostics and not both. Therefore, getting enough resource materials during development and system analysis of this dissertation was both challenging and scarce.

1.7 Definition of Terms

Amsler chart: A chart used to access and record the quality of the central vision.

Blindness: This is a condition in which an individual has no sight at all in the best eye or the sight he/she has could not enable him execute commonest tasks that are sight-demanding.

Color blindness: This is a condition in which an individual cannot recognize a particular color or group of colors.

Color Vision Test (CVT): This is one of the eye tests performed to evaluate how well an individual can recognize and differentiate colors.

Cone: The visual cell inside the eye that is responsible for resolution of image and acute vision.

Consultation: This is a session between a doctor and a patient with an intent of providing medical

services to the patient.

Contrast Sensitivity Test (CST): This is one of the eye tests performed to evaluate how well an individual can distinguish the foreground from the background and vice versa. A perfect contrasting pair is Black (foreground) on white (Background) or White (foreground) on Black (background). For example in the computer displays, the FontColor is declared as ForeColorwhile the background is declared asBackColor.

Cornea: This is the eye's transparent front coating.

Expert system: A computer program that applies artificial-intelligence methods to problem-solving

Glucometer: An Instrument used in measuring the blood sugar level.

Integrated system: This is a computer suite which incorporates many eye test logics into one platform.

Hyperopia: This is another name for long-sightedness

Keratometry: Instrument used to measure the curvature of the cornea.

Low vision: This is a situation in which even with the best surgical, optical and drug intervention, an individual's sight is still very poor that he/she cannot carry out common activities of daily living (such as watching TV, reading newspaper, cooking, signing bank cheque, crossing road, etc) without need for external assistance.

Long sightedness: This is a refractive error condition when an un-aided individual can see better at Far than near

Macular Function Test (MFT): This is one of eye tests performed to evaluate the quality of an individual's central vision.

Medical Assistant: This is a non-expert who does not specialize in domain area but is trained or enabled to perform some tasks which a genuine expert can do.

Model: A simplified version of a system which shows some or all the aspects of the internal workings of the system withthe intentionof analyzing and solving problems or making predictions.

No Light perception: This is a condition when an individual is completely blind

Ophthalmic/Ocular: That which pertains to the human eyes.

Ophthalmoscopy: Instrument used to assess the healthiness of the inner eye.

Optical: That which pertains to Light.

Optotype: This is the characters, symbols and images used in visual acuity test charts

Presbyopia: This is a condition when an individual gradually loses the ability to read near print as he or she grows old.

Refractive Error: The eye condition that can be corrected with eyeglasses.

Retina: The tissue in the eye that receives and transmits the image of an object of regard.

Retinoscopy: Instrument used to determine the refractive error of the eye.

Sphygomanometer: An instrument used to measure the systemic blood pressure.

System: In this dissertation, when written alone without further qualification, system means implementation of "Certainty Factor Reasoning Model For Eye Disease Diagnosis" alias CFRMFEDD.

Vision/sight: A word used interchangeably in this dissertationto imply seeing

Visual Acuity Test (VAT): This is one of the basic eye tests performed to evaluate how sharp an individual can recognize and see objects.

Visual Cortex: The area in the brain responsible for the coordination and perception of visual stimulus.

Visual Field Test (VFT): This is one of eye tests performed to evaluate the extent of vision either in central or peripheral (side) region (measured in angular degrees).

WHO: World Health Organization.

CHAPTER TWO

LITERATURE REVIEW

2.1 Artificial Intelligence in Medicine

Chakraborty (2010), believed that John McCarthy who first coined the term “Artificial intelligence” in 1956, defined Artificial intelligence as the “The science and engineering of making intelligent machines” especially intelligent computer programs (systems). Winston (1977), also defined Artificial Intelligence (AI) as the study of ideas which enables computers to do the things that make people regard it as intelligent. The central goals of Artificial Intelligence are therefore, to make computers more useful and to understand the principles which make intelligence possible.

These intelligent systems as explained by Imre & Janos (2008) "are the systems that provide a standardized methodological approach to solving important and fairly complex problems and obtain consistent and reliable results over time". In other words, an intelligent system is a system that is capable of exhibiting behaviors, features and characteristics which humans may consider intelligible. Such behaviors include the following: reasoning, interaction, problem-solving and learning. In a study conducted by Shiva & Ahmad (2011), in a group of psychologists, computer users and AI researchers, they summarized that an intelligent machine shall possess some of the following features: Learning, Adaption, Goal-Orientation, Using knowledge, Problem Solving, Reasoning, Applying Experience, Generalization, Perceiving Relationships, Planning, Autonomy, Perceptional Recognition Classification, Quickness, Flexibility and Pattern Recognition (See Figure 2.1).

AI has successfully been applied to various aspects of human endeavor and most especially in medicine. AI requires large databases (Knowledge base) to enable its capability in making decisions. Such large amount of data reservoir is one of the characteristics of modern medicine and is usually generated in

medical consultations almost on daily bases. Medicine, therefore provided an already made platform suitable for earlier application of AI mostly for decision support, diagnosis and analysis of patient's clinical data.

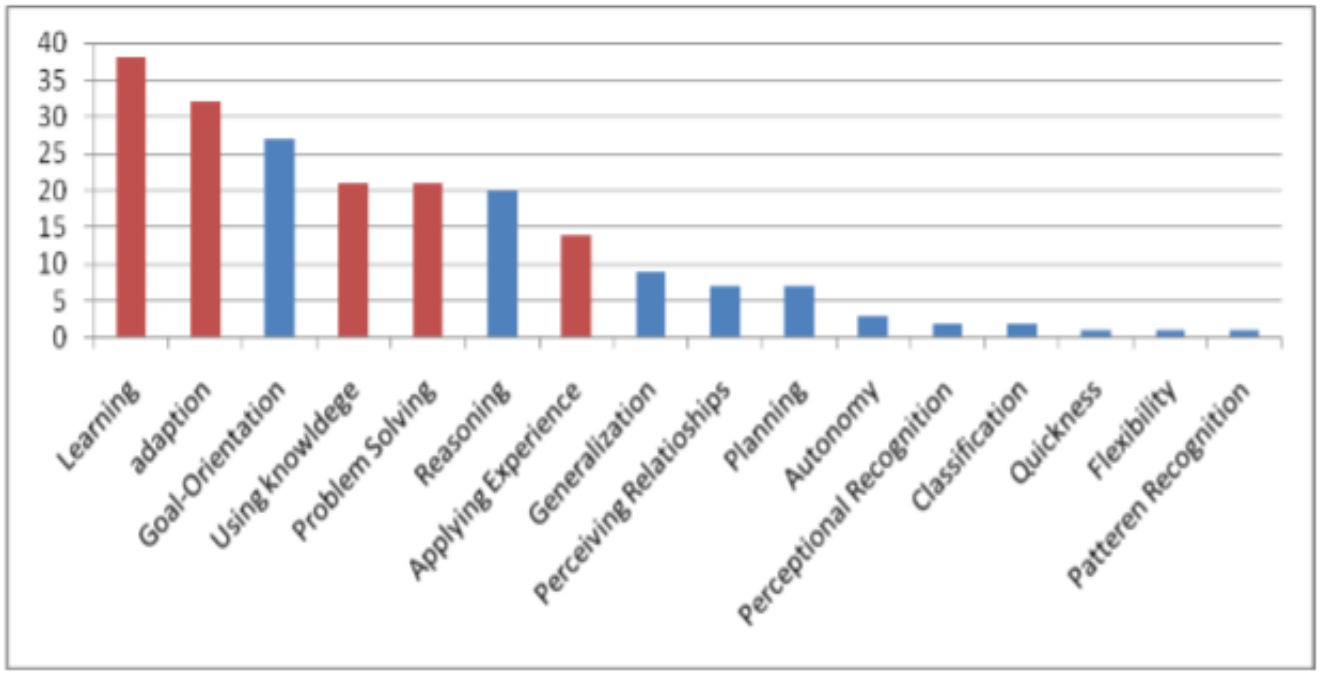


Figure 2.1: Features of intelligent agent (Shiva & Ahmad, 2016)

Unfortunately, since medicine is dealing with human life, any mistake with machines could be disastrous, hence the worrisome concern and debates amongst the early researchers on the rational and justification of entrusting issues of life and death on mere machines.

In one of his concerns to the safety of relying on AI for human health, McCorduck & Pamela (1979) asserted that "Artificial Intelligence in Medicine is specialized to medical applications. Researchers in Artificial Intelligence in Medicine need not engage in a controversy! Although we employ human-like

reasoning methods in the programs we write, we may justify that choice either as a commitment to a human/computer equivalence sought by some or as a good engineering technique for capturing the best-understood source of existing expertise on medicine--the practice of human experts"

In fact, most of the early researches in AI uses various techniques and algorithms to achieve their goals. Chakraborty (2010) in one of his publications claimed that AI techniques include: describe and match, goal reduction, constraint satisfaction, tree searching, generate and test, rule-based systems, neural networks, generic algorithms and reinforcement learning. This has made AI to be categorized further into branches, such as: logical AI, search AI, pattern recognition, knowledge representation, inference, common sense knowledge and reasoning, learning, planning, epistemology, ontology, heuristics, generics, genetic programming. Artificial intelligence technology therefore, is applied in the following areas: game playing, speech recognition, understanding natural language, computer vision and expert systems.

2.2 Expert /Intelligent Systems

Expert Systems (ES) are computer programs that are derived from a branch of computer science research called Artificial Intelligence (AI). AI's goal is to understand intelligence by building computer programs that exhibit intelligent behaviors. It is concerned with the concepts and methods of symbolic inference, or reasoning, by a computer, and how the knowledge used to make those inferences will be represented inside the machine. Expert system therefore, has become an important application area of artificial intelligence (Engelmore & Feigenbaum, 1993).

According to Jackson(1998), an expert system is a computer system that emulates the decision-making ability of a human expert. Hence, Expert systems are designed to solve complex problems by reasoning

about knowledge, like an expert, and not by following the procedure of a developer as is the case inconventional programming (Regina & Daryl, 2012). Expert systems is also referred to as knowledge based systems as it is an application instance of AI programs that achieve expert-level competence in solving problems in task areas by bringing to bear a body of knowledge about specific tasks. Therefore, the term expert systems is reserved for programs which knowledge base contains the knowledge used by human experts, in contrast to knowledge gathered from textbooks or non-experts. Also Sotos (1990), defines **ES** asa computer system that emulates the decision-making ability of a human expert". In other words, expert system should be able to solve complex problems by reasoning about knowledge and also performs activities that lie within the domain of a human expert. **McTear** (2002)**, however stated that a**n expert system has a unique architectural structure, different from traditional programs. It is composed of three major components, vitz: inference engine (an independent constant), knowledge base (a dependent variable) and the interface. These components can be further expanded to include the explanation system. The inference engine reasons about the knowledge base like a human, while the knowledge base stores dynamically the knowledge of an expert (the expertise) and the interface provides the communication link and interaction with the user (See Figure 2.2)

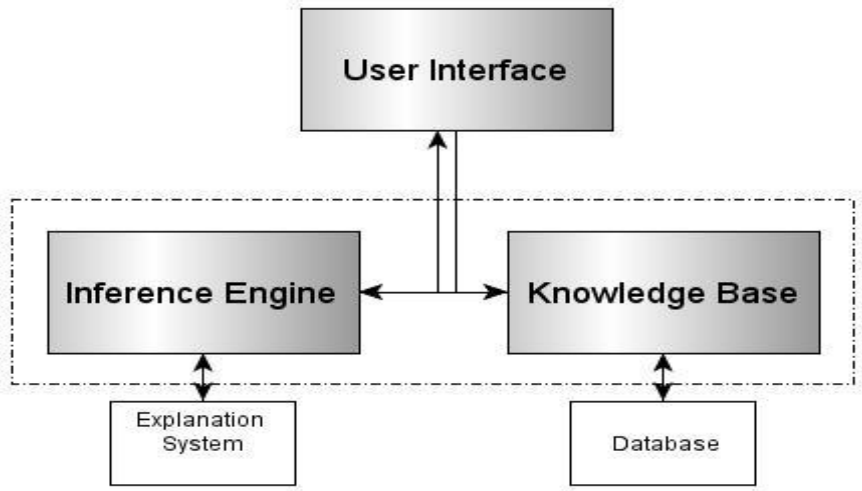


Figure 2.2: Expert Systems Architecture (Roger, 1985)

Jags (2012) explained that since ES covers almost all knowledge domain, it was more convenient for earlier researchers to further classify expert systems into the following seven domain areas: diagnosis and troubleshooting, classification and identification, instruction, interpretation, design and planning, monitoring and control, prediction and finally repair. The area of human expertise which a particular expert system focuses at is known as the knowledge domain (or simply domain) and in this study; our domain is Eye Diagnostics. The development of expert system is a team work that cuts across various professionals. For instance, the task of providing the actual knowledge is done by a domain expert who is a specialist in the domain area (and in this case an eye doctor) and must be willing to describe and provide his knowledge in a form intelligible to the system developers. This knowledge in turn will be extracted and stored into the system as knowledge base by the knowledge engineers. The actual task of implementing the expert system in a particular programming language environment lies within the province of system programmers. Finally, the task of developing new expert systems' techniques and updating or modifying the existing ones lies within the province of knowledge researchers.

2.3 The Knowledge Base

The knowledge stored in expert system represents the expertise of the domain expert. This knowledge is often a pool of experiences gathered as pieces of information by the expert over a long time. For biological systems including the field of medicine, the amount of this information can become very wide and complex with time, hence the need for organized and systematic knowledge management approach. Aniba, et al. (2009) in a publication explained how a knowledge-based expert system could improve management of this biological information. Knowledge can be either factual or heuristic. Factual knowledge is common knowledge that is verifiable and available to all in the domain area but heuristic

knowledge is non-verifiable knowledge that is only available to the particular domain expert as part of his skills or experiences acquired over a long period of practice. Real life experiences involve use of both factual and heuristic knowledge and if expert systems are to mimic the human expert in solving practical problems, there must be ways by which both types of knowledge must be represented in the system. The more qualitative knowledge an expert system has, the more powerful is its ability to reason and make reliable decisions. Therefore as more information becomes available to the domain expert, the knowledge base in the expert system will be upgraded, modified or changed entirely in order to represent facts of the moment. This dynamic knowledge upgrade may be done by the system itself or by external change. This ability to modify the knowledge base has conferred the power of learning, adaptation and evolution to most expert systems.

Shankar et al. (2003) in his publication on decision support systems to identify different species of malarial parasites had earlier opinioned that "encoding human expertise in the computer is challenging". "The difficulty rests on our lack of understanding of how people know what they know". It also rests on technical problems of structuring and accessing large amounts of knowledge in the machine. For instance in a consultation session between a doctor and a patient, the doctor in addition to his medical knowledge, uses his common sense (heuristic or fuzzy knowledge) to associate some symptoms with some non-medical activities that may have provoked them. For an expert system, this common sense is partially lacking as the computer mostly bases its deductions and inferences with the information clearly made available to it via its knowledge base, although nowadays the computers can also apply fuzzy logic technology in a limited sense. However, like every other new inventions, when the benefits outweigh the demerits, modern man has no better option than to proceed with the new invention.

As noted by Szolovits (1982) in his review of expert systems, he stated thus: "relying on the knowledge of human experts to build expert computer programs is actually helpful for several additional reasons: First, the decisions and recommendations of a program can be explained to its users and evaluators in terms which are familiar to the experts. Secondly, because we hope to duplicate the expertise of human specialists, we can measure the extent to which our goal is achieved by a direct comparison of the program's behavior to that of the experts. Finally, within the collaborative group of computer scientists and physicians engaged in Artificial Intelligence in Medicine (AIM) research, basing the logic of the programs on human models supports each of the three somewhat disparate goals that the researchers may hold". The first of this goal is to develop expert computer programs for clinical use, making possible the inexpensive dissemination of the best medical expertise to geographical regions where that expertise is lacking, and making consultation help available to non-specialists who are not within easy reach of human experts (or consultants). Secondly, to formalize medical expertise, to enable physicians to understand better what they know and to give them a systematic structure for teaching their expertise to medical students. Thirdly, to test AI theories in a "real world" domain and to use that domain to suggest novel problems for further AI research.

2.4 Knowledge Representation

Knowledge representation in expert system is a matter of long debate by early researchers. Hvam (2008) explained in his publication, the usefulness of application of knowledge representation and its association with the forms of reasoning in expert system environment.One of the disturbing questions is "Is it possible to represent or model all the expertise of an expert in a mere machine?It is noteworthy that the rationale behind modeling the behavior of a computer system on the expertise of human medical consultants is by no means logically necessary. If it is possible to understand the various inter-relationships between body functions and disease formation, then it is possible to model the detailed

disease processes which disturb health. In principle, one could perform diagnosis by fitting a model to the actually observable characteristics of the patient in question. Modeling the knowledge of human expert in order to deliver a reliable clinical diagnosis and judgment is not as easy as it may sound. Many researchers are much worried about the reliability of entrusting health care on machines since our present knowledge of human function is still a far outcry from perfection and also for the fact that the premises/assumptions under which most expert systems stand are still questionable. In making his input on the raging debate,Roger (1985), in one of his works analyzed the questionable concerns. According to him, the practice of expert system is based on seven basic assumptions or premises about the following characteristics of an expert and his expertise, : uniqueness of knowledge (ie, the best person to ask of knowledge domain) , task efficiency (good and better than others), knowledge representation (his knowledge can be extracted and represented in computer system), fuzzy or heuristics representation (his special experiences, non-formal unique skills, fuzzy as it may be could still be captured) , knowledge base (the knowledge could be represented as logical database) , consensus (groups of experts could still agree to make new rules and validate facts) and finally modification capability (logical updates in terms of knowledge additions and deletions could still be possible to add learning capability). He therefore expressed the opinion that knowledge is mostly represented in expert systems symbolically as series of linked rules and hence is referred to as rule based or production rules. These rules are used in reasoning process. The ability to reason confers to the system its intelligent behaviors.

2.5 Knowledge-Base Generics as variant of Knowledge Representation

Over time, it has become necessary to classify gamut of expert systems available according to its method of knowledge representation as knowledge base generics. Hence, Chandrasekaran (1993) suggested task specific knowledge base, some of which are enlisted as follow: Rule based systems (Production Rule or simply Rule), Frame based systems (Unit/Frame), Hybrid systems, and Model based

systems, Ready-made systems and Real time systems. The rule based systems employ series of IF-THEN-clauses to make inferences about the knowledge base. The "IF" section contains the CONDITION (or series of conditions) that if satisfied triggers the CONCLUSION in the "THEN" section. This process of reasoning involves searching through chains of conditions and matching them with one or more conclusions. Therefore, expert systems employ arrays of search strategies such as depth first search, breadth first search, best first search, hill climbing, beam search, etc.

Young(2009) disclosed that Frame based system uses a unit, schema or list as a representation of data structure that has typical knowledge about a particular object. A component of a frame that describes a particular attribute of the frame is known as a slot. Therefore, frame based generic is an application of object-oriented programming in expert system environment. The datum that is associated with an entity represents the object's attribute. The hybrid system employs a combination of various new concepts such as fuzzy logic, neural network, Bayesian/belief network, etc.

2.6 Inference Process

Inference is a process of making deductions from available facts and rules. In humans, most every day decisions are based on making appropriate inferences. Kelly (2017), gave five simple techniques applied by humans to make inferences as follow: 1) Identifying an inference question or Problem Goal, 2) Trusting the available facts and rules, 3) Hunting for clues, 4) Narrowing down the solution/choices and 5) Practicing or repeating if necessary. Inference process by the expert system implement above techniques through search mechanism during which conditions are searched to match conclusions. This involves application of one form of logic or the other to make deductions or inferences and in some cases may reason through learning(Freeman et al.,2000). Basically, the inference engine may apply any or combination of the following logic types: propositional logic, predicate logic, epistemic logic, modal

logic, temporal logic, fuzzy logic, zeroth-order logic, etc. According to Shwe, etal. (1991), Pearl (1988) and Lauritzen & Spiegelhalter(1988), most of the above techniques apply probabilistic reasoning to make valid inferences. During a search process while solving a problem, the expert system chains through sets of rules, instructions, conditions or conclusions. If the search is in the direction of conditions to conclusion then it is called forward-Chaining. However, if it is in reverse direction, it is called backward-chaining. However, when the search strategy employs both forward and backward chaining technique then it is referred to as mixed chaining. The type of chaining strategy used by an expert system at any point in time depends on the task at hand. For instance, to make diagnosis in situations when the symptoms of a patient is already known by the doctor necessitates the use of forward chaining technique to search through arrays of known symptoms until a matching diagnosis or conclusion is reached. Conversely, in situations where the doctor first makes a tentative diagnosis of an illness (especially in emergency situations and comatose patients) and proceeds to confirm the supposed symptoms by observing the symptoms later, then backward chaining technique is rather used. In some complex situations, the inference engine may have to approximate its decisions(Heskes et al., 2003; Murphy et al.,1999). The complexity of the decisions to be taken may affect the performance of inference engine and in some cases may even overweigh it. For instance, as Mooij, etal.(2007) described a situation in which the "Belief Propagation (BP) algorithm inference method" they applied in the development of "Promedas Network Systems" yielded too large unacceptable errors, and by modifying the inference logic to "Loop Corrected BP inference algorithm", the errors were brought down to a significant level of acceptability for the purpose of medical diagnosis.

2.7 Reasoning under Uncertainty

In many situations, where and when the data is incomplete, fuzzy or inexact, expert system has to reason under uncertainty(Diez & Druzdel, 2006). In real life event such as a consultation session between a

medical doctor and his patient, it is not always possible for the doctor to have all the information concerning a particular disease condition of his patient. For a doctor to make a diagnosis of the patient's ailment, he needs to gather information from the patient through physical observation, direction questioning and investigative (laboratory) results. All these sources of information have some level of bias that often lead to pitfalls in medical diagnosis(Klein, 2005). For instance, the patient may not be exactly certain of the description of his/her symptoms in terms of severity, duration and time of onset. The laboratory and other investigative results are not error proof. Also the doctor may not be very certain (i.e. 100% sure) that the combined occurrence of group of symptoms and investigative results always lead to a particular disease. This becomes even more challenging when more than one disease share a group of similar symptoms as found in eye care medicine. Therefore, the data used by medical expert system are prone with some degrees of uncertainties and bias. If the expert system were to be trusted, there must be a non-biased method of transforming or modifying the input data to make a balance and less biased inference or diagnosis.

According to Bhupendra (2016) the possible sources of such uncertainties include: Weak logical implications (between hypothesis and evidence), Imprecise language of expression (of Curse-effect relationship) Unknown or incomplete data and Disagreement among domain experts (about cause-Effect relationship). Since these uncertainties could not be avoided, several methods are employed in expert system technology to manage them. Some of the popular methods employed by researchers include Probability theory/ belief network, Certainty factor, Fuzzy logic and Dempster-Shafer as discussed below.

2.7.1 Probability Theory/Bayesian Belief Network

According to Mark (2001), “A Bayesian belief network is a graphical representation of a probabilistic dependency method. It consists of a set of interconnected nodes, where each node represents a variable in the dependency method and the connecting arcs represent the causal relationships between these variables. Each node or variable may take one of a number of possible states or values. The belief in, or certainty ofeach of these states is determined from the belief in each possible state of every node directly connected to it and its relationship with each of these nodes. The belief in each state of a node is updated whenever the belief in each state of any directly connected node changes. This belief system assigns the initial probabilities values, known as prior probability to each hypothesis-evidence pair that describes a causal relationship between the hypothesis and the evidence. This prior probability value is used to calculate the final probability referred to as posterior probability. As more evidences become available, the prior values must be given for each combined and conditional hypothesis-evidence couple and new posteriori value will be calculated. However, the number of probability values needed to be provided by the expert and the number of combined probability to be calculated increase exponentially as the number of variables (evidences) increases. Since it is almost impossible for an expert to provide with certainty the vast amount of probability values required as the number of variables increases, the computation becomes more complex and must require large amount of database. While summarizing the implementation of Bayesian network method in expert system environment Kragt(2009) and Zhang (2006) outlined its advantages and disadvantages. According to them, a major advantage is that Bayesian network has sound theoretical foundation in probability theory as it can readily handle incomplete data sets. It also allows one to learn about causal relationships and hence can readily facilitate use of prior knowledge. In addition, it can provide an efficient method for preventing the over fitting of data. Conversely, they noted that Bayesian Networkrequires a huge amount of probability values as primary data input in order to construct a knowledge base. As experts are usually uncertain and

uncomfortable about providing probabilities of events, it is likely that when the number of probabilities required is much, the expert may resort to mere guess work. Moreover, the relevant prior and conditional probabilities are often statically based on population studies and therefore the sample sizes must be sufficient so that the probabilities obtained are accurate. However, in situations where the expert has provided the values, the consistency and comprehensiveness of these values become questionable. The associations between the hypothesis and evidence are reduced to mere numbers and thereby removes relevant information about the hypothesis-evidence relationship that might be needed for successful reasoning about the uncertainties. The reduction of associations to mere numbers also strips Bayesian network the power of explanation. Consequently, this has affected the acceptability of this method by physicians as they distrust systems that cannot provide explanations describing how a conclusion was reached.

2.7.2 Certainty Factor (CF) Method

Illinois (2006) noted that certainty factor method is an alternative method used in expert system to manage or reason about uncertainty. It represents a difference between the belief and disbelief which the supplier of information has about the information he or she has supplied. A weight is attached to such conviction. The value of such weight ranges from +1 (Definitely certain) to -1 (Definitely Not Certain) as shown in Table 2.1. Conversely, CF values less than zero are considered as Disbelief while values greater than zero are considered as Belief. These values are given by both the domain expert (doctor) who supplies the hypothesis (disease attributes) and the user (patient) who supplies the evidence (symptoms). When multiple evidences support the same hypothesis (rule) in a joint (AND) association, the CF of each evidence can be conditionally combined by using a minima function, but for disjoint (OR) association, the CF can be combined using a maxima function. In situations when multiple

hypothesis (rule) support the same group of evidence, the individual CF of each Rule can be combined to give the final CF.

Table 2.1 Certainty factor value (Bogdan , 2006).

Term	*Certainty Factor*
Definitely not	−1.0
Almost certainly not	−0.8
Probably not	−0.6
Maybe not	−0.4
Unknown	−0.2 to +0.2
Maybe	+0.4
Probably	+0.6
Almost certainly	+0.8
Definitely	+1.0

Although certainty factor method uses ad hoc probability approach when compared to Bayesian belief network, nevertheless, it is more realistic of situations normally prevalent in medical consultations. As noted again by Illinois (2006), one of the advantages of CF is that it has a simple computational method that permits experts to estimate their confidence in conclusion being drawn. It permits the expression of belief and disbelief in each hypothesis, thereby allowing the expression of multiple sources of evidence. It allows knowledge to be captured in a rule representation while allowing the quantification of uncertainty. The gathering of the CF values is significantly easier than the gathering of values for the other methods. No rigorous statistical base is required as you merely have to ask the expert for the probability values. Some studies have shown that changing the certainty factors or even turning off the CF reasoning portion of MYCIN does not seem to affect the correct diagnosis as much. Therefore, this reveals that the knowledge described within the rule contributes much more to the final, derived results than the CF values. On the other hand, he reasoned that the disadvantage is that it is an approximation of probability theory. Non-independent evidence can be expressed and combined only by "chunking" it

together within the same rule. When large quantities of non-independent evidence must be expressed, this proves to be unsatisfactory, it is then that belief network may hold sway (Heckerman & Shortliffe, 1992).

2.7.3 Fuzzy Logic Method

Vangie (2017) defined Fuzzy logic as a type of logic that recognizes more than absolute Truth or False. It represents the degree of Truth or False unlike in Boolean logic where values are either truth or false. Therefore fuzzy logic values range from 0 to 1. Fuzzy logic is another method of handling uncertainty but concentrates on mapping numerical data (crisp dataset) to fuzzy sets by using linguistic variables, terms and membership functions and then vice-verse. Humans are more familiar with linguistic terms than with numerical or scalar terms in their daily activities. Goiti (2015) inferred that fuzzy logic system has four basic components for processing of fuzzy or uncertain data. The components are Fuzzifier (maps numerical data to linguistic variables as input during fuzzification), Rule (develops rules), Inference engine (combines various rules to make decisions) and Defuzzifier (maps linguistic variables back to numerical data as output during defuzzification). Like all other methods used in handling uncertainties, fuzzy logic has the following advantages and disadvantages (Reus, 1994). The advantage is that it describes systems in terms of a combination of numeric and linguistic symbol as very often system knowledge in real life is available in such a combination. It is inevitable in solving problems for which an exact mathematically precise description is lacking or is only available for very restricted conditions. Fuzzy logic sometimes uses only approximate data, so simple sensors can be used. The algorithms can be described with small amount of data, so memory requirement is low. The algorithms are often quite understandable and robust and in effect they are not very sensitive to changing environments and erroneous or forgotten rules. The reasoning process is often simple, compared to computationally precise systems, so computing power is saved. Fuzzy methods usually have a shorter

development time than conventional methods. Conversely, he argued that the disadvantage is evident from the fact that fuzzy logic amounts to function approximation in the case of Crisp-Input/Crisp-Output systems. In areas that require sound mathematical descriptions and solutions, the use of fuzzy logic may not be suggested as the proof of characteristics of its systems is difficult or impossible, especially in the area of stability of control systems.

2.7.4 Dempster-Shafer Method

Other methods of managing uncertainty considered hitherto require assignment of probability values to unknown data, incomplete data or ignorance and in fact even when there is no evidence. Dempster-Shafer method was introduced to surmount these challenges. Therefore, it is an evidence-based uncertainty management technique which allows one to combine evidence from different sources (independent sets of probabilities) and arrive at a degree of belief (represented by a mathematical object called *belief function*) that takes into account all the available evidence (Sotos, 1990). However Hoffman & Murph (1993) believed that Dempster-Shafer method is a generalization and subset of Bayesian Network, although with the following differences: Evidence is represented as a Shafer belief function rather than a probability density function represented in Bayesian network. Evidence is combined using Dempster's rule of combination which assumes that the observations are independent and have a non-empty set intersection. The computation of the evidence for a proposition does not require prior odds thereby acknowledging the possibility of ignorance.

2.8 Transparency and Explanation Power

As stated earlier, since conclusions made by expert systems are associated with some degrees of uncertainties, it is pertinent that the user of the system must have a level of conviction and confidence on why the system should make a particular conclusion especially when there are other plausible options or

alternatives available. Why must the system be believed? This is especially important in medicine when any mistake could be fatal. Therefore, most expert systems are imbued with power of explanation such that it could respond to user's query on the rationale behind its conclusions. In fact, as rightly put by Feigenbaum et al. (1992), "When an answer to a problem is questionable, we tend to want to know the rationale. If the rationale seems plausible, we tend to believe the answer"

2.9 Expert Systems in Medicine

As vividly captured by Feigenbaum et al. (1992), using Japan as reference case, amongst all the applications of Expert System (ES) considered, there are probably more diagnostic applications of ES than any other type. The diagnostic problem can be stated in some kind of abstract formalism. For instance, given the evidence presenting itself, what is the underlying problem/reason/cause? In fact, Shortliffe (1976), Anjaneyulu(1998) and Masic et al. (1999), emphasized that medical diagnosis was one of the first knowledge areas to which ES technology was applied. Out of the various branches of medical expert systems currently available, the one that is mostly applied in diagnostic medicine is the Clinical Decision Support System (CDSS) (Coiera, 2003). Therefore, looking at automation of some medical procedures and the techniques used by earlier researchers could be a good pointer to the series of successes and failures that have trailed earlier attempts in the design of eye diagnostic systems. The expert system methodologies employed by early researchers in the development of medical diagnostic systems fall into three types:

a) The rule based systems,
b) The frame-based systems
c) The Hybrid systems.

2.9.1 Rule Based Medical Expert Systems

Rule based systems employ sets of rules and facts in making deductions and inferences about the problem area. The following discussions have delved into the methods and techniques used by some expert systems that apply rule base as method of knowledge representation.

2.9.1.1 The INTERNIST-1 System

One of the earlier attempts in designing a rule-based expert system for use in diagnostic medicine was the creation of INTERNIST-1 also known as Caduceus by the group of researchers at University of Pittsburgh. According to Jack(1982; 1990) and Bank (1986) INTERNIST-1 was a rule-based expert system developed from a 4th year medical students course entitled "The Logic of Problem-Solving in Clinical Diagnosis". Over time, the college of medicine at University of Pittsburgh saw the need to automate clinical diagnosis procedure in internal medicine. The fourth-year medical students that were taking the course at that time helped in coding the program, hence INTERNIST-I project represented fifteen-person-years of work, and by other reports may have covered 70-80% of all the possible diagnosis in internal medicine.

In fact, Gregory(1979) noted that the researchers who developed INTERNIST-1 deviated from the standard deployment of Bayesian network or pattern recognition model which were popular and prevalent at that time, but instead used partitioning algorithm as part of its heuristic rules to create problem areas and exclusion functions to eliminate diagnostic possibilities. Hence, INTERNIST-I uses a problem-formulation heuristic to select from among all its known diseases that set which should be considered as competing explanations of the currently-known abnormal findings in a case. A distinction is therefore made between the tasks of formulating such a differential problem and of solving it. INTERNIST-1 therefore employs Pseudo-Bayesian algorithm (Perry, 1990).

Harry(1976) and Randolph & Miller(1982) hinted that this unique methodology (ie: partitioning algorithm) also enabled the system to rely mainly on hierarchical or taxonomic decision-tree logic,

which linked each disease profile to only one "parent" disease class and this technique alone severely limited the scope of INTERNIST-1 as will be seen shortly. It is to be noted that the partitioning algorithm used in INTERNIST-1 empowered it to produce a list of ranked diagnosis based on disease profiles existing in the system's memory. In situations of doubt or unresolved diagnosis, the system may prompt for further data input from the user or recommend for further tests. The intentional deviation from the programming norm as evident in INTERNIST-1 was necessary because the initial standard method used by the earlier researchers to arrive at diagnosis requires complex information processing which bears little semblance to the statistical manipulations of most computer-based systems and this perhaps was responsible for failures of earlier attempts in developing functional medical expert systems. Despite the achievements and progresses made in the development of INTERNIST-1 expert system by the earlier researchers, the system was considered highly restricted as it was designed to capture the expertise of just one man, Jack D. Myers, who was the chairman of internal medicine at the University of Pittsburgh School of Medicine. Also, INTERNIST-I worked best when only a single disease was expressed in the patient, but handled complex cases poorly, where more than one disease condition was present. The simple heuristic nature of INTERNIST-1 is seen to do well on some complex cases however, but falters on cases requiring an analysis from several different viewpoints, e.g., an interaction between the causal mechanism of the disease and the organ systems involved in it. This was due to the fact that the system exclusively relied on hierarchical or taxonomic decision-tree logic, which linked each disease profile to only one "parent" disease class as previously noted. Furthermore, physicians and paramedics desirous to use INTERNIST-I found the training period lengthy and the interface unwieldy. An average consultation session with INTERNIST-I required about thirty to ninety minutes. This is considered too long a time for most busy clinicians.

As summarized by Miller(1982) on the evaluation which was made on the performance of INTERNIST-1 on a series of 19 patients of Massachusetts general hospital, he noted that the present form of the program is not sufficiently reliable for clinical applications. Deficiencies noted included the system's inability to reason anatomically or temporally, its inability to construct differential diagnosis spanning multiple areas, its occasional attribution of findings to improper causes, and its inability to explain its "thinking". Unfortunately, because of these myriads of challenges already noted, INTERNIST-I never moved beyond its original status as a mere research tool. For this sake, Pople (1976) suggested that there is need to incorporate casual reasoning and a sense or temporal progression into future versions of INTERNIST-1 in order to make it more acceptable.

2.9.1.2 MYCIN

MYCIN was another rule-based expert system developed at Stanford University. Its main function was to identify bacteria causing severe infections, such as bacteremia and meningitis, and to recommend antibiotics, with the dosage adjusted for patient's body weight. Buchanan & Shortliffe(1984) inferred that MYCIN was implemented as a weighted rule-based clinical decision support system that has the following major components, vitz: The knowledge base (500 rules), the inference engine and an interactive user-interface. MYCIN uses a modified backward chaining reasoning methodology to search its knowledge base and hence make its inferences. Through this process, the developers of MYCIN were able to reduce the required size of program algorithm from otherwise thousands of lines of traditional codes to only hundreds of lines of codes in the expert system. The user interface presents the session through which the user makes an input by responding to series of diagnostic questions tantamount to what a human physician may ask a patient. It also prompts for relevant test results. MYCIN either arrives at a conclusive diagnosis with given certainty-probability or

narrows down the questions furthermore. Analysis of both the physicians and the MYCIN's correctness to diagnosis scored 80% to physician experts, 65% to MYCIN and less to non-specialist physicians.

As noted by Fisher(1990), Shortliffe(1976) and Shortliffe& Buchanan(1975) , MYCIN was a derivative of another expert system applied in organic chemistry called DENDRAL. MYCIN was originally written in LISP programming language and was also designed to compete in Turing test. The case histories of ten patients with different types of meningitis were submitted to MYCIN as well as to eight human physicians, including a resident, a research fellow, and five faculty specialists in infectious disease. Both MYCIN and the human physicians were given the same information. Both MYCIN's and the human physician's recommendations (as well as a record of the treatment actually received by the patients) were sent to eight outside specialists, completely unidentified as to which recommendation was MYCIN's and which were authored by the physicians. The external specialists gave MYCIN the highest score as far as accuracy of diagnosis and effectiveness of treatment. Moreover, MYCIN was designed to be cloned through a special architecture in which the core or the inference engine (EMYCIN) was semi-separated from the system to such an extent that it could be used to create other Rule-based expert systems that could carry out similar tasks through an appropriate modification of its knowledge base. Some of the latent advantages of MYCIN include its simple but uniform representation of knowledge. Moreover, the system can reason not only with the knowledge in the rules but also about them. This facility has enabled MYCIN to acquire new rules from the expert user and even at instances when the expert and program disagree, it could suggest generalizations of some of the rules based on their similarity to others and also explain the knowledge and usability of the rules by both the system and the users.

Gerven& Van(1970) had earlier commented that the scarcity of empirical data, along with the fact that a huge number of probabilities is needed to fully specify a joint probability distribution, led to the initial

dismissal of probability theory which lacked certain desirable properties which a measure of belief should adhere to. This led to use of certainty factor model in MYCIN. Although, some critics argued that use of certainty factor in reasoning process is justified if independencies between the domain variables (evidences or symptoms) are guaranteed. At the era MYCIN was developed, the state of technology favored a stand-alone main frame system in which the user has to practically type all the relevant patient's information requested by the system. Moreover the power of explanation in MYCIN is poor. Therefore the practical use of MYCIN by the doctors was hampered by the above facts, although in modern time such a system would have been implemented with a personal computer and patient's information would have been stored in appropriate database. However, MYCIN was a proof that use of certainty factor model is a possibility in medical diagnosis.

2.9.1.3 ONCOCIN

Wiederhold et al.(2001), noted that ONCOCIN was developed by Stanford university to surmount the earlier challenges encountered by MYCIN and its predecessors especially as it concerns the power of explanation. Primarily, ONCOCIN was designed to offer medical advice to non-oncologists, resident doctors and clinical assistants in the area of oncology (ie: the branch of medicine that deals with the physical, chemical, and biological properties of tumors, including study of their development, diagnosis, treatment, and prevention). It thus enables the physicians in taking decisions on medicines, dosages and testing. It can determine the drug doses on the basis of time schedule, toxicity and blood counts. ONCOCIN functions as an integration of two systems, vitz: The medical record system and decision support system. In fact, ONCOCIN was one of the first decision support systems designed to model decisions and sequenced actions over time using OPAL as a customized flowchart language. Hence, the history of prior events is an important input factor to the system. As Ambinder (2000) noted, when oncology patient care stipulated by the computer was compared with care given by oncology fellows, a

compliance rate of 95% among 75 local physicians who used the system was obtained as compared to a 64% rate for cancer center physicians who did not use the automated system. Unfortunately, the general acceptability of ONCOCIN was seriously challenged as the system was too slow (ie: it takes a minimum of 6 weeks to enter and test new protocols), It was not all-inclusive as new protocols were being found and used all the time without any means of ever getting a complete set of the protocols) and finally the advice provided by ONCOCIN was approved by experts in only 79% of the cases. Due to the above challenges, physicians were wary to trust the advice proposed by ONCOCIN. Hence, ONCOCIN ended up being used as a critique tool by the physicians rather than a diagnostic tool it was initially planned for.

2.9.1.4 Quick Medical Reference (QMR)

The challenges which made INTERNIST-1 and PIP to remain at the level of mere research tools, forced researchers at University of Pittsburgh School of Medicine to develop alternative expert system that could surmount the earlier challenges. Quick Medical Reference (QMR) was therefore developed to enable its users to exploit the contents of the INTERNIST-1's powerful knowledge base for carrying out educational, clinical, and computational tasks. Lemaire et al. (1999)was of the view that QMR program acts more as an information tool, providing users with multiple ways of reviewing and manipulating the diagnostic information in the program's knowledge base. It has a comprehensive summary of all the relevant information contained in the literature as it concerns pathologies in internal medicine. QMR operates at three levels, vitz: 1] As an electronic textbook, 2] as an intermediate level spreadsheet for the combination and exploration of simple diagnostic concepts, and 3] as an expert consultant program. The electronic textbook contains an average of 85 findings and 8 associated disorders relevant to the diagnosis of approximately 600 disorders in internal medicine. Inverting the disease profiles creates extensive differential diagnosis lists for the over 4250 patient findings stored in its knowledge base. The

electronic textbook is user-friendly as its displays can be formatted to suit the user's need. In addition, the QMR program has the ability to assist users with generating hypotheses in complex patient cases.

In one of the preliminary studies carried out on QMR, Miller & Masarie(1989) and Miller et al. (1986) concluded that QMR's case-analysis capabilities are of potential benefit in most patients in internal medicine admitted for diagnostic evaluation. Also the preliminary use of the program for education of medical students and medical house officers at several sites had met with an enthusiastic response.

Since the basic kernel (ie: Algorithms and knowledge base) of QMR was derived from INTERNIST-1, it therefore has inherited most of the basic problems that faced its predecessor. Hence, QMR could not compete effectively as a reliable expert systems for medical diagnosis as once again, it could not move far away from being regarded as a mere research tool.

2.9.2 The Frame-Based Diagnostic Medical Expert Systems

The deployment of frame based expert system in medicine became necessary as the rule-based systems earlier had initial intrinsic challenges in matching up with the dictates of modern medicine in handling complex medical cases.

2.9.2.1 The Present Illness Program (PIP)

One of the early attempts in development of frame-based system was the design of Present Illness Program (PIP). This is an applied Pseudo-Bayesian Network System that uses hypothesis or framed based methodology. As noted by Perry (1990), the knowledge in PIP is organized into packets of related information called frames. Within each frame is a rich knowledge structure which includes prototypical findings (signs, symptoms, laboratory data), the time course of the given illness, and rules for judging how closely a given patient might ‘match’ the disease or state which the frame describes”. The Frames

are further organized into networks, and include not only information on approximately twenty different diseases, but commonsense (heuristic) knowledge as well. The program combines patient-specific knowledge with the knowledge base in order to develop and test hypotheses in an iterative process. If a hypothesis does not fit, additional information is then sought from the user. Each disease condition in PIP is represented as a frame with many slots that contain information about the disease.

Sherman& Howard(2012) noted that PIP was developed to counter some of the deficiencies experienced in INTERNIST-1. For instance the organization of database in INTERNIST-1 was implemented as a complimentary link which is applied only when the disease is concluded. However, in PIP, the database is represented as interconnected frame representation in which each disease has a competing and complimentary link. Also to control the number of active hypothesis, INTERNIST-1 used an evoking threshold and a tree hierarchy of diseases to hypothesize one disease condition instead of using similar specific disease types. This again is implemented as categorical reasoning and semi-active state to limit the active hypothesis in PIP. Moreover, in PIP, one strategy (confirm) was used for diagnosis as opposed to several strategies (confirm, rule out, narrow and differentiate) earlier used by INTERNIST-1. Unfortunately, despite the continuous efforts of early researchers in developing a reliable medical diagnostic system, PIP still suffered similar structural deficiencies previously noted in other Pseudo-Bayesian network systems. As earlier stated, one of the greatest challenges facing use of expert systems in medical practice is reliability. The basic question in the minds of clinicians is "How can we trust the accuracy of diagnostic decisions made by a machine (expert system)?" This question is more worrisome especially as it concerns the deployment of machine in matters concerning life or death. Therefore, for clinicians and other users of the system to trust, believe and have confidence in medical advice given by the system, the system must have a means of explaining the reasons behind every decision it takes for

any particular case. When this reason is convincing enough, then clinicians will be bound to adopt and use it. Earlier expert systems lacked, to some extent, this ability or power of explanation.

2.9.3 The Hybrid Diagnostic Medical Expert Systems

Some of the factors responsible for the failure and non-acceptability of earlier systems by the medical doctors and other users can be summarized as follow:

a) Lack of power of explanation
b) Lack of transparency.
c) Use of non-probability based decision approach
d) Inefficient handling of complex medical situations.
e) Inconsistencies in dealing with uncertain and fuzzy knowledge.

To design an expert system that can surmount above challenges demands more than mere deployment of Frame-based or Rule-based methodology. As noted by Wise(1986), one of the major challenges facing the development of medical expert systems is the overwhelming complexities of knowledge representation and reasoning under uncertainty. In fact, the complexity of patho-physiology typically overwhelms the abilities of doctors to understand all the intricate and relevant details about the excruciating predicament of their patients. Unfortunately, this very fact is inevitable in medical diagnosis and had contributed to the failures of previous attempts in developing reliable expert systems which copiously relied on production rule and non-probabilistic scoring schemes. Researchers have therefore found that it is crucial to represent and reason with uncertain knowledge and that the capture and manipulation of uncertain knowledge is fundamentally different from the corresponding tasks for knowledge held with certainty.

2.9.4 Systems that reason under uncertainty

Jimison(1990) emphasized that the goals of modern researchers are to develop various techniques for reasoning under uncertainty and also to develop new approaches to handle complex relationships that exist among evidence and hypothesis. He further stated that understanding and management of numerous problems and challenges that face modern man cannot be explained or solved with accurate certainty. There are sheds of uncertainties that trail most human activities and medicine is not left out of this loop. Attempts have been made by various researchers in developing systems that reason under uncertainty as will be discussed below.

2.9.4.1 The Pathfinder System

One of the earlier attempts in developing a system that employed reasoning under uncertainty was the design of PATHFINDER. Heckerman et al.(1990), stated that PATHFINDER expert system was developed by group of scientists at Stanford University. PATHFINDER concentrated on decision-theoritic methods and uses Bayesian network approach referred to as normative for diagnosis. This decision theory includes probability theory and the maximum-expected-utility principle that provides a set of desirable rules that people believe they should follow or wish to follow when confronted with confusing high stake decisions. This normative methodology adopted by the PATHFINDER researchers may have been abandoned by previous researchers because of difficulties imposed by such technique. Development of normative expert systems involves complexity of traditional representations of knowledge in a decision theoretic framework. Heckerman (1989) had noted that this complexity has dampened the interest of researchers in applying decision theory in computer-based reasoning systems. PATHFINDER expert system, therefore, deploys tractable reasoning strategies, human-oriented classification hierarchies and refinement of normative knowledge base.

Murphy (1966), however noted that PATHFINDER uses hypothetico-deductive reasoning to make inferences about disease condition. Practically, the system reasons about approximately 60 malignant and benign diseases of lymph nodes, constructing differential diagnosis through the consideration of evidence about the status of over 100 morphologic and non-morphologic features visible in lymph-node tissue. The features are each structured into a set of two to ten mutually exclusive and exhaustive values which typically represent the degree of severity of a particular feature. In its operation mode, PATHFINDER system allows a user to enter values for one or more salient features of a lymph node section. Consequently, the system displays a differential diagnosis ordered by likelihood of disease conditions. In response to a query from the user, PATHFINDER recommends a set of features that are the most cost effective for narrowing the differential diagnosis. Further questions or tests may be suggested by the system. This process is iterated and terminates when the differential diagnosis is a single disease or there are no additional tests or questions, or a pathologist determines the informational benefits are not worth the costs of further observations or tests.

Nathwani et al.(1997) evaluated the efficacy and reliability of PATHFINDER expert system by using 30 stained slides from 30 lymph node biopsy specimens on which a consensus diagnosis was made by two group of experts. 10 pathologists in one group used PATHFINDER after a period of training while 9 pathologists used the routine method (diagnosis without computer) to determine a differential diagnosis for 15 slides. The group of experts was later swapped and the process repeated. The results revealed a greater diagnostic accuracy, consistence and reliability when PATHFINDER was used (40%) than when routine method of diagnosis was used (32%). In his conclusion, Nathwani noted that PATHFINDER medical expert system is a valuable tool that assists pathologists in making accurate diagnosis because it has superior attributes than human pathologists to integrate information and to screen for observations incompatible with any specific disease

2.9.4.2 The Dxplain System

Further effort to improve the transparency and power of explanation of expert systems in a hybrid system was the development of Dxplain as a decision support system (DSS). Dxplain is a DDX (Differential Diagnosis) expert system developed at the Laboratory of Computer Science at the Massachusetts General Hospital. By using Bayesian Network methodology, DXplain uses a set of clinical findings (signs, symptoms, and laboratory data) to produce a ranked list of diagnosis. The knowledge base of DXplain has over 2,200 diseases and 5,000 symptoms. DXplain is designed to suggest a set of diseases that are associated with a set of clinical findings entered by a health student or practitioner thereby making it a simple tool in the hands of non-medical experts. Hoffer et al.(2005), noted that unlike the previous ES considered, DXplain has survived several years as its developers were able to constantly update its functions and capabilities for the past two decades to keep them in tandem with modern programming concepts. This new concepts include the deployment of DXplain as internet-based platform (WWW interface) (London, 1998). Its applicability over the internet was possible due to its Problem-Learning based features and Dual Protocol Access Route (Barnet et al., 1998).

Furthermore, Davidzon et al.(2008) described the integration of DXplain with a diagnostic tests sensitivity and specificity and patient demographic data to provide patient-specific positive and negative predictive values at the point of care in a semantic web framework environment. This integration as earlier noted by Elhanan et al.(1996) could be extended as a multiple computer-based medical resources in which the user is neither required to manage the choice of resource and terms, nor use a specialized programming module. However, Cimino et al.(1991), describes a working prototype, the Interactive Query Workstation (IQW) which would allow users to query multiple resources: a medical knowledge base (DXplain), a clinical database (COSTAR/MQL), a bibliographic database (MEDLINE), a cancer database (PDQ), and a drug interaction database (PDR). Another valuable feature of DXplain was its

ability to provide users with an explanation for why each disease displayed should be considered in the differential diagnosis and in this feature lies its power of explanation, transparency and off course its name. Dxplain could therefore suggest what further clinical information would be useful to collect for each disease condition. Due to the various attractive features exhibited by DXplain, it has found wider acceptability and applicability among various users. But, in a related study, Elkin et al.(2010) explained that the introduction of DXplain into the workflow of a teaching hospital service can decrease the cost of service for diagnostically challenging Diagnostic Related Groups (DRGs), as Bauer et al. (2002) also observed in his study that there is high satisfaction rate among the resident doctors in internal medicine in the teaching hospitals that use this system.

In another study, Bond Et al. (2012) compared DXPlain with other DDXs using the following comparison-criteria : Input method; mobile access; filtering and refinement; lab values, medications, and geography as diagnostic factors; evidence based medicine (EBM) content; references; and drug information content source. The Application of these criteria as well as performance testing supports the use of DxPlain over the other currently available DDX generators. In a nutshell, DXplain is relatively self-explanatory system, requiring little or no end-user training. It can easily be adopted by medical libraries offering, or planning to offer their users access to Web-based materials and resources as they may find this system a valuable addition to their electronic collections.

In the literature review considered so far, most of the expert systems were developed for general medicine. Such earlier expert systems were focused on internal medicine, hence leading to exaggerated discussions on MYCIN, ONCOCIN, PATHFINDER, INTERNIST, Dxplain, etc. The partial concentration on internal medicine by earlier researchers may be justified by the following reasons: Firstly, internal medicine is the root as well as the bedrock knowledge for all physicians. Secondly, eye specialty areas such as ophthalmology and optometry belong to the class of emerging new fields in

medicine and are plagued with inadequacy of expertise for development of their knowledge base. Thirdly, the knowledge base in emerging medical fields is volatile and unstable and could make it less attractive to early researchers.

2.10 Expert systems in Eye disease diagnosis

Application of expert systems in the diagnosis of eye disease was delayed until lately as evident from foregoing discussions. However, various methods were deployed by researchers in the development of expert system for eye disease diagnosis as discussed below.

2.10.1 The Causal Association Network (CASNET) system

Kulikowski & Weiss(1982), believed that one of the earliest recordings in development of diagnostic system for eye care medicine was the design of CASNET at Rutgers University in early 1960. CASNET was developed as a diagnostic and therapeutic program for Glaucoma and related diseases of the eye. A CASNET model consists of three main components: observations of a patient, patho-physiological states, and disease classifications. As observations are recorded, they are associated with the appropriate intermediate states. These states, in turn, are typically causally related, thereby forming a network that summarizes the mechanisms of disease. It is these patterns of states in the network that are linked to individual disease classes. Strategies of specific treatment selection are guided as much by the individual pattern of observations and diagnostic conclusions as they are by the disease classification itself. Unlike mathematical models or disease processes, a CASNET model is inherently symbolic and focuses on causality and temporal sequences of events. Although not all medical topics were well understood at that level, CASNET demonstrated that there are areas of medicine in which explicit model representations permit powerful reasoning strategies that go beyond simple matching of treatments with diseases. It is this ability to match treatment plans with the patient's current stage in the progression of a disease

process and with expectations of future events that set CASNET apart from the other early AIM systems. To make reliable diagnosis with a system requires that the patient or his guide must be able to make valid entry as requested by the diagnostic system. And as earlier stated in the theoretical background in this review, one of such entries must include the visual acuity value of the patient. CASNET as an expert system lacked this very important feature. Previous attempts to design an eye diagnostic system failed to couple expert system technology with automated visual acuity measurement system.

2.10.2 Experimental System for Self-Diagnosing of Eye Diseases (ESSDED)

Kurniawan et al.(2014), discussed an experimental online expert system designed for eye diagnosis based on Naive Bayes model. The developed expert system applies Case-Based Reasoning (CBR), which is a paradigm for reasoning from experience while the Naïve Bayes is used as a method for classifying eye diseases by applying Bayes' theorem. The output of the expert system was a classification of an eye disease and information on the best treatment option. Comparison of expected versus actual results using the system revealed 82% accuracy. Kurniawan, therefore concluded that expert system using Naïve Bayes methodology has a potential to be used effectively in eye diagnostic tool, although it still has lots of challenges yet to be overcome by the system, being still at experimental stage. It shall be noted that this system does not test the visual acuity of the patient as a confirmatory tool for validating patient's response.

2.10.3 Expert System for Early Diagnosis of Eye Diseases (ESEDED)

Fatimah et al.(2001), reported the development of a ruled based expert system for detecting various eye diseases in Malaysia. The system can detect five prevalent eye diseases in Malaysia which include the following: allergic or infectious conjunctivitis, secondary and senile cataract, open angle glaucoma and

acute glaucoma, keratitis and dry eyes syndrome. The project was designed and programmed via the object-oriented expert system shell software, EXSYS. Expert rules were developed based on the symptoms of each type of the eye diseases, and they were presented using a tree graph forward chaining with depth search first method. In order to enhance user interaction with the system, graphical user interfaces were employed. Although previous several similar works have been published, they are limited to detecting a single eye disease and also required expert medical officer to operate. This system is promising although the number of diseases handled is low when compared to hundreds of existing eye diseases. Moreover, the system is restricted as it does not have open architecture such that more diseases could be added by the expert. Once more the visual acuity of the patient was not taken into consideration as a confirmatory tool for validating patient's response.

2.10.4 Expert System for Diagnosing Eye Diseases Using Clips (ESDEDUC)

Naser & Zaiter (2008) reported on the design of a rule based expert system for eye diagnosis using CLIPS language. An initial evaluation of the expert system was carried out and a positive feedback was received from the users. According to the report, CLIPS program is used by reason of its flexibility, expandability and low cost. The knowledge acquisition followed the routine and known standard approach. The scope of the expert system covered four eye diseases: Eye discharges, Bulging Eye, Double Vision, and Drooping Eyelid. The system will conclude the eye disease diagnosis based on answers given by the patient to specific question asked by the system. The inference engine uses a forward chaining technique to match the questions with the corresponding symptoms, as answered by the patient, by relying on the facts from the facts and rules in the knowledge base. An initial evaluation of the expert system was done by doctors and patients. A number of doctors and patients tested the system and gave a positive feedback but commented on the low scope of the system, a factor that hunts

most of the expert systems that were tried on eye diagnosis. Unfortunately, this system does neither test nor use the visual acuity of the patient as a confirmatory tool for validating patient's response.

2.10.5 Neural Networks and Decision Trees for Eye Diseases Diagnosis (NNDTEDD)

Kabari & Nwachukwu (2013) also reported an attempt they made in the design of expert system for the diagnosis of eye diseases. The system adopted neural network as technique of knowledge representation and decision tree as technique for its reasoning process. The system could also explain rational of diagnosis to the user. Unfortunately, the range and capacity of diagnosis is low as the system uses only 22 signs & symptoms and could diagnosis maximum of 12 eye diseases. NNDTEDD is meant for use by doctors although it is very promising in training young ophthalmologists. However, it is not designed for use by non-medical experts.

In the review made so far, we have attempted to look in details the various techniques and methods used by researchers in the development of expert system for eye disease diagnosis, all of which made diagnosis based only on unverified symptoms presented by the patient. In reality, the process of disease diagnosis by eye doctors does not rely on symptoms alone. The doctor also conducts visual acuity test in order to ascertain the actual way the patient sees and uses this value to validate patient's symptom claims as well as guide his diagnosis. The various methods and techniques applied by other researchers in the development of visual acuity measurement system and eye examination protocol is hereby discussed.

2.11 Visual Acuity Measurement and Eye Examination Protocols

Visual acuity measurement is the first line diagnostic tool in evaluating eye conditions. As succinctly put by American Optometric Association (2016), "Visual acuity measurements evaluate how clearly each eye is seeing". It is also one of the basic standards required in every eye test (Ophthalmology, 1984).

Visual acuity is a functional test performed during routine eye examination (Gary & Jeniffer, 2016) to determine the ability of the human eye to detect and recognize the smallest form or object possible. Theoretically, it is described as minimum separable and minimum cognizable. Therefore, Visual acuity test is the measure of the form sense of the eye, which takes into consideration the minimum separable and the minimum cognisable. In practical terms, the minimum separable defines how efficient the eye can resolve and discriminate two adjacent points in space, whereas the minimum cognisable defines how efficient a visual stimulus can be recognized by the visual cortex. For two adjacent points to be discriminated at the retinal level, the image must at least fall within two excitatory border cones separated by another inhibitory central cone. The gap between these two cones corresponds to a visual angle of one minute of arc (1'). Therefore, the minimum visual angle required by the eye for object discrimination is 1'(See Figure2.3). However, for the points to be recognised at the cortical level, experiment has shown that the points must also subtend at least 5' of arc of visual angle.

Cara (2013), Mark(2006), and August(2001; 1988) were of the opinion that the above two parameters form the basis for the design of visual acuity optotypes and characters.

2.12 The design of visual acuity charts (optotypes)

The optotypes are designed such that the external diameter of the character subtends 5' of arc whereas the internal diameter subtends 1' of steradian angle. Therefore, the ratio of the external diameter to the internal diameter of an optotype is **4:1**. (See Figure 2.4)

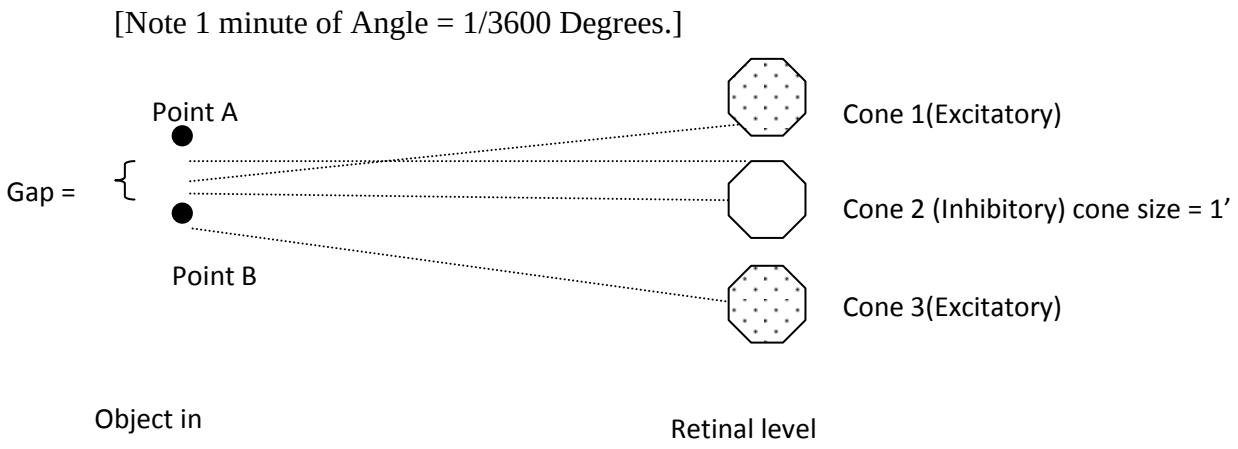


Figure2.3: Minimum Separable (Kumar, 2008)

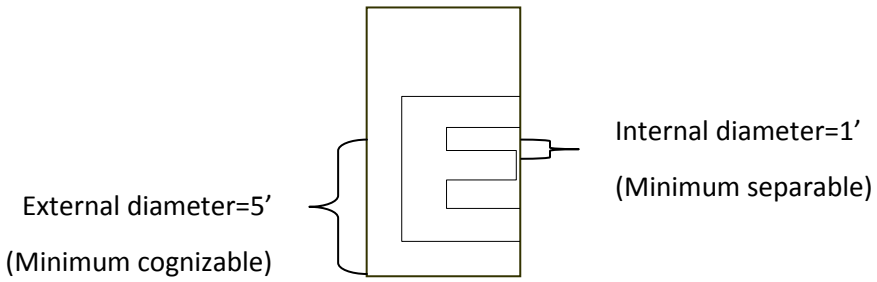


Figure2.4: Minimum Cognisable (Kumar, 2008)

Bailey (1976) in his paper introduced a new principle for the design and use of letter charts for the measurement of visual acuity. He advocated that the test task should be essentially the same at each size level on the chart. Such standardization of the test task requires the use of letters of equal legibility, the same number of letters on each row, and uniform between-letter and between row spacing. He also advocated that, combined with the test task standardization, there should be a logarithmic progression of

letter size. Charts incorporating these design features have been made as LogMar charts or EDTRS charts. These charts facilitate the use of nonstandard testing distances which might be used when there is low visual acuity, when examination room layout prevents testing at the standard distance, or when it is necessary to validate visual acuity scores or detect malingering. Adjusting the visual acuity score according to the chosen testing distance is simplified by the use of logarithmic scaling which could be easily implemented in computer enabled platform.

Taylor (1978) had earlier stated that tumbling-E has the widest applications in all categories of patients. Since, it is only made of vertical and horizontal arms, it does not suffer from jagged-edge image distortion. He also maintained that Tumbling-E could be used in patients with low intelligent quotient, as well as on the illiterates and the children. However, the age limit for the application of this optotype is dictated by the minimum age at which most humans attain their full visual acuity. However, Catford et al. (1973), stated that this minimum age was found to be 3 years. Later, Reich& Ekabutr(2002) showed that visual acuity thresholds for the Tumbling-E were slightly better than the Landolt-C, particularly in the presence of any astigmatism. This study therefore, concluded that more confidence can be placed in the visual acuity thresholds obtained with the Tumbling-E.

Friendly (1984), developed an automated visual acuity testing program that uses a Tumbling-E optotype with surrounding confusion bars. The computer software program runs on Apple-II equipment and a black-and-white monitor with a fifteen-inch screen. The program is available in response box and joystick versions. The test is suitable for children older than 3 years and for adults. A t-test on the same floppy disk as the visual acuity programs is used to test the probability that the differences in test results are greater than chance. Visual acuities of 20 normal subjects were reduced by means of plus lenses. Test-retest acuity correlation coefficients were similar for letter charts and computer generated E-optotypes, suggesting approximately equal reliability under the test conditions employed. Visual acuities

of 12 amblyopic eyes were obtained by a Ferris-type letter chart and computer-generated E-optotypes. The correlation coefficient was +0.93, suggesting similar test results by these two methods. Although the method used was crude, this development at least gave hope that automation of visual acuity is a possibility in the nearest future. However, Lars(1986) studied acuity test letters generated on a television monitor with regard to detection and resolution thresholds, both for the native configurations and after high-pass spatial frequency filtering. Comparisons were made with printed acuity charts of different contrast. Filtering diminished the interval between detection and resolution thresholds. Under some circumstances, a small (1 dB, about 26%) increment in size could make a previously invisible optotype clearly visible, or vice versa. Lars, therefore, concluded that vanishing optotypes do not seem useful for routine visual acuity testing, but they may be advantageous, for example, in preferential looking-acuity tests for infants and visual field examinations.

Other possible methods of presentation of optotype in computer environment were considered. Shah et al. (2011) considered vanishing optotype letters but found that they have pseudo high-pass design so that the mean luminance of the target is the same as the background and the letters thus vanish soon after the resolution threshold is reached. He wanted to determine the variability of acuity measurements using these letters as compared to conventional letters, and in particular how acuity is affected by the number of alternatives available to the subject. Acuity wasmeasured using high contrast letters of both conventional and vanishing optotype design for three experienced normal subjects. Thresholds were determined for central vision in a forced choice paradigm for two alternatives (2AFC; AU and OQ), 4AFC (AQUO), 6AFC (QUANGO) and 26AFC (whole alphabet) using a QUEST procedure. Three measurements were made for each condition; it was found that the threshold letter size was always larger for the vanishing optotypes than conventional letters, although the size of this difference depended on the number of alternatives and whatthey were. The effect of the number of AFC, and the

individual letters employed, was smaller for the vanishing optotypes, implying that they are more equally legible than conventional optotypes. Therefore, he concluded that the smaller effect of the number of letter alternatives combined with more equal discriminability and lower threshold variability implies that vanishing optotypes may be appropriate targets from which to design letter charts to measure subtle changes in acuity.

2.13 Classification of Visual Acuity Charts

Various criteria were used by researchers to classify visual acuity. According to Karunagapally(2013), the charts can be summarised into the following categories.

a) Classification according to Make
    i. Snellen charts (See Figure 2.5)
    ii. Sloan charts
    iii. Jaeger charts
b) Classification according to use
    i. Universal charts
    ii. Direct charts
    iii. Indirect charts
c) Classification according to test distance
    i. Near charts
    ii. Distance charts
d) Classification according to patient type
    i. Paediatric charts
    ii. Illiterate E- charts (See Figure.2.6)

iii. Picture charts

This classification was necessary as it guides eye care professionals to deploy a particular type of chart for a related group of circumstances. For instance special type of charts were designed to cater for special category of patients such as children and illiterates.

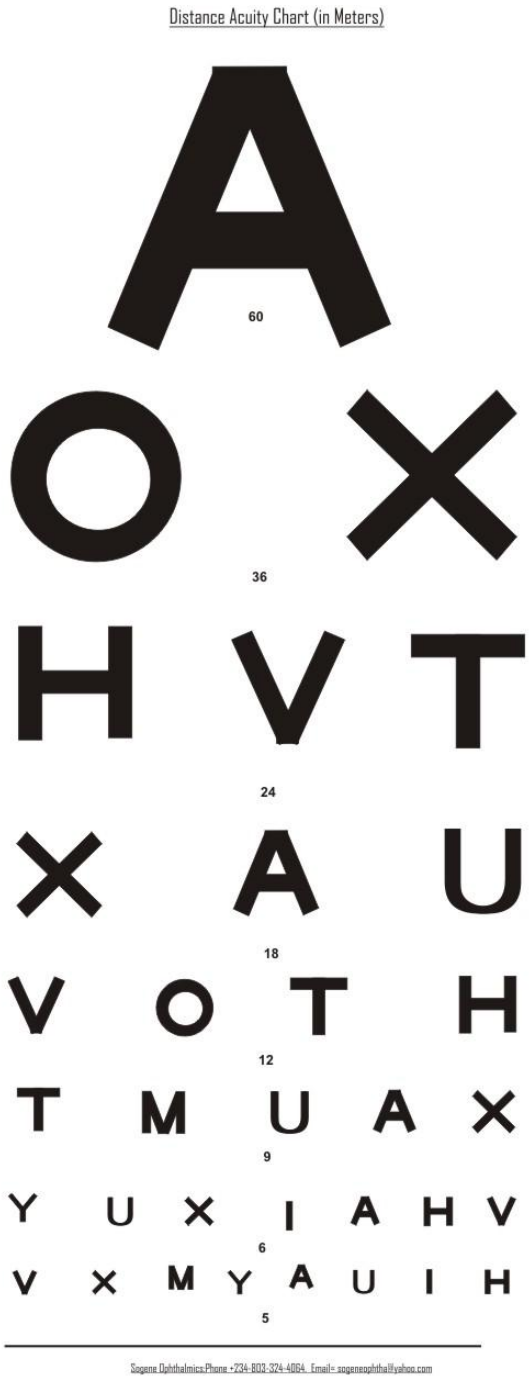


Figure 2.5: Snellen chart (Kumar, 2008).

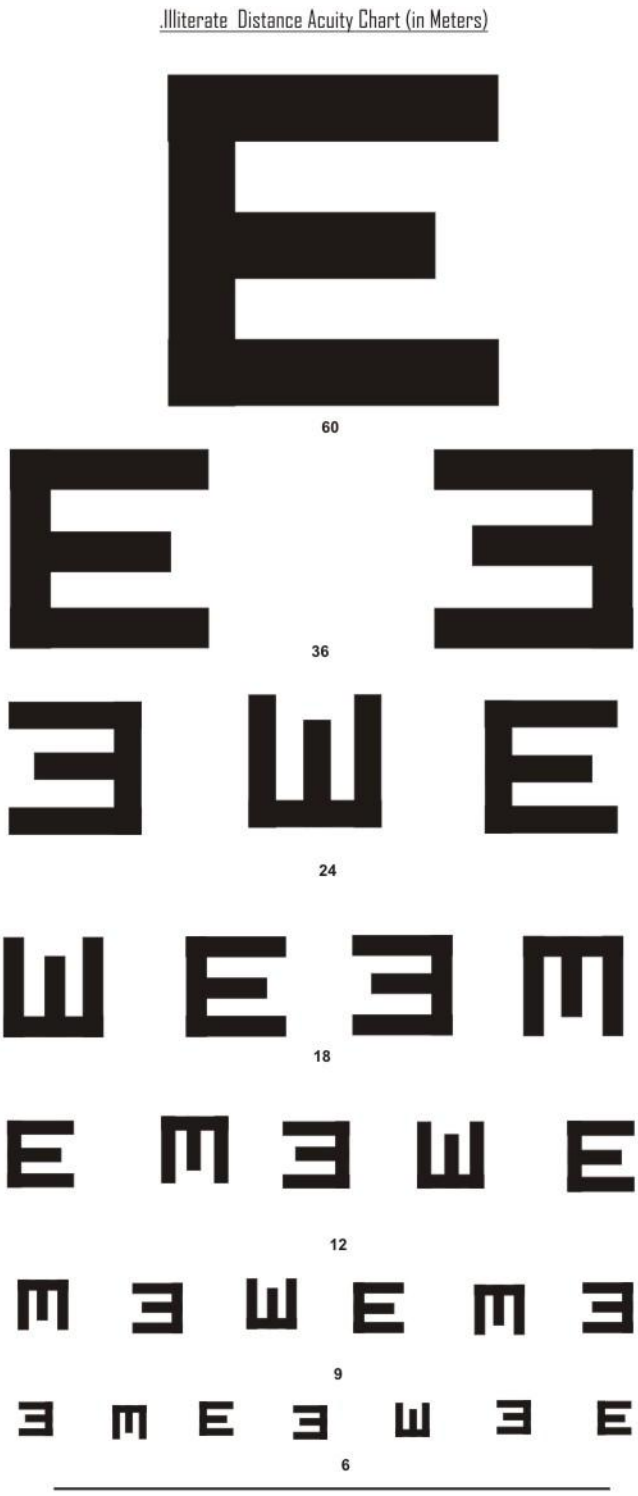


Figure 2.6: Illiterate-E Chart (Kumar, 2008)

2.14 The Relevance of Visual Acuity Test

Jesse et al.(2010), noted that the onset of most eye diseases and defects begin with a reduction in visual acuity of the individual. Therefore, visual acuity measurement is the first line quantitative indices of assessment of the level of vision an individual has at any given time. During admission and discharge of any patient from the eye clinic, the patient's visual acuity must be recorded at both the entrance and exit point. This serves as a reference data to monitor improvement or deterioration of patient's eye condition in his/her subsequent appointment(s). It is also advised that every individual shall test his/her visual acuity at least every six months as to enable early detection of numerous eye problems. In fact, many institutions demand that an individual undergoes visual acuity assessment before being allowed to carry out some tasks that require optimal vision. For instance, visual acuity assessment is a requirement in the following areas: Admission of students into schools (secondary, tertiary, etc), Employment into some job cadres (military, aviation, industry, transport, etc.), and Acquisition of driver's license, Application for life insurance, Etc.In a nutshell, visual acuity measurement is a mandatory test performed in a systematic and orderly manner (Wendy, 2003) in the evaluation of both healthy and unhealthy eyes and therefore automation of this procedure has occupied the activities of many researchers from time immemorial.

The import and result of visual acuity measurement will be meaningless if it cannot be interpreted by non-experts and ordinary persons as to how it relates to the way we see. Also since humans are not so good in memorising numbers, categorising visual acuity values with words may be an easier way to work with these values in some situations. WHO (2006) categorised visual acuity with respect to the level of vision to range from Normal vision to total vision loss (See Figure2.7).

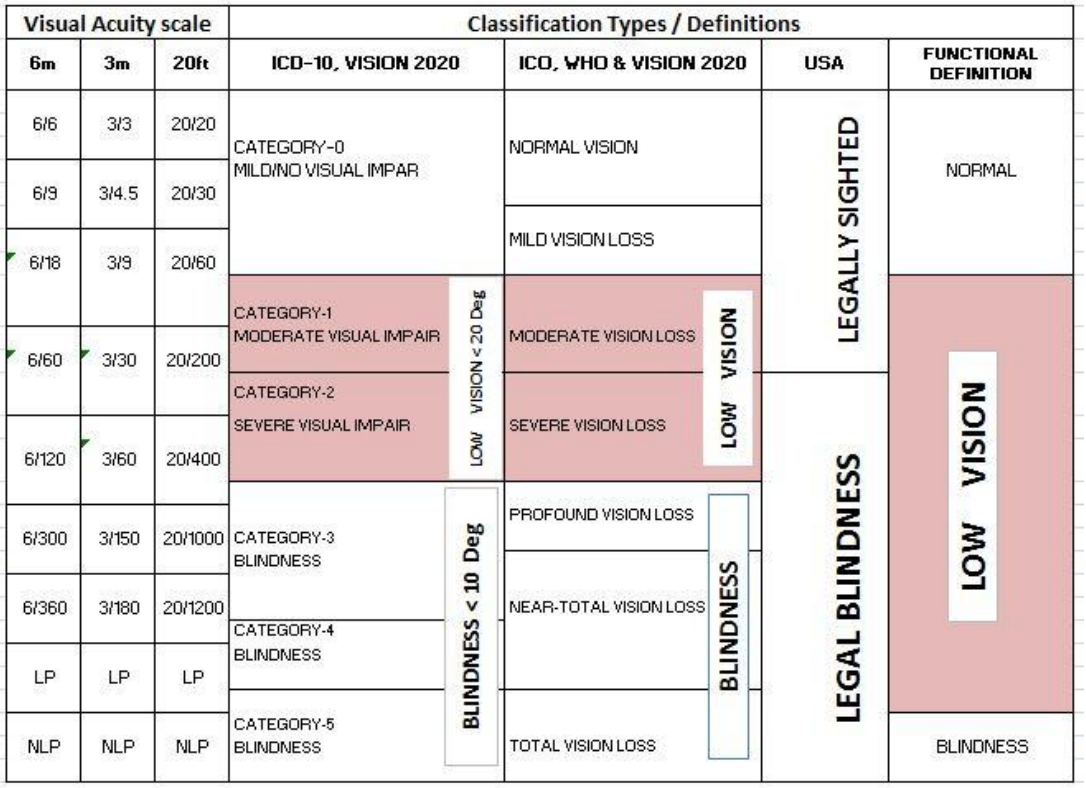


Figure 2.7: Visual acuity classification (WHO,2006)

2.15 Automation of Visual Acuity measurement in eye examination

Manual method of visual acuity assessment discussed above is rigorous, time consuming and requires the physical presence of a trained staff. Automation of this process has occupied the interest of many researchers. This automation, requires high image resolution and presentation of various sizes of optotypes. Since graphic images and displays are stored as memory units, the strain on the computer processing power and speed could be enormous and challenging. To avert this challenge, Daly(1989), patented an efficient method and apparatus for creating and storing characters for display on a video screen. The shape of the graphic character is displayed at various degrees of resolution. The graphic character is stored as a bitmap or as coefficients of spline curves. These can be scaled up or down to

give different character sizes. The coefficients can be converted to form pixel-maps which are rectangular arrays of pixels and may have gray scale values.

2.15.1 Freiburg Visual Acuity Test (FrACT) System

Bach (2011; 2007; 1996) described the introduction of "The Freiburg Visual Acuity Test (FrACT) tool into eye examination protocols. He explained that it is an automated procedure for self-administered measurement of visual acuity. Landolt-Cs are presented on a monitor in one of eight orientations. The subject presses one of eight buttons, which are spatially arranged on a response box according to the eight possible positions of the Landolt-Cs' gap. To estimate the acuity threshold, a best PEST (best Parameter Estimation by Sequential Testing) procedure is used in which a psychometric function having a constant slope on a logarithmic acuity scale is assumed. Measurement terminates after a fixed number of trials. With computer monitors, pixel-discreteness distortions limit the presentation of small stimuli. By using anti-aliasing, (smoothing of contours by multiple gray levels), the spatial resolution was improved by a factor of four. Thus, even the shape of small Landolt-Cs with oblique gaps is adequate and visual acuities from 5/80 (0.06) up to 5/2.4 (3.6) can be tested at a distance of 5m. However, FrACT has its limitations. The system assumes that the user has a working knowledge of the principles and practice of the assessment of human visual acuity. Also, system calibration is required to be done manually by the user. By using various optotypes such as Landolt-C, Sloan, tumbling-E, the system tends to be more complex than simple. Although it has auditory feedback and result is exported to the clipboard for further processing, there are technical limits on the highest and lowest acuity, which depend on the display resolution in pixels per inch and on the distance of test done. FrACT is therefore an automated system that is best used by an expert in a clinical setting.

2.15.2 iChartPlus

The major challenges associated with resolution issues and jagged-edge distortion inherent in most automated visual acuity systems was again tackled. As reported by Claffle (2006), iChartPlus is a Visual Acuity Digital Eye Chart Testing Software designed for eye care professionals. It was primarily developed to provide cheaper and better quality systems for eye experts devoid of numerous compatibility issues which had plagued other automated eye chart systems. iChartplus was developed to be fast, simple and easy to set up. It is compatible with all windows-based platforms, works on any size monitor or display (HD or analog) and provides a crisp, clear and bright screen for the patients. With over 10 different sets of optotypes to choose from, iChartPlus provides almost all an eye care expert needs to test his patients. With a remote control features, it has full QWERTY (standard) remote keyboard keys, pre-programmed and loaded with a time-saving and useful HOT KEYS. Although, iChartPlus was developed to meet up the demands of modern eye hospitals, it still remains the instrument for measuring visual acuity alone without suggesting any diagnosis.

2.15.3 Interactive Visual Acuity Chart (IVAC) System

Efforts to standardize secured online services to remote patients have been rekindled in the recent time. Interactive Visual Acuity Chart (IVAC) was introduced as an automated chart system that includes Snellen, HOTV and pictures charts in which the user can select viewing reference as either isolated or crowded. As described by Scott (2006), the selection is done through four navigation buttons that enlarge, decrease or change optotypes. The user is expected to recalibrate the screen resolution by physically measuring a given line on the monitor and also provide data on (the test distance which the system uses to recalculate the optotype size. IVAC could be used over the internet by the patient with less guide, simple and easy to use. Unfortunately, the optotype size stops at 20/800, the image jags after

20/200 as the system does not provide dithering and anti-aliasing support. Moreover, it does not use LogMar chart which has become gold standard in eye test and acuity measurement world-wide. IVAC seems to be too generic to provide a reliable eye test platform.

The automation of visual acuity test has its own challenges. Several studies have focused on such challenges as it concerns the consistency and reliability of test responses given by the patients. In a particular study, Bach(2007) reported the test-retest variability of visual acuity on short runs by post-hoc re-analysis using Freiburg Visual Acuity Test (FrACT) tool as described earlier. The sequence of optotypes presented follows an adaptive staircase procedure referred to as the Best PEST algorithm. The Best- PEST threshold obtained after 18 trials was compared to the result of a post-hoc re-analysis of the acquired data, where both threshold and slope of the psychometric function were estimated via a maximum-likelihood. Post-hoc psychometric fitting reproduced the Best-PEST result within I %, although the individual slopes varied widely. The FrACT offers advantages over traditional chart testing with respect to objectivity and reliability. Unfortunately, FrACT is a visual acuity measuring tool and did not incorporate diagnostic capability.

2.15.4 Computer-Based Visual Function Testing (CVFT) System

Kumar (2008) described the design of computer-based visual function testing (CVFT) system. The CVFT chart is designed to optimize visual acuity data collection in population-based surveys. The chart uses the design principles currently advocated for the measurement of visual acuity in clinical research. The CVFT chart incorporates design principles in terms of test administration and optotype presentation, which include: black-on-white, logarithmic letter size progression, inter-letter spacing, inter-line spacing and Tumbling-E and Landolts ‘C’ optotypes. It also has an equal number of letters (three) per line and a screening phase to train and determine the initial level of acuity. The screening phase is followed by

reinforcement and threshold determination phases. The test is quick and easy to perform and aims to provide a means for detecting change in letter acuity, with increased confidence. Four different orientations (up, down, right, left) of the Tumbling-E optotype were constructed on a 5 x 5 unit format and graded according to LogMAR principles of acuity scaling. Hence, the size of letters in the rows progresses in uniform steps of 0.1 logarithmic units. Each central letter is flanked with surrounding letters to simulate visual crowding. To provide flexibility, the chart is designed for use at three or six meters. The LogMAR acuity data are readily convertible to snellen acuity notation for those unfamiliar with LogMAR notation. However, CVFT is designed for use in routine vision examinations by the eye experts and in the eye clinics only.

2.15.5 Aspect Ratio Adaptable Data Set (ARADS)

In order to make the displays screen-independent, Lemay (2008) tackled the problem of aspect ratio by developing a resource manager which can vary the content for various display aspect ratios used to display information in a computing environment. This allows providing content that is more suitable and/or especially designed for display on a particular aspect ratio. Also, in order to support multiple aspect ratios, he suggested that the resource manager embedded within the operating system can use an Aspect Ratio Adaptable Data Set (ARADS) that effectively supports displaying graphical content for various aspect ratios. The (ARADS) can include “base data” and “aspect-ratio-specific data” that can complement and/or replace the base data. Hence, the base data can be used as an initial basis for displaying graphics on any one of a plurality of different aspect ratios while the aspect-ratio-specific data can be specifically designed for and/or accommodate a particular aspect ratio.

2.15.6 Psychometric Analysis Systems

Use of Computer to perform psychometric tests has become one of the current developments in the automation of eye examination procedures. Milanich (2008), reasoned that in recent times, the felt need for simple optometric devices by means of which the patient would be able to check the basic parameters of his or her own vision either independently or with only minimal consultation with specialist have called for the design of different types of optotypes for computer use. Such an adventure has its challenges. He noted that due to the unique nature of computer displays which must take into consideration the screen resolutions, aspect ratios and pixilation of images, the standard optotypes used in manual eye examination procedures could no longer suffice for computer adaptation. Since the screen pixels are composed of matrix of square dots, any optotype which has oblique extension is likely to suffer from jagged-edge distortion and consequent image degradation which are progressively worse at higher image enlargement and magnification. Having analyzed other' types of optotypes with respect to their simplicity of use, legibility and less user bias, he once again re-echoed the recommendation of the earlier researchers for use of tumbling-E optotype in computer vision tests as this optotype has only vertical and horizontal extensions.

2.15.7 The Eyesite System

Another effort in the development of automated eye test system was the design of EyeSite system by SoloHealth. As documented by Dave (2010), EyeSite was developed as a free self-service vision test kiosk. In addition, it also contains programs that educate the patients about various eye conditions like cataracts, glaucoma, and macular degeneration. Its doctor locator feature encourages users to schedule an appointment with an eye care professional to get a full eye health exam. EyeSite employs a simple touch screen method, with helpful interactive video to walk the user through the simple test. The users

receive a customized vision test report that shows an assessment of their near and distance vision, listing of eye doctors, and valuable offers from vision care partners. Requesting an appointment is easy as users can choose a doctor on the screen and then are contacted by that office to schedule a convenient appointment, or they can contact the office directly if they prefer. The EyeSite self-service vision test kiosk encourages people to check their vision more often, resulting in more regular visits to eye care professionals, better visual outcomes and, ultimately, more sales of vision care products. However, EyeSite is more of a commercial-based outfit designed to give the users a glimpse of their vision status and then directs the user to contact enlisted eye doctors. It is a stand-alone, fixed, non-portable system that is not designed for private usage.

2.15.8 Internet-Based Eye Visual Acuity Measuring Systems.

Attempts to conduct eye test via the web with its potential setbacks have been recorded. Kuchenbecker (2002) studied the reliability of online based visual acuity measurement. According to him, the number of visual function tests on the internet is continuously increasing. These tests are potentially available for over 400 million internet users with different hard and software requirements. He noted that various visual function tests, such as visual acuity tests, the Amsler grid, stereo and color vision test can be delivered via the internet. The variability of such tests ranges from a simple presentation of graphic elements to a laboriously programmed interactive input by the user to specify the test result. Most of the tests are presented by opticians and the optical industry. In the study, he noticed that such online tests do not make compensation for considerable variability of the test conditions, such as data concerning the room lighting. Worst still there was lack of monitor calibration in majority of the online tests. In order to obtain comparable test results, differences in size and resolution as well as in brightness, contrast and color of computer monitors must be taken into consideration. He therefore concluded that because of the

test deficits determined, the results of visual function tests on the internet are to be classified as limited and doubtful as such endeavors have not followed any known vision test standard.

Also in designing an automated eye test system, the user has to interact with the system through various modes of feedback control which may be either through keyboard or touch screen. For systems that may employ touch-screen approach, the form (ie: shape and size) of the control objects may be a critical issue. In a study by Fjed (2003), the design-relevance of perceptual cues for the design of touch screens buttons was evaluated. The effect of button form (round and rectangular) and button extensions (height and size) were examined. For each of the two forms and with size and height as perceptual cues, the perceptual threshold in terms of pixels was estimated by using a within-group experimental design and four conditions. Significant differences in perceptual thresholds between the conditions were observed. It was concluded that button height should be preferred over button size as perceptual cue, which is equally valid for round and rectangular buttons. However, if height is chosen as cue, round buttons should be preferred and if size is chosen as cue, rectangular buttons should be preferred.

2.15.9 The TeamViewer and COMPIog systems

Research in developing the optimum means of delivering automated visual acuity system is an ongoing exercise and continues to attract the interest of numerous researchers as many free eye test systems dot the internet. Krithica (2012) once more looked closely at possibility of enhancing these free online services. He conducted a study in which visual acuity was tested using a laptop or computer- based LogMAR chart (COMPIog) for all subjects by two different methods. The methods differed by the physical presence and absence of an eye doctor and in the mode of instructions provided. Remote access was obtained through the internet, using Teamviewer software to control the system linked to COMPIog and instructions were provided by telephone. The order of measurements and the eye to be tested was

randomized. LogMARvisual acuity and time taken were recorded. After analysis of his work, he noted that there was no statistically significant difference both in the median visual acuity measurement ($p = 0.648$)) and time taken ($p = 0.457$) between the two methods. He therefore concluded that Tele (remotely controlled) visual acuity measurement is as reliable as that measured with the physical presence of an expert. However, he also demonstrated that the poor reliability inherent in internet-based examination systems was not due to the network distortions but the non-compensation of test variables and necessary system adjustment at the user terminal of the network.

2.16 Summary of Review and Research gap

From the survey of all the related medical expert systems and clinical decision support systems in eye diagnosis considered so far in the available literature, the following observations are noted:

a) Most of the expert systems reviewed so far (Internist-1, PIP, Pathfinder, Dxplain, etc) used Bayesian network model as the method of reasoning. Use of Bayesian network model for diagnosis is ideal when there is large database (to datamine causality or relationship) and when the number of variables to consider are less especially for joint probability calculations. Also as the number of rules or conjunctions increases, the domain expert must provide a prior probability value for each of these combinations, a feat that is almost impossible as the number of combinations increases. Hence, Bayesian network model requires a complex calculation for joint probability processing, performs poorly with small databaseset and does not give the patient the opportunity to score the degree of confidence he/she has in the responses he/she has provided to the system. These stringent requirements demanded by Bayesian network model may be ideal in general medicine applications hence its deployment. However, it may not be ideal in eye diagnosis which is a smaller segment of medicine as the amount of disease database is relatively

small, the number of symptoms that constitute eye diseases are often many, both the patients and the experts are not often very certain of their submissions (thereby necessitating the need to weigh these uncertainties) and where there are less dependencies between various variables (symptoms).

b) Fewer expert systems (MYCIN) use Certainty factor model as the method of reasoning. Although, MYCIN which was the first expert system that implemented certainty factor model failed to see the light of the day, the failure was not due to inclusion of certainty factor model but due to the existing technology at the time MYCIN was developed. Implementation of MYCIN in main frame computer and lack of database for the storage of patient's information were the main reasons behind the failure of MYCIN (Sotos, 1990). Despite some weak points noted in use of certainty factor models, researchers have in recent times come to terms with the good side of certainty factor model as it allows both the domain expert and the patient to rate their degree of belief or disbelief in the hypothesis (diseases) and evidences (symptoms) provided, the handling of joint probabilities are simpler and it does not require presence of large databases as often is the case in eye medicine. Therefore certainty factor model may find a promising implementation in eye disease diagnosis.

c) Most expert systems reviewed are designed to be used by the medical expert assistants or the experts to relieve them from repeatable tasks and hence simplify their work. They are therefore not configured for use by non-medical personal. For instance, CASNET was designed as questionnaire-based system that relies heavily on unverified data input made by the user.

d) Important data entry such as the current visual acuity value of the patient could not be made without carrying out and authenticating the actual visual acuity of the patient by a doctor. If the patient has to see an expert (eye doctor) each time he wants to test his vision, then the aim and

objectives of assisted health-check philosophy currently advocated in public health medicine is negated. As noted by Rotheram-Borus et al. (2012), self or assisted health management is helpful in reducing symptoms and increasing quality of life of an individual.

e) There is lack of integration of the diagnostic expert system and visual Acuity automation system into a single platform. The systems available are either expert system or visual acuity automation system but not both. For instance, computer-based visual function testing system (CVFT), EyeSite, Freiburg Visual Acuity Test (FrACT), etc, can only measure the visual acuity but cannot at the same time diagnose an eye condition that could be responsible for the recorded visual acuity level, especially in pathological cases. Conversely, CASNET as expert system can diagnose an eye disease by using external data provided by the user but cannot measure the visual acuity of the patient. The non-integration of these two processes into a unified system/platform has made successful implementation of expert systems for use by non-experts for regular monitoring of eye health, a matter of legendary.
f) All the expert systems implemented for eye diagnosis considered so far have low scope of diagnosis ranging from 4 to 12 eye diseases. This may be due to the fact that the knowledge base design and the inference mechanism used are not open-architecture and therefore has restricted the expansion of the system to cover more eye diseases. There is therefore the need for a robust system design that can permit domain experts to update the knowledge base at will without affecting the inference code so as to permit diagnosis of several eye diseases.

From the literatures reviewed hitherto, there is a need to develop an eye diagnostic system that could determine the patient's visual acuity level as well as use this data to authenticate patient's claimed

symptoms and thereafter proffer diagnosis. The system will also need to allow both the expert and the patient to provide their degrees of beliefs on the information they have provided.

CHAPTER THREE

RESEARCH METHODOLOGY, SYSTEM ANALYSIS AND DESIGN

3.1 Source of data

In this study, the data used in the system analysis were from the following sources.

i. Primary data

- Interview (Patient, Doctor, clinical assistant)
- Documents (Patient's Medical records, Drug Rx sheet, Glass Rx sheets, Lab request forms, patient referral forms, etc.)
- Processes (diagnosis, prescription-writing, etc)
- Events (Eye consultation, patient registration,)
- Materials (Instruments manuals, computer systems, Network devices, etc.)
- Relationships (Patient<>doctor, patient<>assistant, doctor<>assistant, etc)

ii. Secondary data

- Internet
- Library (Medical Books of Ophthalmology and Optometry)
- Literature review

3.2 Method of data collection

Background: Data collection techniques are ways in research process through which data are gathered from the existing system for investigation and analysis with the aim of developing a better efficient system in the proposed system. The system under investigation and which data we need comprises all the relevant entities that participate in the overall working of the system.

There are various data collection techniques available today that guarantee efficient and reliable information gathering. However, only a subset of this is relevant for any particular project. Therefore, in this study, the following data collection techniques were used.

a. Review of documents
b. Oral interview
c. Books, Journals and online sources
d. Direct physical observation
e. Consent form

3.2.1 Review of documents

Documents provide useful information about the activities of any organization, process or events and are channels of storage of data for the entity under investigation. Documents often are preserved in two formats, vitz: Hard copy and soft/digital copy. The hard copy comprises mainly of paper work while the soft copy is composed of screen displays, audio sounds, video displays, graphics, etc. The soft copy is stored in storage media such as floppy disk, CD/DVD, Hard Disk, Video tape, USB, memory stick, etc.

In this study, the followingdocuments were reviewed

- Patient's medical record:
- Drug Rx sheets
- Glass Rx sheets
- Lab request forms
- Patient's referral forms
- Doctor's memos

- Job schedule forms
- Patient's booking forms
- Patient's consent forms

Relevant notes and summary comments were compiled by the researcher after perusing all the necessary documents and files.

Review of document is considered quite critical for the success of this analysis stage; hence a one week visit was dedicated for this process alone. After digesting the contents of the document review, an oral interview was consequently organized.

3.2.2 Oral interview

The review of documents only gives the researcher static information as it stores event that has been executed. It does not give an instant answer to a query. Oral interview is therefore useful in extracting information that could not be easily deduced from the document review. However, prior analysis of the document review helps the researcher in developing vital questions that may have skipped his/her attention. The persons interviewed are those persons who in one way or another are concerned with the running of the system. In this study, the following persons at the selected study center were interviewed:

- The Patients
- The Eye Doctors
- The Clinical Assistants

During the oral interview, some of the following questions were posed to the eye hospital staff

- How are the patients booked?
- How is illiterate patient examined?

- Can the assistant interpret the result in the absence of the doctor?
- How are children and persons with unsound mind or low IQ tested?
- When the clinic is closed for the day, how is emergency and odd-hour patient's request handled.
- When is referral considered?
- How is referral made and to who?
- Can the patient access his/her record by self?
- Can the patient interpret final result?
- Who makes the final diagnosis?
- How is the diagnosis arrived at (for doctor only)?

3.2.3 Books, Journals and Online sources

The following medical textbooks and journals were consulted with the aim of getting necessary information on symptoms, signs, risk factors and treatment plan for eye diseases

a) Kanski's Clinical Ophthalmology (8th Edition): Systematic Approach edited by: Brad Bowling. This is the book used for the training of resident ophthalmologists.
b) Borish's Clinical Refraction (Second Edition), Irvin M. Borish, edited by William J. Benjamin: This is the book used for the training of resident optometrists.
c) http://www.ajo.com/.... :This is a popular online journal of the American Journal of Ophthalmology
d) http://www.college-optomtrists.org/.... : This is a popular online journal of the British College of Optometrists.

Information from the textbooks and journals were used to resolve and validate the symptoms, signs, risk factors and treatment plan for eye diseases supplied by the domain experts especially where there are conflicting information.

3.2.4 Direct physical observation

Background: To see is to believe! Physical observation is for me the most crucial aspect of data collection technique as on-the-site observation of the system in action is noted. There are non-salient issues that could be discovered during physical observation which might have been missed out in document review, oral interview and textbooks. However, it is not always possible to keep mute and just observe. There is often the temptation to combine oral interview with physical observation and by so doing the shady areas noted during observation is immediately followed with oral interview.

During direct observation, the following aspects of system are often considered:

- Input to the system
- Output from the system
- The processing performed
- External agents (entities) and their relationships
- The events
- Etc

In this study, physical direct observation of the eye consultation session was done at the selected study center. The following segments of the consultation system were observed.

- Patient registration
- Retrieving of patient's medical records

- Performance of visual acuity test by the doctor
- Process of diagnosis
- Writing of prescriptions
- Giving of medical advice and other information to the patient by the doctor
- Referring a patient to another doctor
- Discharging a patient

3.2.5 Consent form

Consent form (see appendix D) was given to each patient or in case of minors to the guardian. Only patients who gave their consent were included in the research.

3.3 SYSTEM METHODOLOGY USED

Since any successful system development project must have a "Beginning", an "End" and a "Continuum" and in fact a life cycle, the methodologies used in this dissertation followed System Development Life Cycle (SDLC) philosophy for building information systems in a predictive, deliberate and structured manner as described by Kendal(1988). The stages of SDLC are listed as follow:

a) Initiation, Planning or Preliminary analysis
b) System analysis
c) Implementation
d) Systems design
e) Maintenance

3.3.1 The Methodology considered and adopted

Development of expert system requires different approachesand methodologies from the conventional software development. According to Shu-Hsien(2005), the following methodologies have become noticeable in the development of expert systems in thelast two decades.

1. Knowledge representation methodologies
    a. Rule-based methodology
    b. Knowledge-based methodology
    c. Case-based methodology
2. Reasoning methodologies
    a. Neural networks methodology
    b. Certainty factor methodology
    c. Fuzzy logic methodology
3. Object-oriented methodology
4. Database methodology

It shall be noted that Rule-Based, Knowledge-Based, Case-Based, Neural Network, Fuzzy Logic and Certainty Factor methodologies with their advantages cum disadvantages were discussed appropriately in chapter 2 and therefore need not be repeated here. However, for completeness of information, only Database Methodology will be discussed briefly here while Object-Oriented Methodology is discussed in section 3.2.3.

- **Brief overview of Database Methodology**

Database is a type of data management paradigm in which data are aggregated in a format that makes data storage, retrieval and management very optimal. The two outstanding types of database are:

Hierarchical and relational database. In hierarchical database, data are stored in tree-like structure such that data are represented as records in which data items are linked to one another while in relational database, data are stored as records which are represented as rows in a table with the columns representing the data fields. This type of methodology is not ideal for development of CFRMFEDD as an expert system as the type of data structure required by CFRMFEDD is more complex than this.

- **Methodologies adopted**

It is evident hitherto that depending on the type of expert system being developed, a single methodology is not sufficient for complete and successful development of the system. Therefore, in this study, a combination of methodologies were adopted. After evaluation of various research methodologies discussed above, the following methodologies were adopted for this study:

- Rule Based Expert System Methodology (RBESM)
- Object-Oriented Analysis and Design Methodology (OOADM)

3.3.2 Rule Based Expert System Methodology (RBESM)

A rule based expert system is a computer system which could do the work of human expert by relying on sets of rules and facts supplied by the domain expert. It comprises Knowledge base (facts and rules), inference engine, interface and working memory.

The following expert system developmental stages as suggested by Agrawal & Singh(2014)were adhered to during the design and development of CFRMFEDD.

a) Definition of the problem
b) Evaluation of alternative solutions
c) Verification of expert system solution
d) Estimation of the payoff

e) Choosing an expert system tool

f) Performing the knowledge engineering

g) Building the knowledge base

h) Developing the software

i) Testing and validating the system

j) Maintaining the system

3.3.2.1 Knowledge Representation Method

The knowledge stored in the expert system is known as the knowledge base and in this study it is represented in the following knowledge base generics:

a) Facts: This was represented in form of predicates as a clear cut truth.

   Example: EyeDisease (glaucoma)

b) Rules: This was represented as series of facts joined through appropriate logical connectors such conjunctions (AND), disjunctions (OR) and NOT. Horns clause was used to represent the rules where the conclusion represents the precedents and the condition represents the antecedents.

   Example: eyeDisease (X):- eyeSymptom (Y) AND eyeSymptom (Z).

c) Objects: These are represented as classes and modules.

3.3.2.2 The Inference Method

This involved goal search and satisfaction by matching, instantiation and binding of the goal data from the working memory with the facts in the knowledge base. Also certainty factors were used to moderate decisions. The search could be in forward or backward direction.

In this study both types of chaining techniques were used.

a) Forward chaining: This was used when the search was in the direction from conditions to conclusion or evidence to hypothesis or symptoms to disease.
b) Backward chaining. This was used when the search was in the direction from conclusion to conditions or hypothesis to symptoms or disease to symptoms

3.3.2.3 The Expert system interface

The ability of the user to operate this system would be highly truncated if the feel and look of the system were not user-friendly. Therefore, in this study, a robust user-friendly menu-driven interface was used. This is explained in chapter 4 of this dissertation.

3.3.2.4 Object Oriented Analysis and Design Methodology (OOADM)

Object-oriented (OO) methodology recognizes the fact that an entity or object has states and behaviors which are closely interwoven and could not be separated without loss of function. The state defines the properties or attributes of the object while the behaviors are defined by the object methods.

In effect the object state is represented as class facts which can be public or private while the methods are represented by the class predicates which can be public or private. Access to the object properties from an external agent must be done through the class interface.

This way, developers focused on *the entity* in the system that actually does processes and carries data, rather than focus primarily only to one aspect. OO-based system development extensively uses a tool called UML (Unified Modeling Language), which is a set of standard in diagramming and modeling techniques. This tool was used as appropriate in the relevant section of this dissertation.

In addition OO approachhas the following advantages:

a) It is Use-case driven

This means that use-case is the primary modeling tool used to define system behavior. Use-cases describe how the users of the system interact with the system to perform activity. And as a use-case focuses only to one activity at a time, it is inherently simple.

b) It is Architecture centric.

The software architecture chosen for the system should drive the specification, construction, and documentation of the system itself. The system architecture can support the following views of the system:

- *Functional view*
- *Static view*
- a) *Dynamic view*

c) Development is Iterative and Incremental

Each iteration of the system development must bring the system closer to the requirements. As SDLC is a gradual process, the UML diagrams used in OO-based development moves from a conceptual and abstract stage in the analysis and design phase to become more and more detailed in the implementation phase.

d) Polymorphism

The ability to assume instances of many classes through some common superclass relationship.

e) Data encapsulation

This is a way of hiding the implementation details from the user and only exposes the properties of some hidden members through use of special functions or methods.

f) Inheritance

This is a way of sharing common features or traits by passing properties and methods from one superclass to subclass without loss of meaning.

3.3.3 The Organization and her environment

Since this study is focused on the use of intelligent system as a diagnostic tool in eye consultation process, there was the need to select a relevant study center for information gathering and system testing.

3.3.3.1 Selection of study center

A list of all the registered eye hospitalsand their facilitiesin south eastern Nigeria for the year 2012 was retrieved from the appropriate professional registration body(ODORBN, 2012). Only the few eye clinics that use automated system for eye examinations were shortlisted for final selection. UNTH Eye clinic Enugu was finally adopted as the study center due to the following reasons:

- It has adequate number of domain experts (eye doctors) and medical assistants
- It has modern eye examination equipment
- It offers a wide range of eye care services
- It has large patient turn-over
- It has a visible web presence and information platform
- It is easily accessible both to the researcher and the patients

3.3.3.2 Description of the study center

a) **Domain area and Specialization:**UNTH Eye clinic is an ultra-modern eye center that is specialized in management of many forms of eye diseases and disorders.

b) **Location**: The clinic is located at Itukku-Ozalla, Enugu State and it's accessible within 200m of public transport route.

c) **Services provided**: The following services are offered by BMC

- Cataract extraction (SICS, ECCE, ICCE and Lens Washout) + IOL
- Cataract extraction (SICS, ECCE, ICCE and Lens Washout) without IOL
- Phacoemulsification + IOL
- Trabeculectomy
- Enucleation
- Evisceration
- Modified exenteration
- Eye Lid surgery
- Squint surgery
- Exploration and repair of Corneo-scleral Laceration
- Superficial Corneal foreign body removal
- Intra-ocular foreign body removal – Anterior segment
- Intra-ocular foreign body removal – Posterior segment
- Incision and Curettage of Chalazion
- Pterygium excision
- Epilation of Lashes

- Dermoid Cyst excision
- Vitrectomy
- Corneal Transplant
- Refraction
- Auto-Refraction
- Low Vision Evaluation
- Contact Lens Evaluation
- Orthoptic Evaluation/Training
- vision training for professional
- Non-contact Tonometry
- CVF
- Biometry
- Color blindness Test
- Contrast Sensitivity Test
- B-Scan Ultrasonography
- OCT- Pachymetry
- OCT – Glaucoma scan
- OCT- Macular scan
- OCT – Ant. Segment scan
- OCT Goniometry
- AMD Screening _Macular Pigment Density Measurement
- Fundus Photography
- Fundus Flourescein Angiography

- Fundus Indocyanin Green Angiography
- Teleoptometry distant patient surveillance
- Tele-Ophthalmology Consultation

d) **Equipment and facilities**: The clinic has current eye equipment necessary to make vast arrays of eye diagnosis. It also has good e-library facilities.

e) **Visibility**: The hospital has a good web presence as important information on eye care tips are available on the organization's web portal.

f) **Staff strength**: The clinic has the following staff strength

- 10 consultant ophthalmologists (Domain experts)
- 6 consultant optometrists (Domain experts)
- 10 resident doctors
- Variable number of intern optometrists
- 10 medical assistants
- 8 ophthalmic nurses
- Other auxiliary and support staff

g) **Patient population**: The clinic records average patients' daily attendance of 100 on week days.

3.4 Analysis of existing System

Analysis of the existing system is tantamount to asking the big question: Where are we now? Craig(2011), discussed that the analysis of the existing system involves detailed investigation and study into the functionality currently provided by the existing system(s), both manual and automated. The objectives of this analysis were to understand how the requirements are currently being met with the

existing system(s), document the flow, processing and use of information within the existing system(s), identify the limitations with the existing system(s) and then finally define new requirements.

From the literature review, the following expert systems were applied for eye diagnosis:

- The Causal Association NETwork (CASNET)
- Neural Networks and Decision Trees for Eye Diseases Diagnosis (NNDTEDD)
- Expert System for Diagnosing Eye Diseases Using Clips (ESDEDUC)
- Expert System for Early Diagnosis of Eye Diseases (ESEDED)
- Experimental System for Self-Diagnosing of Eye Diseases (ESSDED)

Out of the five existing expert systems, a random selection was made and ESSDEDwas finally selected to represent the existing system

3.4.1 Detailed description of the existing system

Here the existing system is described in details.

3.4.1.1 Existing system descriptive narrative

A patient who has complaints related to his sight reports to a center using an expert system.

- **Registering a patient**

Patient registers his/her name.

- **Consultation session**

The first tentative symptom is displayed and the patient is expected to provide Yes or No response. More questions are presented for patient to respond until when the entire questions are exhausted.

- **Analysis of findings and final diagnosis by the system**

After collection of symptoms from the patient, the system finally arrives at a diagnosis of the patient's eye disease by matching the signs and symptoms using the already stored symptoms in its knowledge base. However, in some situations a group of symptoms supplied by the patient may not have similar matching homologue in the knowledge base and in such cases, eitherthe closest matching disease is returned or the case is considered as unresolvable. All unresolvable cases will be marked for the medical assistant's attention. Diagnosis is made in form of disease classification

- **Treatment and discharge**

When the system has successfully made a diagnosis of the patient's eye condition, it will proceed to proffer best medical advice and/or information on best treatment options.

- **Knowledge acquisition**

Several past medical case files are loaded into the system during knowledge acquisition

3.4.1.2 Existing system descriptive model

Figure 3.1 demonstrates the descriptive model of the new system in which the symptoms provided by the patient are matched with disease-symptom cases already in the knowledge base. If a match of the symptom complex (homologue) is found, the system will retrieve a corresponding disease that is linked with the disease-symptom case, retain the symptoms and then make a confirmed diagnosis. Conversely, if a match is not found, a review is made by getting more symptoms from the patient until a closest match is found or the system has exhausted all its questions and in either case the closest disease match is suggested.

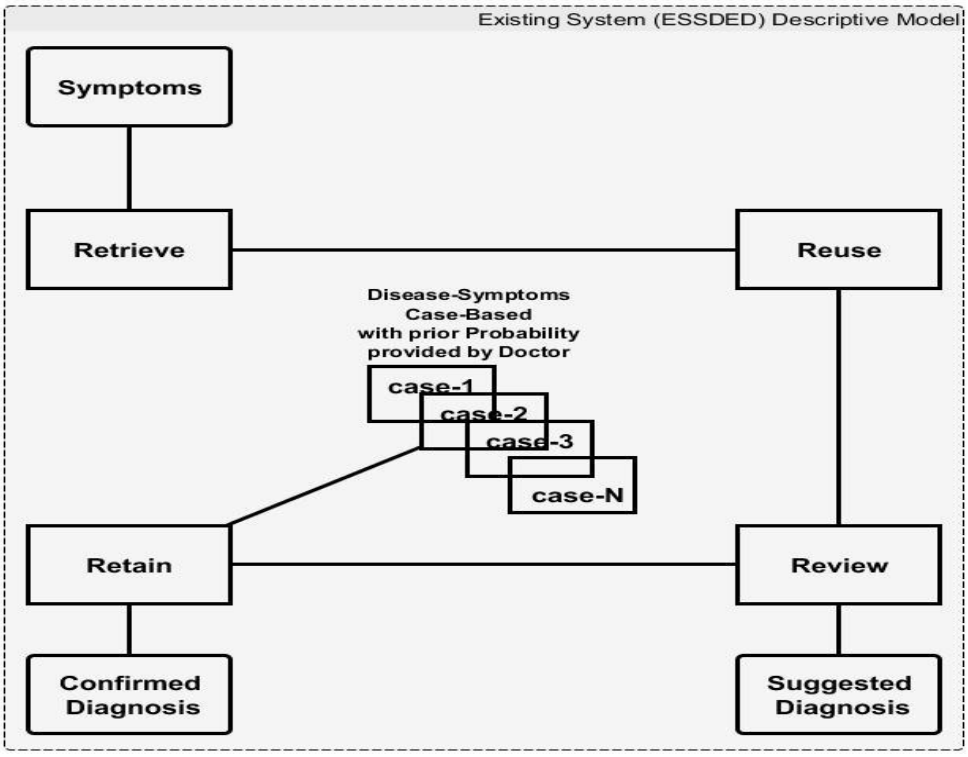


Figure 3.1: The Existing system Descriptive model

3.4.2 Analysis of the diseases diagnosed by the existing system

- A total of 20 cases were selected from the medical records already seen by the eye doctor.
- The selected cases were re-tested using the existing system
- "An inter-rater reliability/Agreement analysis using the Kappa statistic was performed to determine consistency/Agreement between the diagnosis made by the existing system and that made by the domain expert."

3.4.2.1 Analysis of existing system using Cohen's Kappa Agreement Tool

Using a 2 x 2 matrix (a, b, c, d) for 2 raters X, Y accessing two categorical variables (YesDisease or NoDisease) for sample size, N.Where a, b, c and d represent the frequency of agreement or disagreement of the two raters, X, Y as follow:

a = YesDisease, YesDisease, …..(Agreement)

b = YesDisease, NoDisease, …..(Disagreement)

c = NoDisease, YesDisease,……(Disagreement)

d = NoDisease, NoDisease…….(Agreement)

$P_{observed}$ = [a + d] / N ……..Eqn (1)

$P_{Expected}$ = [(a +b) (a +c)]/N + [(b +d) (c +d)]/N …….Due to chance…….Eqn (2)

K= [$P_{observed}$ – $P_{Expected}$] / [1- $P_{Expected}$]……Eqn (3)

The computed analysis is shown in Tables 3.1 – 3.5.

Tables 3.1 and 3.2 show a comparison of the diagnosis made by the existing system and that made by the domain expert on the same patients. Analysis of the two methods of diagnosis for agreement revealed that both methods agreed in 80% of the cases (This compares closely with the quoted accuracy of 82% by the existing system by Kurniawan et al, 2014) and disagreed in 20 % of the cases. Out of those cases that were in agreement, 75% of the cases were found to have eye problems while the remaining 25% were normal. Also, for those cases that were in disagreement, 50% have eye problems while 50% were normal. The symmetric measure (Table 3.3) indicated that Kappa value was 0.524 with standard error of +/- 0.208 when null hypothesis is not assumed and +/-2.343 when Null hypothesis is

assumed. This kappa value corresponds to “Moderate Agreement” as recommended by Landis & Koch (1977)(Table 3.4). A closer look at the input data requested by both systems before making diagnosis (Table 3.5) indicated that visual acuity status of the patient was not taking into consideration by the existing system but which was used by the domain experts. This, it is suspected may contribute to possible source of diagnostic disagreement in the few cases. It is therefore evident that lack of visual acuity inclusion in the existing system may have affected the reliability of its diagnostic output.

Table 3.1: Cohen’s KappaCase Processing summary of the existing system

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Domain Expert * ExistingSystem	20	100.0%	0	0.0%	20	100.0%

Table 3.2: Cohen's KappaDomain Expert versus ExistingSystem Crosstabulation

			ExistingSystem		
			YesDisease	NoDisease	Total
HumanExpert	YesDisease	Count	**12**	**2**	**14**
		Expected Count	**9.8**	**4.2**	**14.0**
	NoDisease	Count	**2**	**4**	**6**
		Expected Count	**4.2**	**1.8**	**6.0**
	Total	Count	**14**	**6**	**20**
		Expected Count	**14.0**	**6.0**	**20.0**

Table 3.3: Cohen's Kappa Symmetric Measures of existing system

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	**0.524**	0.208	2.343	0.019
	N of Valid Cases	20			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table 3.4: Interpretation of Kappa's values (Landis & Koch, 1977)

Kappa	**Interpretation**
<0	Poor Agreement
0.0 – 0.20	Slight Agreement
0.21 – 0.40	Fair Agreement
0.41- 0.60	Moderate Agreement
0.61 – 0.80	Substantial Agreement
0.81 -1.00	Almost Perfect Agreement

Table 3.5: Major input parameters used by domain expert and existing systems

Domain Expert input data	Existing system input data
Symptoms	Symptoms
Visual acuity	Nil

3.4.2.2 Summary of the Analysis of existing system

- **Knowledge acquisition**

Existing system uses Cased Base as technique for knowledge representation

- **Uncertainty management**

Existing system employs Bayesian network for management of fuzzy and uncertain information

- **Accuracy**

16 out of 20 (80%) diagnosis were correct. The accuracy of the existing system as given by Kurniawan et al. (2014) is 82%.

- **Range**

12 out of 16 eye diseases presented were diagnosed, hence the range is <=12.

- **User mode**

It is a self-diagnosis tool and relies on the information supplied by the patient

- **Consideration of visual acuity**

Non-inclusion of visual acuity as input parameter by the existing system may have affected its diagnostic ability.

3.4.3 Advantages of the existing system

a) Case based systems are popular among expert system developers as there are many expert system shells and support tools available (as open source software) for system development.

b) Bayesian network model is also a popular reasoning tool used by expert system developers for uncertainty management in large knowledge base scenario, hence there are lot of support tools for the developers.

c) By using rule based knowledge representation approach and Bayesian network reasoning technique, the existing model therefore has optimal decision making capability to cater for diagnostic decisions in medicine.

d) The model employs a popularly accepted probability approach in its decision making protocol.

e) Presence of more symptoms (evidence) re-enforces the belief in occurrence of disease (hypothesis) as the model has a robust combinational probability derivation function.

f) The consultation process is simple and less-time consuming

g) The consultation can be carried out by a medical assistant rather than the expert (doctor) and therefore can free the expert time for other serious engagement.

h) The system can discover new disease-symptoms-relationship (datamine) easily from vast amount of information already existing in its knowledge base.

3.4.4The disadvantages of the existing system

a) The system does not allow the patient to rate his/her confidence level (belief, disbelief or certainty) on the symptom he hascomplained. This is one of the artifacts of using Bayesian network approach.

b) The system excludes visual acuity as a vital input parameter in diagnosis and therefore lacks objective assessment and verification of patient's claim.

It shall be noted that most eye diseases affect the visual acuity of the patient, therefore if patient's claims point to suspicion of particular eye disease, then such eye condition will invariably affect the quality of his/her vision and invariably the visual acuity of the patient will be affected. An efficient system should be able to verify the patient's claim through visual acuity measurement!

c) The system performance depends heavily on the prior probability values being provided by the domain expert for each rule and for each joint/combinational probability occurrence. Since the number of combinational probability values needed increases exponentially as the number of variables (evidence/symptom) increases, it becomes almost impossible for a domain expert to provide all the required prior probability values especially in eye conditions where many symptoms characterize a single or multiple disease occurrence.

d) Determination of posterior and joint probability values become more complex as the number of variables (evidences/symptoms) increases. This becomes challenging to the system developers and therefore may have prompted most developers to limit the number of variables (symptoms) and hence the number of diseases the system can handle. Currently, only a maximum of twelve eye diseases are covered by existing expert system. This again exposes one of the artifacts of using Bayesian network model as a reasoning tool for eye diagnosis.

e) Bayesian network model works on the assumption that there is no dependency or association between the variables especially in joint/combinational probability derivations. However, this assumption cannot be guaranteed at all times in medicine. Therefore, when the contrary holds sway, then the diagnosis made by expert systems that rely on Bayesian network becomes untrusted and unreliable.

f) Bayesian network systems perform better in situations where there is large database/knowledge base as may be found in general medicine. Unfortunately, eye medicine, being a branch of medicine has limited database/knowledge base of eye diseases and therefore Bayesian network based-model may not be the ideal reasoning methodology in diagnosing eye diseases.

3.5 Analysis of the New System

Analysis of the newsystem is akin to asking the big question where are we going?

The new system is an intelligent eye diagnostic system with the sole purpose of testing and diagnosing the health status of a human eye through a user-friendly interface and then issuing appropriate prescriptions or advice. It comprises two major components: The visual acuity automation system and the expert system.

The automation system component would deliver visual acuity test/measurement while the expert system component wouldconduct differential diagnosis using the result of visual acuity earlier measured and then issue prescription/advice. After reviewing the user's requirementspecification, the following describes the functionality of the new system.

3.5.1 Detailed Analysis of the newsystem

Here the detailed description of the new system is done.

3.5.1.1 New system descriptive narrative

A patient who has complaints related to his sight reports to a center using an expert system.

- **Registering a new patient or retrieving existing patient's folder**

The medical assistant enables a new patient to register by entering the following patient's information into the patient's database (medical folder). Names (Surname, First name), Sex, Age, occupation, phone no. Existing patient or patient who has registered previously will have his/her medical folder retrieved by logging with patient mode.

- **Measurement of visual acuity**

The visual acuity of the patient is taken with the help of medical assistant. During the process, the following procedure is undertaken.

The patient sits 3 meters in front of the computer screen in a well illuminated room. The system displays instruction on the screen informing the patient the purpose of the test and what he is expected to do. Thereafter, the patient is asked to close one of his/her eyes (preferably the left eye). A Visual acuity chart (upper case letter E) and four arrow buttons are displayed on the screen. The patient is expected to click on any of the arrow buttons with the help of a wireless keyboard or extended-cable. The correct arrow button to be clicked is the button which has a corresponding orientation with the displayed E. Once the patient clicks on any of the buttons, the system automatically rotates (tumbles) the E to another orientation. The following four orientations are possible: Up, Down, Left, Right. As the patient continues to click on the buttons correctly, the system will continue to change the E both in orientation

and in size thereby gradually increasing the visual challenge to the eye being tested. But, when the patient clicks at a wrong button, the system notes this failure and alerts the patient accordingly with an audible beep. On incidence of a failure, the system assumes that either the patient does not see the displayed E or that he has made a mistake. The system therefore records the number of times and the sequence of failures. After a reasonable number of failures (which is dynamically determined by the system) the test automatically halts and records the result. Also when the patient fails to click on any button for considerable period of time (as dynamically determined by the system), the test automatically halts and the patient is asked to repeat the test. The entire process is again repeated for the fellow (untested) eye. The test can be skipped for one eye but not both if necessary.

- **Consultation session**

The first tentative symptom and a confidence barare displayed and the patient is expected to provide Yes or No answer and also indicate his level of confidence with the following ranges: Unknown (0-20%), May-be (21-40%), Probably (41-60%), Almost-Certainly (61-80%) and Definitely (81-100%). After submitting the answer by clicking submit button, further context-sensitivequestion(s) based on the previous answer(s) will be displayed (through pre-processing technique). This process is repeated until when the system has exhausted all the relevant questions or a matching tentative diagnosis has been found. Also within the period of the consultation, the user can request for explanation for reasons behind any diagnosis arrived at by clicking on <Explain> button.

- **Analysis of findings and final diagnosis by the system**

After collection of symptoms from the patient, the system finally arrives at a diagnosis of the patient's eye disease by matching the signs, symptoms and the earlier recorded visual acuity value using its knowledge base. However, in some situations the symptoms supplied by the patient may not lead to any

known eye disease in the knowledge base and in such cases, the patient may be advised to start all over again or the case is treated as unresolvable. All unresolvable cases will be referred by the assistant.

- **Discharge, Treatments and output of result**

When the system has successfully made a diagnosis of the patient's eye condition, it will proceed to proffer medical advice, treatment options and counselling to the patient. The results can be printed out as summary note in hard copy or copied out to external storage device or stored in the patient's medical record in the system.

- **Provision of learning facility**

A user who wants to learn about eye diseases can click the appropriate button. Depending on the category of user (determined by the system during log-in session), either as a patient, student or doctor, the system will display relevant aspects of eye disease attributes which may include one or all of the following: Disease name, Disease image, signs, symptoms, risk factors and treatment options. Under student mode, the user can type combinations of symptoms and study the type of corresponding eye diseases such symptoms could lead to and vice-verse.

- **Knowledge acquisition**

The knowledge to be used are stored as sets of facts and rules in the knowledge base. These facts and rules will be initially supplied by the domain expert (eye doctor) during the design stage (knowledge acquisition) of the expert system. For each rule provided, the domain expert shall attach a corresponding certainty factor (CF_1) value which represents the expert's belief or degree of certainty and also the expected vision acuity range associated with the rule. The facts to be used in this model shall come from two sources: The facts about eye diseases, signs, symptoms and treatment options are supplied by the domain expert while the facts about the current symptom, the certainty factor values (CF_2) and the

current visual acuity of the patient is supplied by patient. The fact from the domain expert is stored in the knowledge base while the facts from the patient is stored in the working memory. The proposed expert system shall use rule based approach as its knowledge representation and certainty factor as its reasoning method.

- **Adding and deleting disease/attributes**

A new eye disease can be added to the knowledge base when the system is run on doctor or Admin mode. Adding new disease involves declaring the disease name, then associating the existing disease image, symptoms, signs, risk factors and treatment (disease attributes) to the disease or where the desired attribute is non-existent, by creating new ones. Conversely, deleting existing disease from knowledge base involves declaring the disease name to be deleted.

3.5.1.2 The New System Descriptive Model

A prototype of the new system(See Figure 3.2) was developed and used for analysis of the system. The system consists of the input sub-system, diagnosis sub-system, database sub-system and output sub-system.The facts, rules and associated certainty factors once supplied by the eye doctor constitute the knowledge base which also serve as primary input data. The symptoms, the certainty factors and the visual acuity results extracted fromthe patient at every consultation constitute the secondary input data to system. The two sources of CF are combined by CF calculator to produce composite CF which in conjunction with other input data enable the system to infer diagnosis.

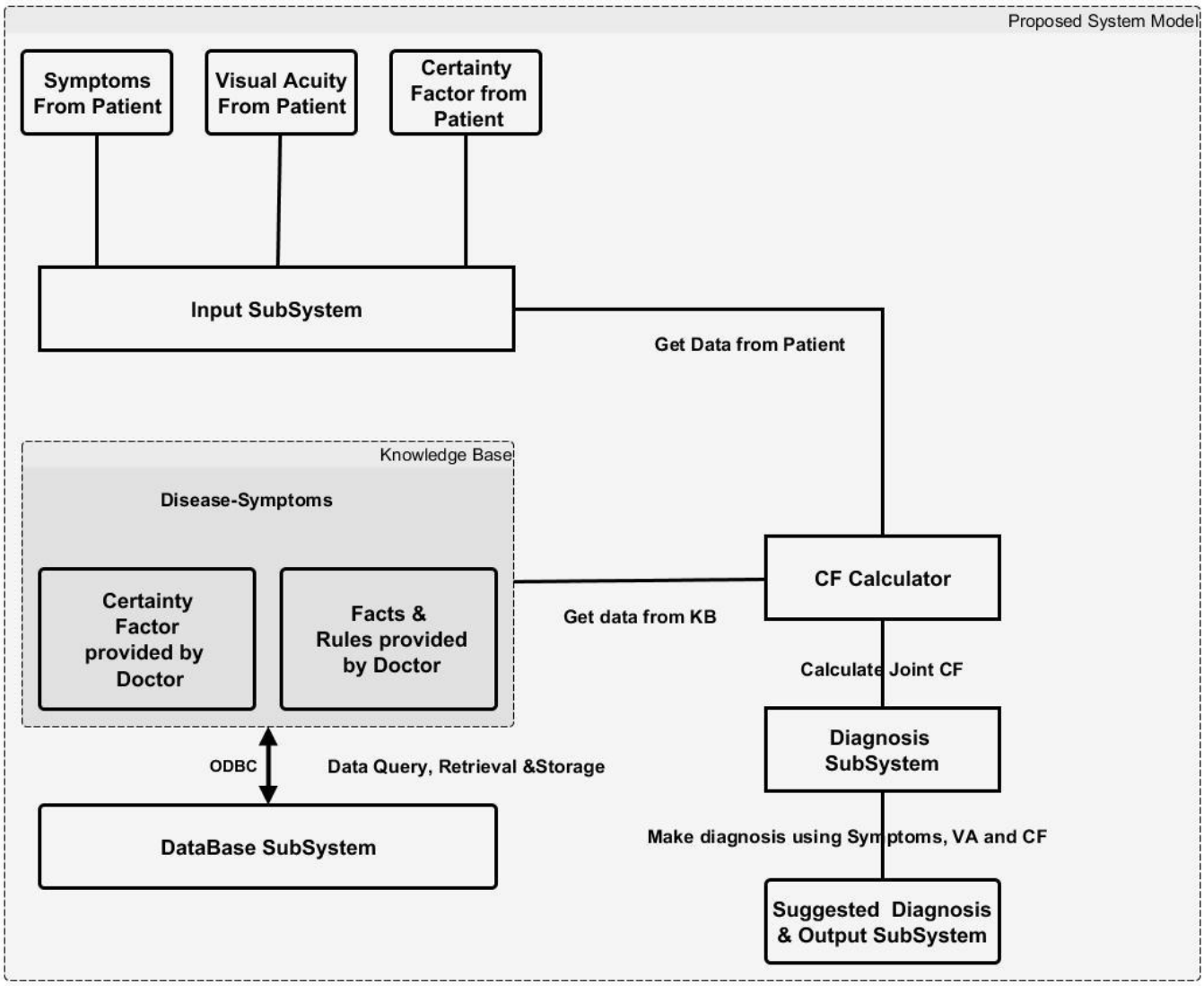


Figure 3.2: The Architecture of the New System

3.5.1.3 Analysis of the diseases diagnosed by the new system

The same 20 cases which were previously used during existing system analysis were selected.

The selected patients were tested using the new system prototype. An inter-rater reliability/Agreement analysis using the Kappa statistic was performed to determine consistency/Agreement between the diagnosis made by the new system and that made by the domain expert". The results of the analysis are shown in Tables 3.6 - 3.10.

A comparison of the diagnosis made by the new system and that made by the domain expert on the same patients was done (Tables 3.6 and 3.7). Analysis of the two methods of diagnosis for agreement revealed that both methods agreed in 90% of the cases but disagreed in 10 % of the cases. Out of those cases that were in agreement, 78% of the cases were found to have eye problems while the remaining 22% were normal. Also all the cases that were in disagreement have eye problems. The symmetric measure (Table 3.8) indicated that Kappa value was 0.737 with standard error of +/- 0.17 when null hypothesis is not assumed and +/-3.416 when Null hypothesis is assumed. This kappa value corresponds to "Substantial Agreement" as recommended by Landis & Koch(1977)(Table 3.4). A closer look at the input data demanded by both systems before making diagnosis (Table 3.9) indicated that visual acuity status of the patient was taking into consideration by both systems. It is therefore evident that inclusion of visual acuity in the new system may have contributed to improved diagnostic agreement of both systems in most cases and thus improved the system reliability.

Figures 3.3 - 3.4 demonstrate the benefits of applying pre-processing technique by the proposed system whereby the actual number of questions asked before diagnosis of astigmatism could be made was 8 as against 132 questions in the database which would have been asked the patient were this technique not applied. With the inclusion of certainty factor method, per-processing technique and visual acuity evaluation, the system was able to exhibit at least 7 basic features of intelligent system (Table 10).

Table 3.6: Cohen's Kappa Case Processing Summary of the new system

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Domain Expert *New System	20	100.0%	0	0.0%	20	100.0%

Table 3.7: Cohen's Kappa Domain Expert versus New System Cross tabulation

			New System		
			Have Disease	No Disease	Total
Domain Expert	Have Disease	Count	14	0	14
		Expected Count	11.2	2.8	14.0
	No Disease	Count	2	4	6
		Expected Count	4.8	1.2	6.0
	Total	Count	16	4	20
		Expected Count	16.0	4.0	20.0

Table 3.8: Cohen's KappaSymmetric Measures

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	0.737	0.170	3.416	0.001
	N of Valid Cases	20			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Table 3.9: Major input parameters used by domain expert and the new system

Domain Expert input data	New system input data
Symptoms	Symptoms
Visual acuity	Visual acuity

Number of questions asked									Number of questions to ask
0	**Rem 132**								
1	Symptom1	**Rem 47**							**132**
2	Symptom1	Symptom2	**Rem 36**						**47**
3	Symptom1	Symptom2	Symptom3	**Rem 14**					**36**
4	Symptom1	Symptom2	Symptom3	Symptom4	**Rem 3**				**14**
5	Symptom1	Symptom2	Symptom3	Symptom4	Symptom5	**Rem 2**			**3**
6	Symptom1	Symptom2	Symptom3	Symptom4	Symptom5	Symptom6	**Rem 1**		**2**
7	Symptom1	Symptom2	Symptom3	Symptom4	Symptom5	Symptom6	Symptom7	**Rem 0**	**1**
8	Symptom1	Symptom2	Symptom3	Symptom4	Symptom5	Symptom6	Symptom7	Symptom8	**0**

Figure3.3: Demonstration of Pre-processing technique for Astigmatism by the proposed system

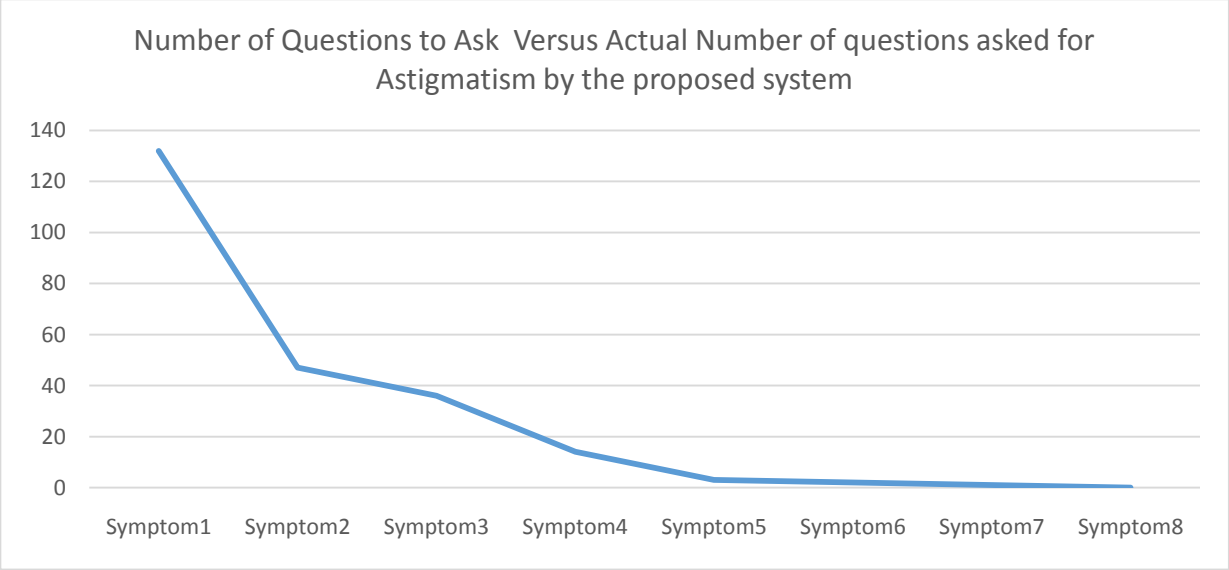


Figure 3.4: Plot of Number of questions to ask versus Actual no of questions asked for astigmatism by the proposed system

Table3.10: Intelligent features of CFRMFEDD

Intelligent Features	**CFRMFEDD Features**	**Justification**
Learning		
Adaptation		
Goal-Orientation	YES	Prolog Goal satisfaction technique is used
Using knowledge	YES	Rules and Knowledge base techniques of expert system are used
Problem Solving	YES	Diagnosis of eye diseases is achieved
Reasoning	YES	Certainty factor technique is used
Applying Experience		
Generalization/Classification	YES	Visual acuity classifier is used
Perceiving Relationships		
Planning Autonomy		
Perceptional Recognition Classification		
Quickness	YES	From Consultation to diagnosis takes average of 5 minutes
Flexibility	YES	Flexible and Updatable Knowledge base, multiple user views and privileges are supported
Pattern Recognition		

3.5.1.4 Summary of Analysis of the new system

- Knowledge acquisition

Proposed system uses Rule based system as technique for knowledge representation

- Uncertainty management

Proposed system employs Certainty Factor technique for management of fuzzy and uncertain information

- Accuracy

18 out of 20 (90%) diagnosis were made correctly.

- Range

All the eye diseases analyzed except one were diagnosed.

- User mode

It is an assisted eye diagnostic tool and relies on the information supplied by the patient through symptoms and visual acuity measurement.

- Consideration of visual acuity

Inclusion of visual acuity as diagnostic input is once more re-emphasized in the new system

- Intelligent features

The proposed system exhibited some of the features of intelligent systems (Shiva & Ahmad, 2016) as follow: Goal-Orientation, Use of knowledge, ability to Solve Problems, Reasoning,Generalization/Classification, Quickness (via pre-processing) and Flexibility.

3.5.2 Justification of the new system

Development of new system is justified as follow:

a) Existing systemdoes not validate patient's claim but totally relies on the symptoms claimed by the patient. In the new system, the patient's claims could be validated objectively through visual acuity matching.
b) Visual acuity measurement was not included as input parameter for diagnosis in the existing system which is now included in the new system.
c) The new system allows patient to input the level of his/her belief/certainty in the symptoms he has provided which the existing system does not.
d) The new system gets estimate of uncertainty from two independent sources (the patient and the doctor) and thereby improving its ability to deal with uncertainties while existing system gets estimate of uncertainty from only one source (the doctor).
e) By using certainty factor model, the new system can explain its actions to the user which the existing system that uses Bayesian network could not do.
f) Derivation of joint probability calculation for independent symptom variables is more complex in existing system as it relies on Bayesian network model. Such calculations are simple and straight forward in the new system as it uses certainty factor model.
g) Existing system power relies on presence of massive database and therefore could not function effectively with small database set as routinely encountered in eye medicine. The new system

derives its power from small database set and is therefore more adapted tool for eye disease diagnosis.

h) New or more diseases and symptoms cannot be added in the existing system without recoding the system. By separating the database from the internal system architecture in the new system, more diseases can be added or deleted without any need for recoding.

i) The number of eye diseases that could be diagnosed by the existing system is limited to 12. In the new system, the number of eye disease that could be diagnosed are unlimited and depends on the size of database.

j) By having an updatable database, the new system can meet up with the volatility of ever changing medical information.

k) The new system uses simple tumbling-E visual acuity chart which can be recognized by all categories of patients irrespective of education, age and Intelligent Quotient (IQ) differences.

l) By applying anti-guess algorithm both during visual acuity measurement and during symptoms checking, the new system can extract more reliable information from the patient.

m) Existing system is strictly meant for self-testing and cannot be extended for learning purposes

n) Both the Diagnosis and visual acuity measurement are not integrated in one platform in the existing system. The new system has brought the two tools into a single platform.

o) By applying pre-processing technique by the new system, the total consultation time is faster, the patient's attention spam could be maintained and the consultation process shall be less tedious to the patient.

p) By knowing his/her ocular status at all times, the new system empowers the user to have the destiny of his/her ocular health at his/her own hand.

q) By enabling eye tests to be performed by non-doctors, the new system releases the eye doctors to concentrate on more serious eye conditions as well as giving them more opportunities and time for research work.

r) By empowering the patients to know the status of their vision, the new system can influence reduction of avoidable blindness and enhancement of preventive medicine especially in developing countries.

s) The total cost of assessing eye health services by the patient such as consultation fees, drugs and laboratory fees, transport fares and other inconveniences will be reduced to barest minimum if the new system is implemented.

t) The risk of frequent travels and its associated risks often encountered by the patients while seeking for eye consultations will be reduced to barest minimum by the new system.

u) A successful implementation of the system will once more prove that computer technology can be gainfully deployed to help alleviate the problems of modern man especially in developing countries.

v) Finally, the efforts connected to the development of new system will contribute to the databank for related studies as well as provoke further research interests in areas of e-medicine and telemedicine.

3.6 High Level Model of the new System

Figure 3.5 describes the high level model of the new system. The model consists of patient registration module, visual acuity automation module, knowledge base and working memory module, certainty factor calculator, diagnostic module and "storage, output and display module". The major data input originate from both the patient and the doctor. Patient is registered the first time with biodata information. Visual acuity test is performed first then followed by symptom

extraction during which certainty factor is provided by the patient for each symptom. Also certainty factor is provided for each disease definition in the knowledge base by the doctor. Diagnosis is inferred using the certainty factors, the visual acuity result and the symptoms provided by the patient to match the disease definitions provided by the doctor in the knowledge base. The database is linked with the knowledge base at the program startup. The model also provides other features which include: Learning facilities, administrative routines (which permits updating of knowledge base by adding or deleting diseases, symptoms, signs, treatment, risk factors and disease images) and various output features.

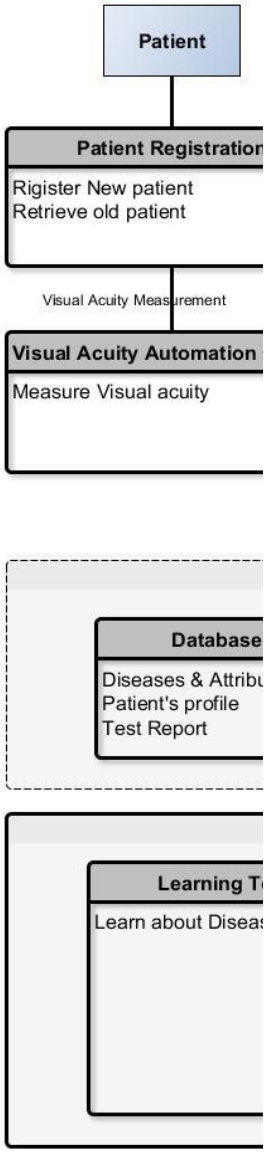


Figure 3.5: High level Model of New system

3.7 Objectivesof the Design

The objectives of the design are to design a system that can:

i. Measure the visual acuity through digitally projected chart

ii. Make disease diagnosis by asking questions and getting symptoms and certainty factors from the patient.

iii. Provide a user-friendly menu-driven interface

iv. Register new patients, diseases, symptoms, signs, risk factors and treatment into the database

v. Output result in form of health advisory note

3.8 Decomposition and Cohesion of the High Level Model

The High level model of CFRMFEDD is decomposed into five modules (See Figure 3.6) as follow:

- Menu System
- Expert System
- Database System
- Visual Acuity Module
- Utility Module

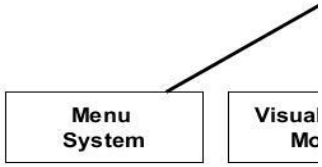


Figure 3.6: IEDM Module

3.8.1 The Main Menu

The main menuis the first level menu through which the user enters the system, navigates, carries an action(s) and exits the system(See Figure 3.7). It is represented as a graphical user interface designed after a standard window template. The main menu consists of the following menus:

a) File

b) Log In/Out

c) Eye Diseases

d) Eye Testing

e) Reports

f) Settings

g) Windows

h) Help

Purpose: The main menu gives the user navigation access to the entire system

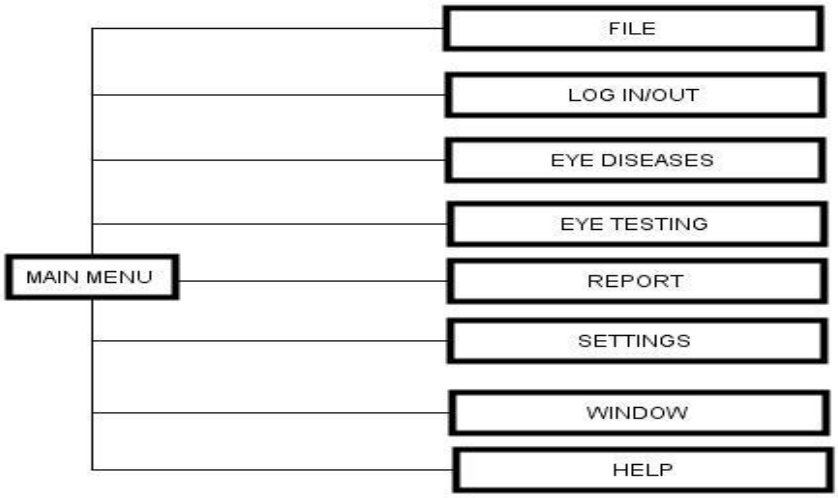


Figure 3.7: Main Menu

3.8.2 The Sub-menu design

The sub-menu design involves the design of each element of main menu.

3.8.2.1 File Menu

The File menu has three sub-menus (Figure 3.8) as follow:

a) System admin …

a. (Menu properties: Enabled: True, Checked:False)

b) Print …

a. (Menu properties: Enabled: True, Checked:False)

c) **Exit**

a. (Menu properties: Enabled: True, Checked:False)

The file menu provides a major navigation route to the user through which the user can carry out some administrative functions, print reports and exit the system.

Purpose: This menu allows the user to carry out sensitive administrative functions that involve updating of knowledge base and database: creating new patients, new disease attributes new Rules, etc.

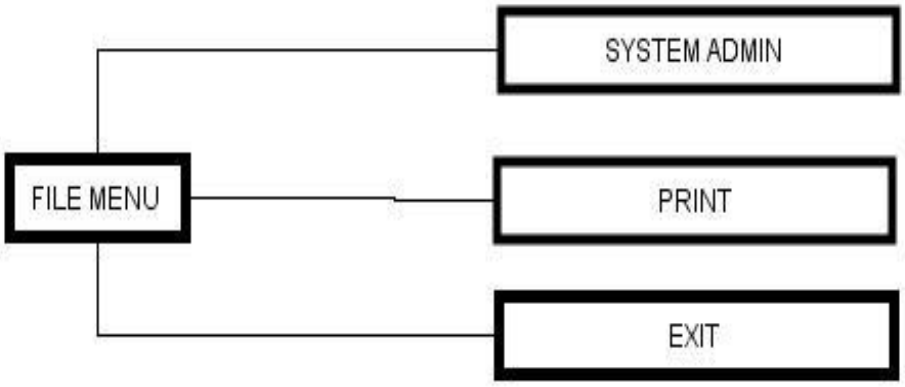


Figure 3.8: File Menu

3.8.2.1.1 System Admin Submenu

The system admin submenu has two sub-menus(Figure 3.9) as follow:

a) Update database …

a. (Menu properties: Enabled: True, Checked:False)

b) Add new Patient …

a. (Menu properties: Enabled: False, Checked:False)

The system admin sub-menu can only be accessed through appropriate user log-in as either a doctor or a system administrator with password.

Purpose: It functions as its name suggests.

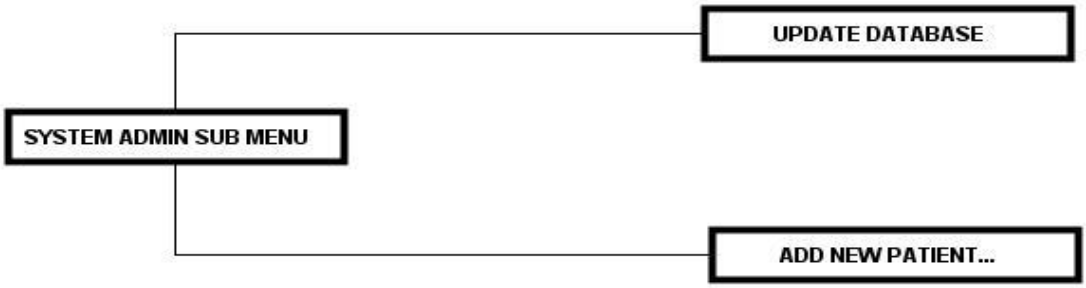


Figure 3.9: System Admin Sub-menu

3.8.2.1.2 Update Database Sub-menu

The Update Database sub-menu has the following sub-menus(Figure 3.10):

a) Add New Disease Attributes

(Menu properties: Enabled: False, Checked:False)

The disease attributes functions to carry out include:

i. Adding new disease symptoms
ii. Adding new disease signs
iii. Adding new disease risk factors
iv. Adding new treatment options

b) Delete Existing Eye Disease

(Menu properties: Enabled: False, Checked:False)

c) Add New Eye Disease

(Menu properties: Enabled: False, Checked:False)

Purpose: This menu allows the user to add new eye disease attributes which includes: new symptoms, signs, risk factors and treatment, new eye disease and deletion of existing eye disease from the knowledge base.

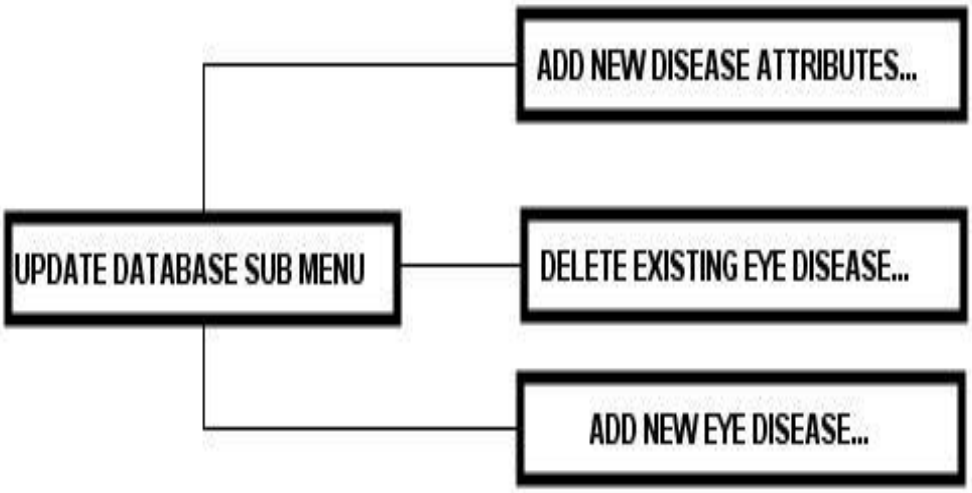


Figure 3.10: Update Database Sub-Menu

3.8.2.1.3 Print sub-menu

The Print sub-menu has two sub-menus(Figure 3.11):

a) Print My case Report

(Menu properties: Enabled: False, Checked:False)

b) Print Others case Report

(Menu properties: Enabled: False, Checked:False)

Purpose: This menu allows the user to print out the result of the eye test.

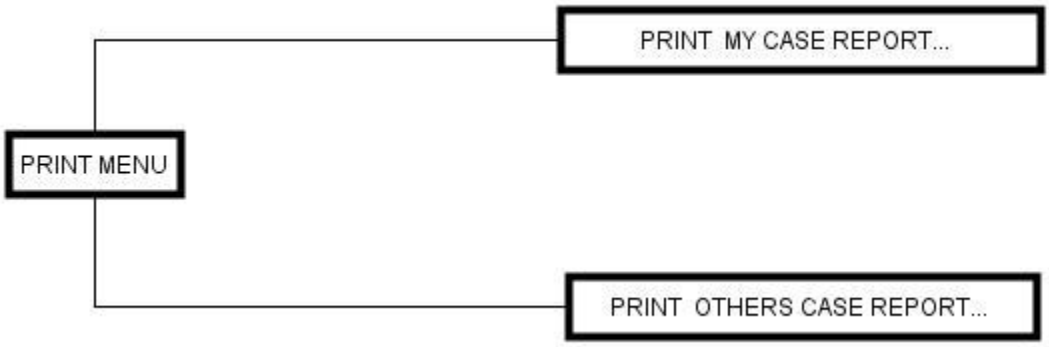


Figure 3.11: Print Sub-menu

3.8.2.2 Log In/Out menu

The Log In/Out menu has two sub-menus(Figure 3.12):

a) Log in

i. Login as a patient (Menu properties: Enabled: True, Checked:False)

ii. Login as a doctor(Menu properties: Enabled: True, Checked:False)

b) Log out

(Menu properties: Enabled: True, Checked:False)

Purpose: This menu gives log-in and log-out access to the user. User can either log-in as a patient or as a doctor. This will automatically hide/show and enable/disable view privileges and rights as appropriate

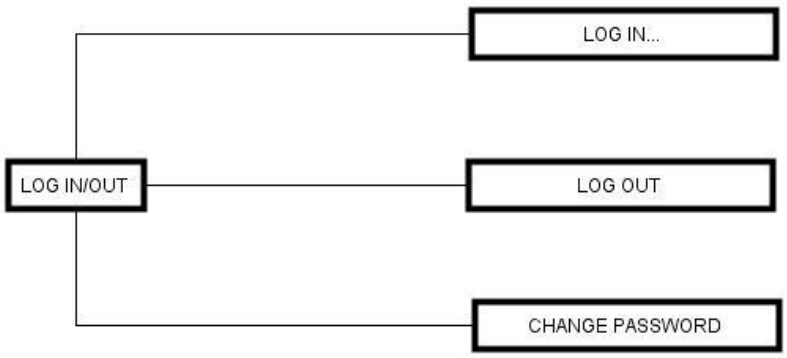


Figure 3.12: Log In/Out menu

3.8.2.3 Eye Diseases Menu

The Eye Disease menu has five sub-menus (Figure 3.13) as follow:

a) Browse Eye diseases

(Menu properties: Enabled: True, Checked:False)

b) Browse Symptoms List

(Menu properties: Enabled: False, Checked:False)

c) Browse Signs List

(Menu properties: Enabled: False, Checked:False)

d) Browse Risk Factors List

(Menu properties: Enabled: False, Checked:False)

e) Browse Treatment List

(Menu properties: Enabled: False, Checked:False)

Purpose: This menu allows the user to browse eye diseases and disease attributes in details with relevant pictures to enhance understanding. Sub-menus 2-5 can only be enabled by system administrator or a doctor.

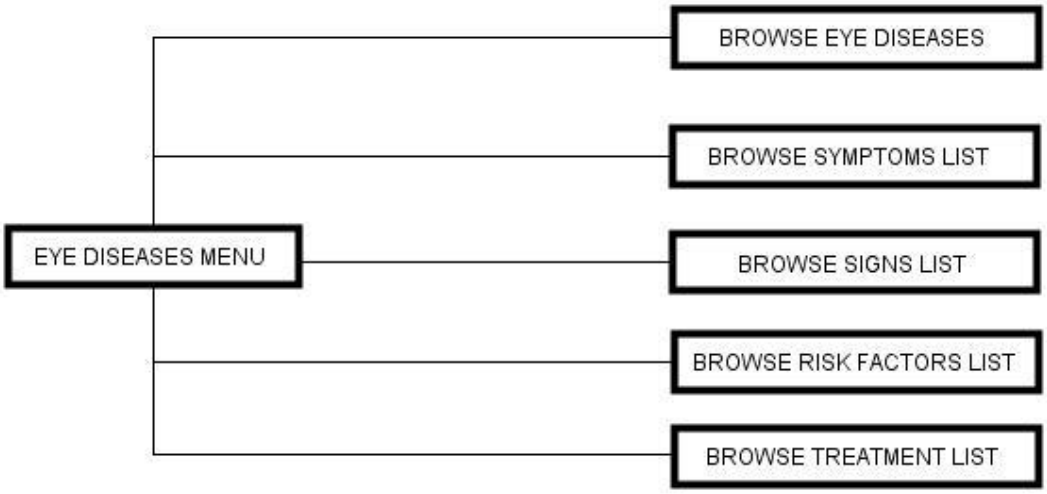


Figure 3.13: Eye Diseases Menu

3.8.2.4 Eye Testing Menu

The Eye Testing menu has two sub-menus (See Figure 3.14)as follow:

a) Demo mode for doctors

(Menu properties: Enabled: conditional, Checked:False)

b) Test my vision as a patient

(Menu properties: Enabled: conditional, Checked:False)

Purpose: This menu allows the user to carry out eye testing. When the user logs-in as a patient, the visual acuity test manager will be invoked first and then followed later by invoking symptom checker manger.If the user logs-in as a doctor, then either visual acuity manager or symptom checker could be invoked separately.

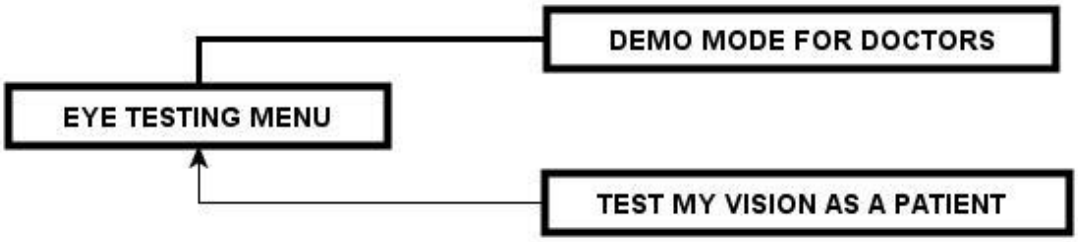


Figure3.14: Eye Testing Menu

3.8.2.4.1 Demo Mode for Doctor's Sub-menu

The Demo mode for doctor's sub-menu has two sub-menus(Figure 3.15) as follow:

a) Test Visual Acuity Demo

(Menu properties: Enabled: False, Checked:False)

b) Test symptoms checker Demo

(Menu properties: Enabled: False, Checked:False)

Purpose: This menu item is only enabled when a user logs-in as a doctor. Through this menu the doctor can call up visual acuity test demo or symptoms checker diagnostics demo. Result from any of the demo tests are not saved to database.

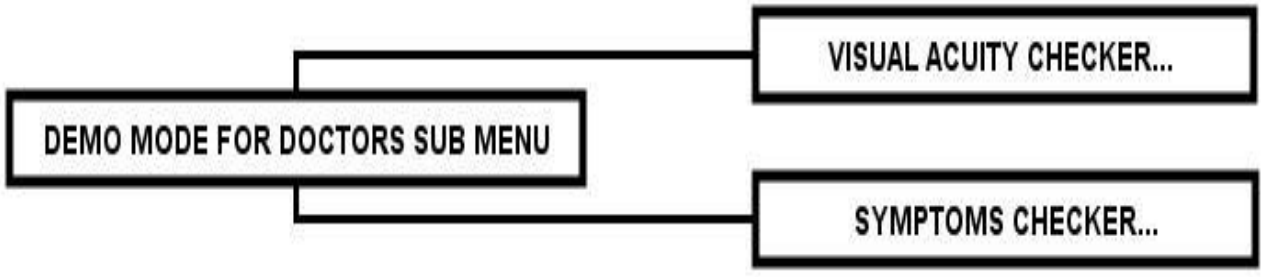


Figure3.15: Demo mode for Doctors

3.8.2.4.2Test My vision as a patient sub-menu

Purpose: This menu permits the user who logs-in as a patient to commence eye consultation which begins with visual acuity evaluation and immediately followed by question based symptoms checking.

3.8.2.5 Report Menu

Figure 3.16 shows the Report menu with two sub-menus as follow:

a) View My case Report

(Menu properties: Enabled: False, Checked:False)

b) View others case Report

(Menu properties: Enabled: False, Checked:False)

Purpose: This sub-menu allows the user to view the records of current test or all his/her eye test results in the past. However, if a user logs in as a doctor, he/she will see other patients' result as well.

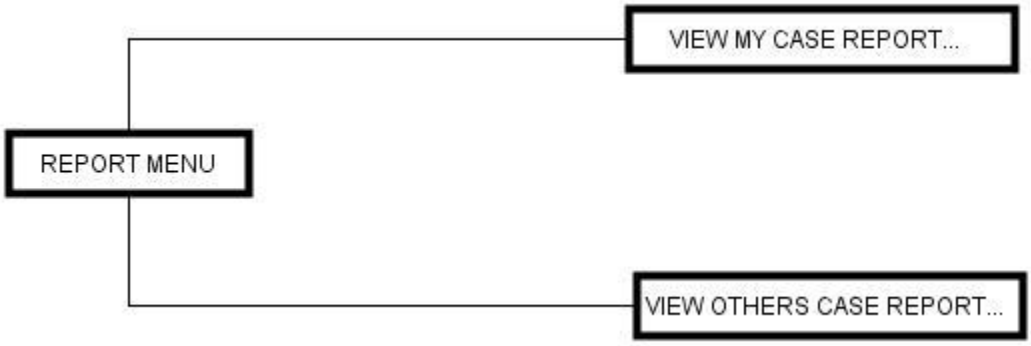


Figure3.16: Report Menu

3.8.2.6 Settings Menu

The settings menu has one sub-menu (See Figure 3.17).

a) Test Distance Settings

(Menu properties: Enabled: True, Checked:False)

Purpose: This menu allows the user to set the actual distance in meters at which the visual acuity test shall be carried out. The distance options are: 6m, 3m and 1m.

Figure3.17:Settings Menu

3.8.2.7 Window Menu

The window menu has three sub-menus(See Figure3.18):

a] Title

(Menu properties:Enabled: True, Checked: False)

b] Cascade

(Menu properties:Enabled: True, Checked: False)

c] Arrange icons

(Menu properties:Enabled: True, Checked: False)

Purpose: This menu allows the user to have various views of the system especially in a multi-tasking environment.

Figure3.18: Window Menu

3.8.2.8 Help Menu

The Help menuhas three sub-menus (Figure 3.19)

a) Report Bugs

(Menu properties: Enabled: True, Checked:False)

b) Contact Author

(Menu properties: Enabled: True, Checked:false)

c) About This Software

(Menu properties: Enabled: True, Checked:False)

Purpose: This menu allows the user to learn more about the software, contact the author or report bugs as appropriate for continuous refinement of the program

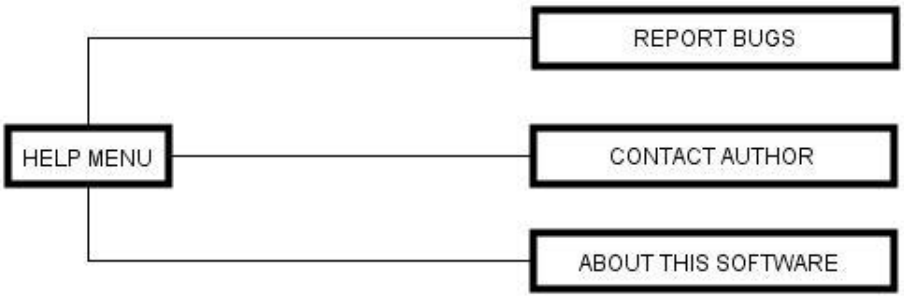


Figure3.19: Help Menu

3.8.2.9 Expanded Menu view

The expanded menu consists of 8 main menus (See Figure 3.20) as follow: File, Log in-out, Eye diseases, Eye testing, Report, Settings, Window and Help menu. There are a total of 33 sub-menus, out of which 17 sub-menus cannot be accessed by the patients but reserved for system administrator or the domain expert. These restricted menus provide access to the system database and some other vital program settings and tasks. Some of the tasks include deleting and adding disease information such as signs, symptoms, risk factors, treatment, disease image, etc. Restricted menus and sub-menus are protected and a user requires password check before getting the necessary access permission and privileges. Restricted menus and sub-menus are automatically disabled at program start-up thereby preventing un-authorized users from making futile efforts.

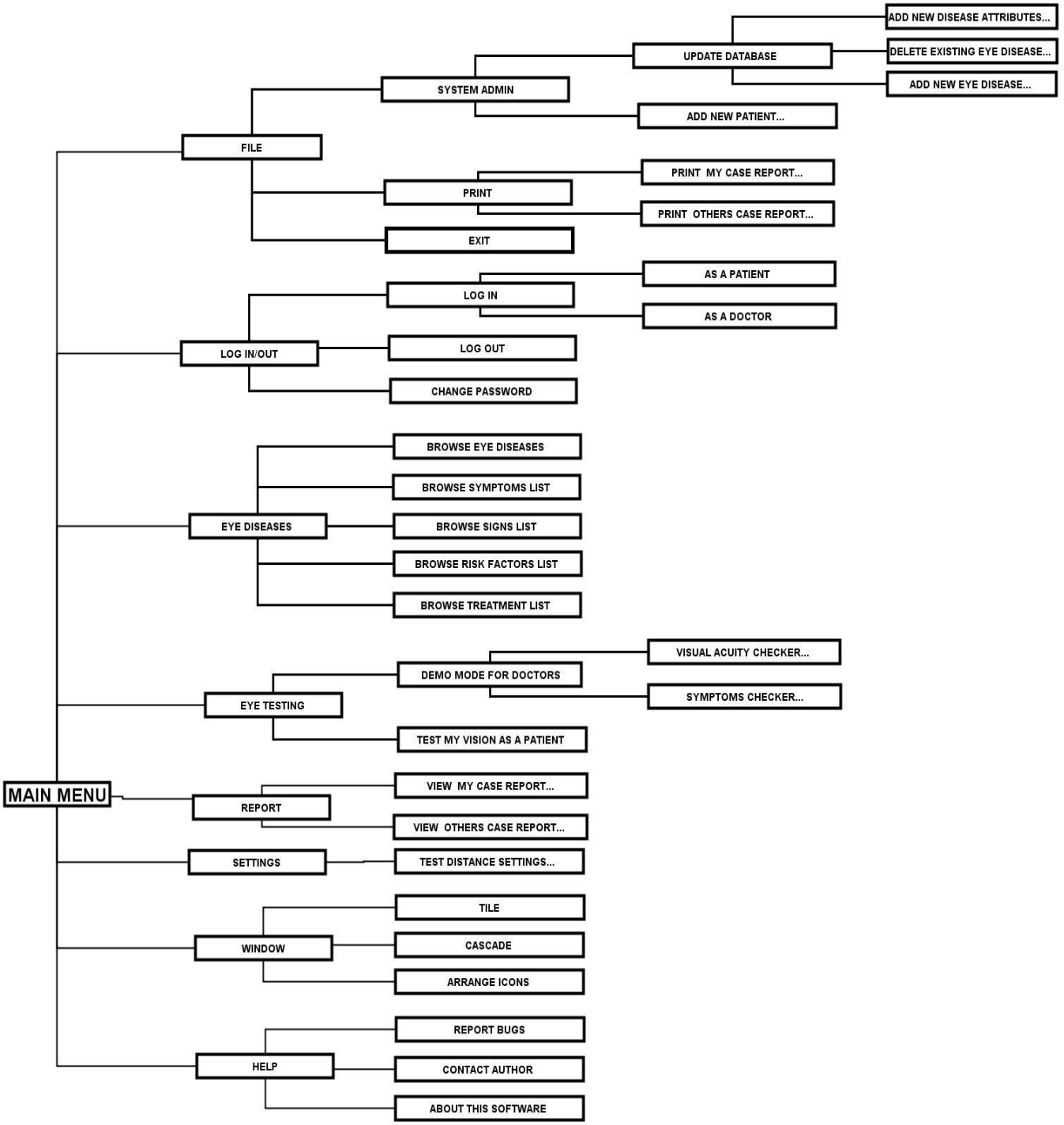


Figure 3.20: Expanded Menu view

3.8.3 Expert System

The expert system component of CFRMFEDD was designed with Visual prolog 7.5 expert system shells.

The following are the basic Key elements in using Prolog as a design tool

Constant: This is a data that cannot change in value during program run once it is set.

Domain: This is a range of values within which data value must come from.

Predicate: This is a named functor with 0-or n-arity (or argument parameters) which may or may not return a value.

Clause: This is a prolog statement (ending with full-stop) which is composed of disjunctions ((;) logical OR) and conjunctions ((,) logical AND) of facts and/or rules of given predicates.

Goal: This is aggregation of sub-goals which prolog program is set to satisfy.

Constructor: This is a reserved new() Predicate in prolog that creates new objects.

The building block for the components of CFRMFEDD comprise the following:

a) **Class Definition**
   i. Class declaration
   ii. Class implementation

b) **The Interface Definition**
   i. Interface definition

c) **Package & Resources**

Each component is stored in separate file as shown below:

Prolog component	**stored in file**
Class declaration	**(.cl)**
Class implementation	**(.pro)**
Interface definition	**(.i)**
Package definition	**(.pack)**
Package Header	**(.ph)**
Resource definition	**(.res)**

3.8.4 The Expert System Modules

The Expert system used is composed of the following modules (See Figure 3.21)

- The Knowledge Base & Working Memory (See Figure 3.22 for details)
- The Inference Engine (See Figures 3.23 and 3.24 for details)
- The Interface (See Figure 3.25 for details)

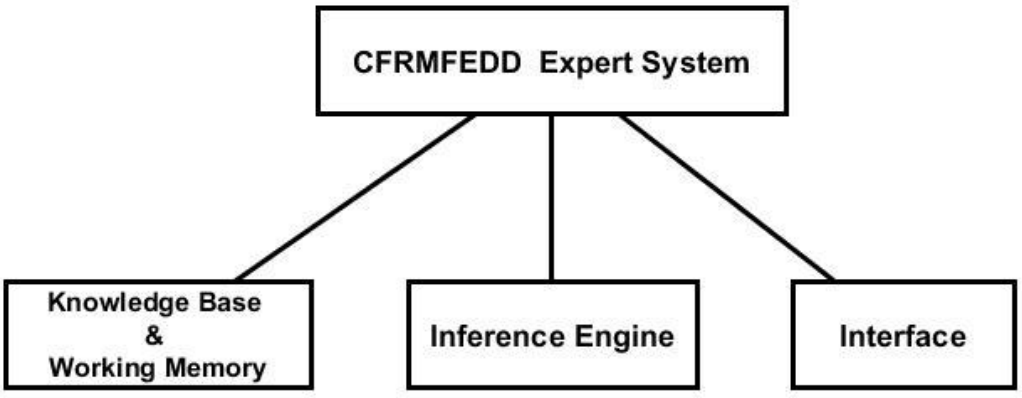


Figure 3.21: CFRMFEDD expert system structure

3.8.4.1 The Knowledge Base and Working Memory

Rule based paradigm was used as the method of knowledge representation. The knowledge base contains the Facts and Rules. The rule contains expression of relationship between the hypothesis and the evidence and in this case the relationship between the disease and the symptoms. The hypothesis and the disease profiles were provided by domain expert in the form of signs, symptoms, risk factors, treatment, images and certainty factors. The purpose of this is to convert these intentions into appropriate facts and rules in the knowledge base (See Figure 3.22)

3.8.4.1.1 The Design of Facts

The facts declared in the knowledge base are declaration of truth about eye diseases, symptoms, signs, risk factors and treatment as provided by the eye doctor (domain expert)

The syntax used for declaration of knowledge base facts is as follows:

```
factName (factArgumentList).
```

This is further illustrated as follow:

```
diseaseSymptoms (glaucoma, headache).
diseaseSymptoms (glaucoma, visualFieldLoss).
disease (glaucoma).
sign (constricted pupil).
symptom (tearing).
symptom (visualFieldLoss).
riskFactor (hypertension) .
treatment (wash eye with warm water).
```

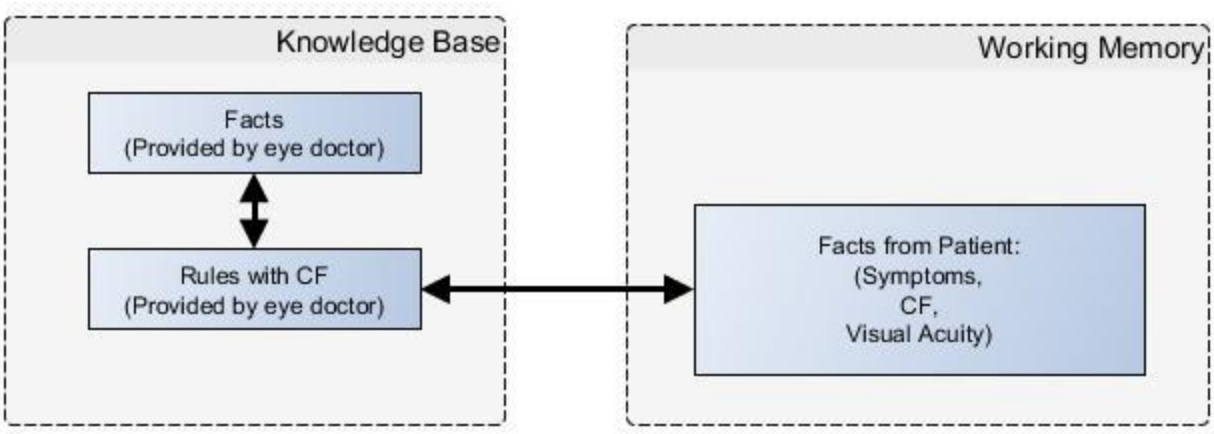


Figure3.22: Knowledge Base and working memory structure

3.8.4.1.2 TheDesign of Rules

The rule contains an expressed relationship between different facts and (at times) other rules and joined by logical connectors (AND, OR, NOT). In this study, the rule contains expressed relationships between facts on eye diseases, symptoms, signs, risk factors and treatment with declaration of certainty factor (CF) for each rule.

The general syntax for defining the rule is:

ruleName:- fact1(fact1Arguement), fact1(fact1Arguement),…. factN(factNArguement) <CF>

This can be further illustrated with the following example:

Rule1>

Diagnosis(X):- disease (X), symptom(Y), diseaseSymptoms (X, Y), CfX=0.6, CfY = 0.5

Designing rules as illustrated above, involved using variables as placeholders for diseases and symptoms CfX represents the certainty factor from the working memory submitted by the patient during

consultation session while CfY represents the certainty factor initially attached to the rule in the knowledge base by the domain expert. X is a variable representing any eye disease and Y is a variable representing any symptom.

The knowledge contained in the above rule example states thus:

> *The diagnosis of an eye disease, X, with symptom, Y, is inferred if X and Y are known eye disease and symptom respectively,given that the probability/ certainty factor of Symptom, CfY, provided by the patient during consultation is 0.6 and the probability/certainty factor of the Disease, CfX, provided by the domain expert during knowledge acquisition is 0.5.*

3.8.4.1.3 The Working Memory

The working memory stores the goal facts which are used to query the facts and rules in the knowledge base during a program run. This type of fact represents the evidence provided by the patient and therefore is associated with certainty factor value.

The goal or working memory fact was declared with following syntax>

> ***symptom (factName) Cf= X***

Ex: symptom (headache) Cf = 0.6

3.8.4.1.4 Domain Knowledge and knowledge acquisition of Eye diseases

The information used by eye doctors (domain experts) to make diagnosis often come from the following sources.

a) Direct questioning to get the medical history,
b) Physical eye examination to get the signs,
c) Visual acuity measurement to determine the extent of vision loss or damage
d) Laboratory/medical imaging tests to determine cause of eye disease.

From the combination of the examination methods mentioned above (a-d), eye doctors can associate some group of symptoms to a particular or group of eye diseases. Details of information elicited from the above sources is shown below.

a) Direct questioning/ medical history

This can reveal the following information

i. Severity of the eye condition
ii. Duration of condition
iii. Age of onset
iv. Types of symptoms experienced
v. Previous treatment
vi. Any resolution over time
vii. recent change in life style
viii. Level of education
ix. Current Drugs/medications
x. Presence systemic disease
xi. Evidence of previous Hospital admissions
xii. Evidence of previous trauma including the head region
xiii. Marital status
xiv. present job
xv. food or drug allergy
xvi. history of recent weight change
xvii. history of headaches
xviii. history Loss of consciousness

xix. history of seizures.

xx. Family History of eye disease

xxi. genetic defect in the family

b) Physical examination

This can reveal the following information:

i. Presence of eye disease

ii. type of eye disease

iii. extent of defect

iv. Presence of eye discharge

v. color of eye discharge

vi. color of eye

vii. level of visual field

viii. color blindness

ix. low contrast sensitivity

x. intra-ocular pressure

xi. prognosis of the condition

c) Visual acuity measurement

This can reveal the following information:

i. current level of visual acuity

ii. degree of vision loss

iii. the better seeing eye

iv. the preferred eye

v. presence of blindness

vi. need for eye glass

vii. need for visual rehabilitation

d) Laboratory/medical imaging tests and their implications.

The following information will be revealed:

i. Culture and sensitivity>> bacterial conjunctivitis

ii. Skull Xray/CT scan >> orbital mass, foreign body, cancer

iii. FBS: ocular diabetics

iv. SEUR: Renal Disease

v. FBC: Anaemia

vi. Serum electrolytes: Cardiac diseases

vii. A & B scan: Glaucoma

viii. MPS: Macula disease

ix. OCT: Cataract, Retinal disease

x. CVF: Glaucoma and visual field defects

xi. Blood smear: Cerebral malaria with ocular involvement

The direct implication of the information derived from these sources is that they are used in generating the Signs, Symptoms, Risk Factors and treatment of eye disease as will be illustrated in chapter 4 (Tables 4.10 – 4.16)

3.8.4.1.5 General Rules of treatment of Eye Diseases

The treatment of eye diseases is dependent on its cause or etiology through disease markers such as signs, symptoms and risk factors extracted directly or indirectly form the patient. For instance the symptoms are gotten directly through medical history and oral interview during consultation session whereas the signs are gotten from both physical examination and indirectly from investigative studies

such as laboratory and radiological results. This rule is illustrated in Table 3.11. The complete rules are shown in table 4.11

Table 3.11: Rules of eye disease treatment

Disease	**Symptoms**	**Treatment**
Age Related Macular Degeneration ARMD	• Increased sensitivity to light • Color vision defect • Blurring of central vision • Image distortion • Inability to recognize faces from distance • Require brighter light to read • Visual hallucination	• Anti VEGF Drug For Wet ARMD • Balanced Diet Rich In Anti-Oxidants • Laser Photocoagulation • Low Vision For Dry ARMD • Photodynamic Therapy • Polaroid Or Anti-Reflective Lenses • Quit Smoking
Aides Pupil	• Increased sensitivity to light • Light glare • Difficulty reading near prints while below 35 years (early presbyopia) • Unequal pupil size	• Bifocal Spectacle • Cosmetic Masking Contact Lens • Photochromic Lenses • Pilocarpine or Brimonidine To Constrict Pupil • Polaroid Or Anti-Reflective Lenses

3.8.4.2 The Inference Engine Design

Inference engine is the processing brain of any expert system. The expert system shell used in the design of this model has its own intrinsic inference capability. However, the purpose of this design is to customize and adapt the inference engine to extend its functionality for solving the problem goal. Therefore, the goal of CFRMFEDD is to find a Diagnosis (EYE DISEASE) and associated TREATMENT qualified with certainty factor or confidence for a given set of SYMPTOMS as reported by the patient during consultation session.

The eye disease and treatment represent the antecedents, the hypothesis or the conclusions while the symptoms, signs and risk factors represent the precedents, the evidence or the conditions.

By using the concept of modus ponem and Horn clause predicate logic, the CONCLUSIONcan be inferred by first proving the CONDITION.

4.8.4.2.1 The Inference Engine Components

The inference engine of CFRMFEDD comprises mainly four components (See Figure 3.23):

- **The symptoms Checker**

  The function of this component is to collect symptoms and certainty factor from the user, preprocess them and present them to the diagnostics.

- **The Diagnostics**

  The function of this component is to analyze the input from the symptoms checker by matching the symptoms, certainty factors (from patient and the doctor) and the visual acuities, make diagnosis or request for more symptoms from the symptoms checker. Final output from this module is printed out as diagnosis and medical advice in the form of computer display, hard-copy or system storage.

- **The explanation system**

This component provides explanation for diagnosis reached by method of backtracking of previous steps taken and retrieval of symptoms that are associated with the current diagnosis and then match them with the symptoms complained by the patient.

CFRMFEDD can also infer both single disease diagnosis and multiple disease diagnosis as evident from the model (See Figure 3.24)

- **Certainty Factor Calculator**

Certainty factor (CF) is a popular method in rule based systems used to manage inexact, fuzzy and incomplete knowledge. It is therefore an expression or the measure of Belief (MB) or Disbelief (MD) associated with any given hypothesis (H) and evidence (E). In this study, the hypothesis represents the rule or the relationship between the disease and its symptoms while the evidence represents the facts and hence the symptoms. The hypothesis was provided by the domain expert and was stored in the knowledge base while the evidence was provided by the patient during consultation session and was temporary stored in the working memory.

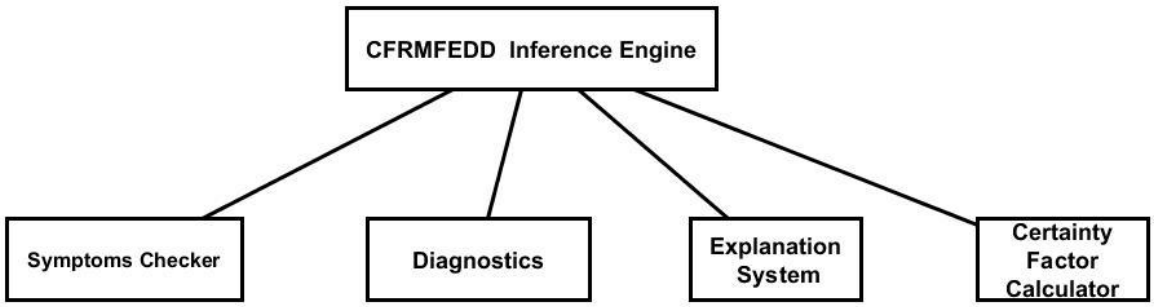


Figure 3.23: CFRMFEDD inference engine components

3.8.4.2.2 CFRMFEDD Inference Engine Model

Figure 3.24 shows the inference engine model of CFRMFEDD. The model consists of 4 main modules as follow: The Symptoms-checker, Diagnostics, Explanation system and Certainty factor module. The Symptoms- checker is responsible for presenting diagnostic questions to the patients and then analyze the patient's responses. At the first stage, a list of symptoms stored in the database is loaded into the working memory as Temporary Symptom List (TSL). The first question (S1) from the list is presented to the patient as the patient is expected to respond by clicking Yes or No. Each presented question is removed from TSL and added to Reported Symptom List (RSL). For each Yes answer, a Certainty factor (CF) list is displayed and patient must select a probability value (ranging from 0 to 1 but reduced to terms), that describes his level of conviction with the symptoms he has provided. The systemwill record this value against the particular symptom. Using the symptom(s) already provided by the patient, the system will search the knowledge base again using RSL as the search criteria. This will off course return only the diseases that have the reported symptoms. The system will display a new TSL excluding the RSL and this will reduce the total number of questions yet to be asked (pre-processing facility). Further questions are asked and consultation will stop either when only a single disease (SDD) has all the RSL or the TSL is empty list. However, when TSL is empty and multiple diseases (MDD) have all the symptoms in RSL, the system will return this group of disease. In the meantime, any disease returned at this stage is regarded as tentative diagnosis. The system will still calculate a composite certainty factor using the certainty factors of all the symptoms (CFS) as provided by the patient and the disease certainty factor (CFD) associated with the suspected disease(s) initially provided by the doctor in the knowledge base. If the combined CF is equal or greater than the default certainty factor set for the system by the system admin, the system will proceed to diagnostic stage. At this stage, the system will compare the actual visual acuity test result recorded for the patient with the visual acuity ranges which persons suffering from the suspected disease should have. If there is a match in visual acuity

comparison, the system will confirm the suspected disease(s) as the diagnosis otherwise it will reject the suspected disease(s) and advise patient to consult a human doctor.

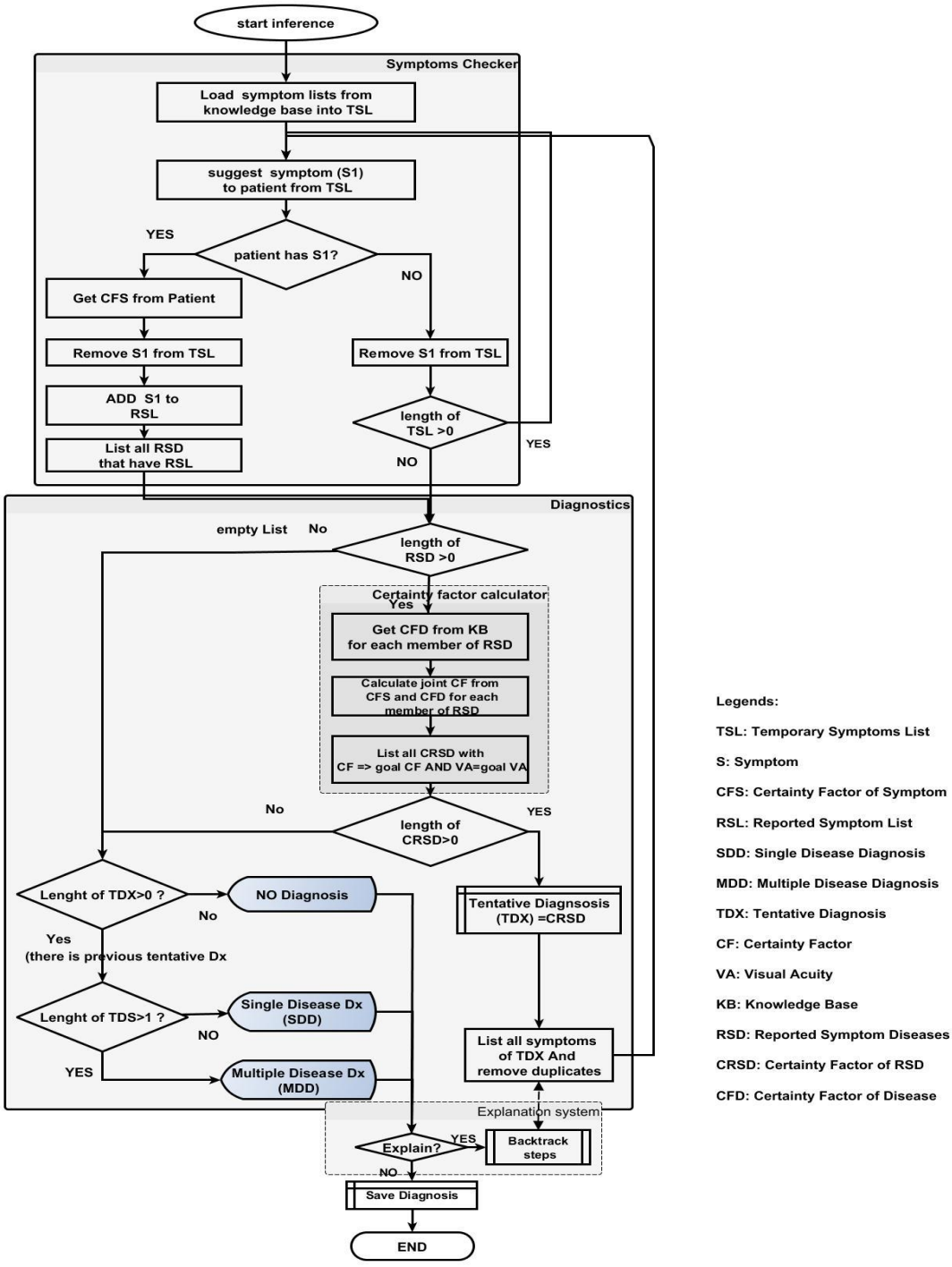


Figure 3.24: CFRMFEDDInferenceEngine Flowchart model

3.8.4.3 The Interface

The interface provides the means for the user to interact with the system. Hence, the main goal of a user interface is to serve as a communication channel between the system and external entity so as to enhance efficient and easy flow of interaction between them. When the external entity is human, the interface may take the form that could communicate with the user through the user's physical senses such as sight and sound via multimedia presentations such as Graphics (ie, images, texts and literals), Audio (ie, sound) and Video (ie, Motion). In reality, the user does not need to know the logic behind the system before using it but could interact with the system with ease within a limited training/adaptation time. In fact the user interface is a physical representation of the system to the user. No matter how fantastic a computer system is, the user is enticed to use or judge its features based on how easy and user-friendly the system is. Therefore, a good user interface shall be user-friendly. Being user-friendly also implies that the user does not need to go to another school to study how to use a particular program. This implies that all the interactive elements (such as the icons, buttons, etc) to be used in the interface must be the types that most users are familiar with. Therefore, in order to achieve good user acceptability, good user interface design strategy must be ensured.

3.8.4.3.1 CFRMFEDD Interface design

In order to create a user-friendly system, the following UI design strategies were used

a) Use of familiar interface elements

CFRMFEDD user interface is designed to resemble familiar programming elements. Windows has become one of the most popular graphical user interface in today's computing. Windows users are already familiar with common elements such as controls, forms, toolbars, icons, etc. Also most popular software packages such as MS-Excel, MS-Word, etc, are using windows

platform. Therefore designing the user interface after the already familiar GUI environment will make the program easy to learn and understand.

b) Adequate and context sensitive Messaging

Most often users of new system may not fully understand the actions to take and the appropriate keys to press while using the system. The ability of the program to detect or anticipate any mistake or wrong responses from the user and then give appropriate information will make the system more user-friendly. CFRMFEDD has event/action triggered messages which are displayed for user's guidance. In fact, before any task panel such as visual acuity testing is called, relevant messages and instructions are displayed to the user. Once the task panel is open, a message will pop up and explain the intending task briefly and clearly.

Hence on startup of CFRMFEDD, a welcome page is displayed with a brief introduction of the system. Also pressing wrong button attracts a system beep so that the user shall review his/her action immediately.

c) Help menu

The task panels have help buttons which when pressed display relevant information that could help the user overcome any current challenge. Also help menus are provided to enable users learn more about the software, send their reports for bugs, comments, suggestions to the program designer and in such way feels they are part of the program development family.

d) Redo-Undo action

The redo/undo action enables the user to possibly repeat or conversely, reverse last action.

e) Toolbars

The toolbar elements are placed as image buttons/icons at the upper portion of the system's window. At a click of a desired toolbar button, the associated function will be consequently invoked.

Therefore, toolbars are another friendlier and simpler ways of making often-used tasks available. With this setting, even a novice and un-initiated user can easily carry out a given task without having the need to navigate through series of menu options and rigorous paths. By wisely representing some tasks with self-explained pictures or icons the system becomes self-documented, self-explained, easily understood and user-friendly.

f) Tooltips

Tooltip displays a set message when a cursor pointer hovers over a given control. In essence it implies that each control declares its intentions to the user. With this kind of setting, important self-explanatory message is delivered to the user on what each control does and how to carry out a given task.

g) Taskbars

Taskbar also displays information at the bottom section of the screen on current task to the user.

h) Simple menu system

Windows Menu system provides the user a friendly opportunity to navigate the program. By enabling and disabling some aspects of sub-menus, the user is saved the frustration and annoyance associated with attempting to carry out an action which he has hitherto no privileges.

i) Window-Menu

In situation where more than one window is open at a time, the window menu enables the user to arrange, cascade or tile sub-windows for user's convenience.

j) Large font

CFRMFEDD is a program designed to test vision and therefore, it is probable that the majority of the users may already have one form of eye defect or the other. Eye defects affect the way we see things especially tiny objects. Therefore, using large font of 14-20 points will make the displays and controls more visible to the user and this will enhance and encourage optimal system usage.

k) Good Color contrast

Good color contrast enhances visibility of object and identification of foreground from background. Since users of this system may already have vision challenges, improving on the object color contrast will improve the general visibility of the graphics elements and texts used by the system.

At each major phase in the design of CFRMFEDD user interface, prototype was used to demonstrate to the target user the feel of the new system and to also ensure that the interface meets up the desired requirement and specification as stated briefly below.

When CFRMFEDD prototype is run from desktop platform, it displays a welcome page in a customized window GUI. The welcome message displays brief user instruction and disclaimer. On clicking OK button, the message clears, menu comes into view and the system waits for further user action. The user can run the program in demo mode to view/learn disease profiles in which case he does not need to log

in with any password. To run eye test, the user must log in with password as either a patient, a doctor/System Admin. New patient will be prompted to enter and save new registration details. If the patient wants to run eye test, he will click <Eye Testing menu>----><test my vision as a patient sub-menu>. The system will automatically display appropriate instruction message and then displays Visual acuity Test panel. After undergoing visual acuity testing, the system will automatically display symptoms checker panel with its associated instructions. Finally, the system shall display diagnosis finding and associated treatment plan or advice(See Figure3.25).

3.8.4.3.2 Block diagram of CFRMFEDD user interface

Figure 3.25 describes the CFRMFEDD user interface model. It relies on window, menu and sub-menu system interface for its displays. At start-up, a welcome message is displayed, introducing the program and instructions on how to use it. Menu is displayed and the program waits for further user action as it is event-driven. A patient logs in with his name and unique Id No if he has used the system before, but a new patient will register his bio data first, a unique Id No will be automatically generated for him. After logging in, the patient will select "Test my eye as a patient" from <Eye testing menu>. Consequently, an instruction is displayed on how to carry out visual acuity test. After undergoing visual acuity test, the result is saved and control is automatically transferred to symptoms checker. Patient will provide answers to series of diagnostic questions and also provide certainty factor associated with each answer. Finally the system will use the visual acuity result, the certainty factor and the symptoms to infer diagnosis. Results can be displayed, saved in the computer or printed. Patient may wish to carry out other tasks such as viewing and learning about eye diseases, symptoms, signs, etc, in which case he selects the appropriate menu for each option. If the user has logged-in as admin or doctor, he can carry other tasks such as setting the test distance, updating the knowledge base, viewing all the patients' medical records, etc. Display of options is through pull-down menu technique and selection of option is

by clicking a list member or pressing enter key at a control button. A user who does not want to log-in can use the system at demo mode. In this case only limited tasks excluding eye tests can be done but majority of the menus and sub-menus will be disabled.

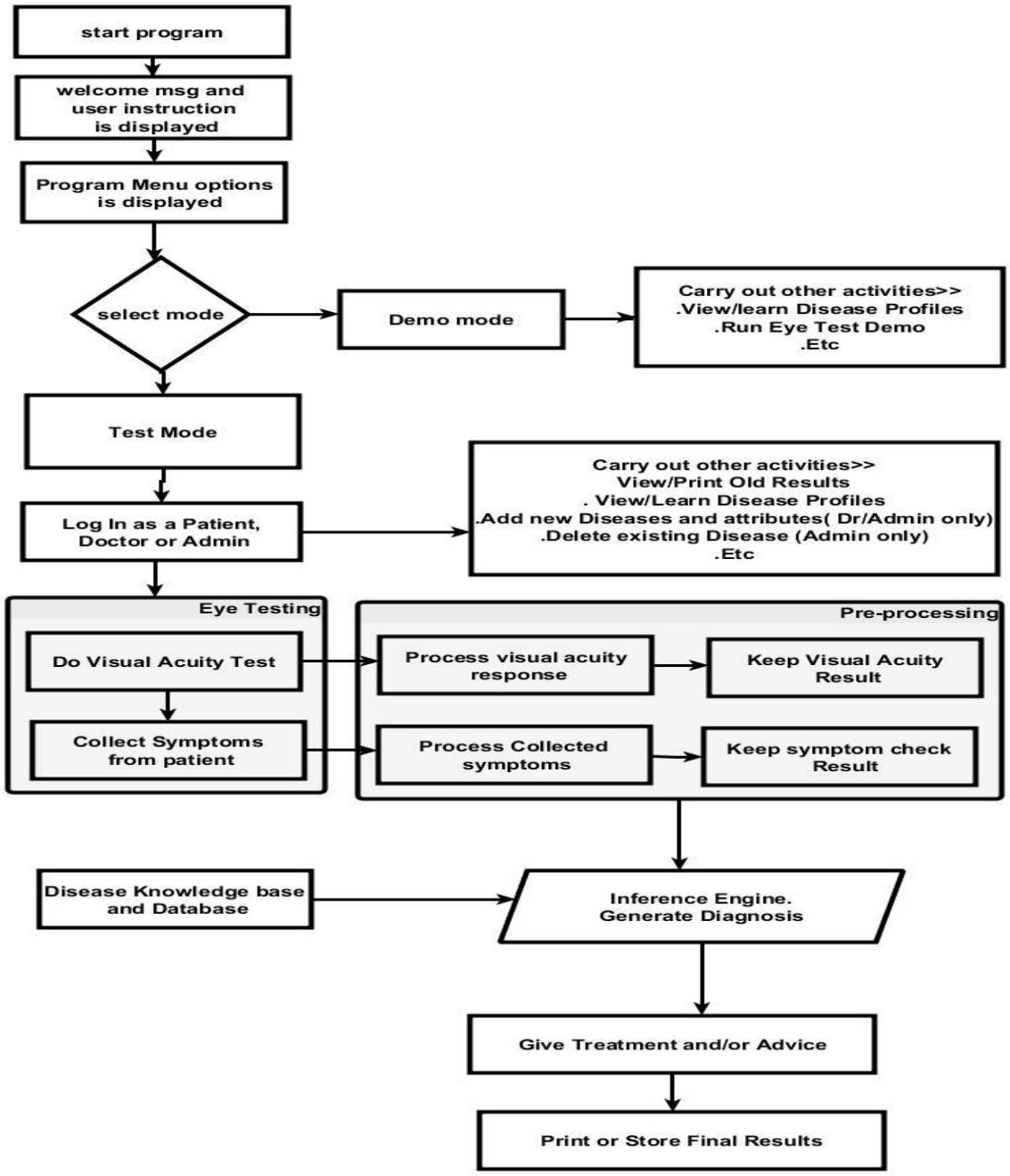


Figure 3.25: Block diagram of CFRMFEDD user interface

3.8.5 Visual Acuity Module

Figure 3.26 shows the visual acuity module and its subsystems.

Purpose: This module is designed to measure the visual acuity level of a patient. This will later serve as an objective method of validating patient's claims with respect to the symptoms and certainty factors presented by the patient during the consultation session.

Design techniques: In order to ensure that maximum reliability prevails during the test, the following design techniques were applied.

- Chart orientation is presented at random order so that patient cannot anticipate in advance what orientation the next chart display should be. This reduces clamming, memorization and guess work.
- E-Chart was used as it is easier to be identified by all categories of patients (Illiterate, children and adults)
- Four orientations (UP, DOWN, LEFT and RIGHT) were used as each of these orientations does not have jagged-edge image artifact.
- Four large arrow keys corresponding to each possible chart orientation are displayed to make it easier for patients to select choice.

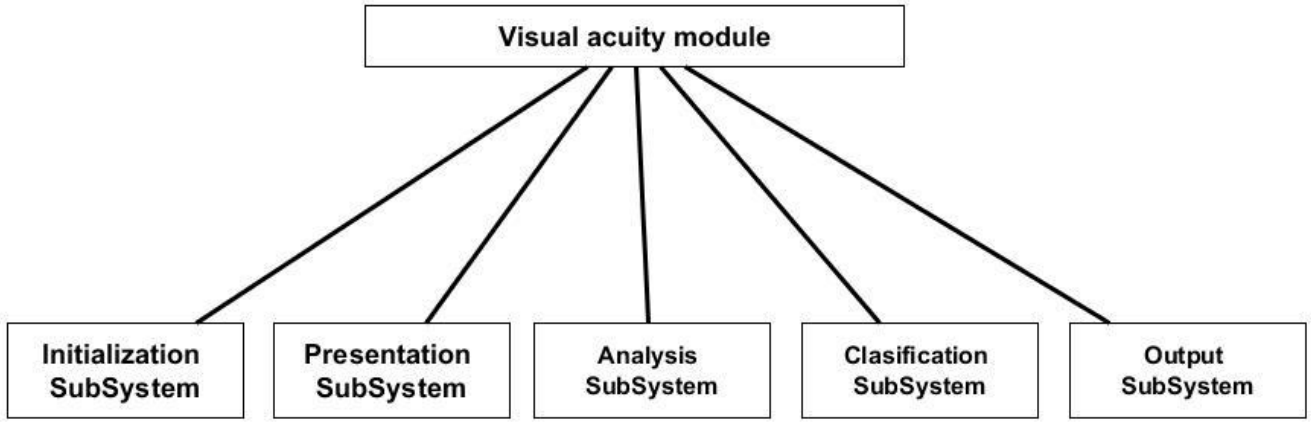


Figure 3.26: Subsystems in Visual Acuity module

3.8.5.1 Visual Acuity Subsystems

The goal of each subsystem in this module is uniquely to carry out a specific task required in the overall testing and recording of the visual acuity status of the patient. The logic model consists of five subsystems (See Figure 3.27):

a) Initialization subsystem

This subsystem initializes the important counter variables such as Correct Match Count, Presentation counter (PC) and Visual Acuity level (VAL). In this case the acuity level is determined by the size of acuity chart.

b) Presentation subsystem

This presents the chart to the patient with appropriate size and orientation. If the patient recognizes the chart's orientation by clicking the appropriate arrow button, the chart is automatically rotated to another random orientation and chart size will be decreased when he is able to correctly identify the four chart orientations. Conversely, if the patient clicks an arrow button not corresponding to the displayed chart orientation, the system interprets this wrong click as not-seeing the chart and will halt when the user makes further two consecutive incorrect clicks.

c) Analysis subsystem

This analyzes user clicks and then computes the next size and orientation of chart to be displayed by the presentation subsystem. It can also halt further testing when the patient cannot see the displayed chart after two consecutive failures.

d) Classification subsystem

The final visual acuity is noted as a decimal numerical value when the user can no longer identify the chart orientations or when he has identified all the charts displayed. This value is not directly useable by the system and therefore must be converted to visual acuity status by a fuzzy classifier. The classification ranges from “normal vision” to “profound vision loss”

e) Output

This subsystem outputs the result of visual acuity test by displaying it, saving it and forwarding visual acuity value and its classification to the expert system as input data for diagnosis.

3.8.5.2 Visual Acuity Process Model

Figure 3.27 describes the visual acuity process model used by CFRMFEDD. The initial instruction on how to carry out the visual acuity test is displayed. The first large size E character (optotype) is randomly displayed at a particular orientation (RX), the presentation counter (PC) and Correct Match Count (CMC) are initialized to 0 while Visual Acuity Line (VAL) is initialized to 6/120. Patient is expected to click one of the four arrow buttons (Left, Right, Up and Down) that corresponds to the orientation of the displayed E. If arrow button clicked (ORP) is correct (ORS), then E will automatically and randomly be rotated to another orientation and PC, CMC and ORS incremented by 1 while ORS is incremented by RX. The chart presentation is continued until the 4^{th} presentation when the chart size will automatically decrease by one visual acuity line. However, when the patient fails to identify the chart correctly for 2 consecutive times, the test will stop and the last visual acuity line identified correctly shall be returned as the final visual acuity of the patient, with some modifications showing how many extra characters he sees or fail to see on that line.The visual acuity is finally classified by fuzzy classifier to get the vision status and the result are saved and transmitted to next stage of diagnostic process.

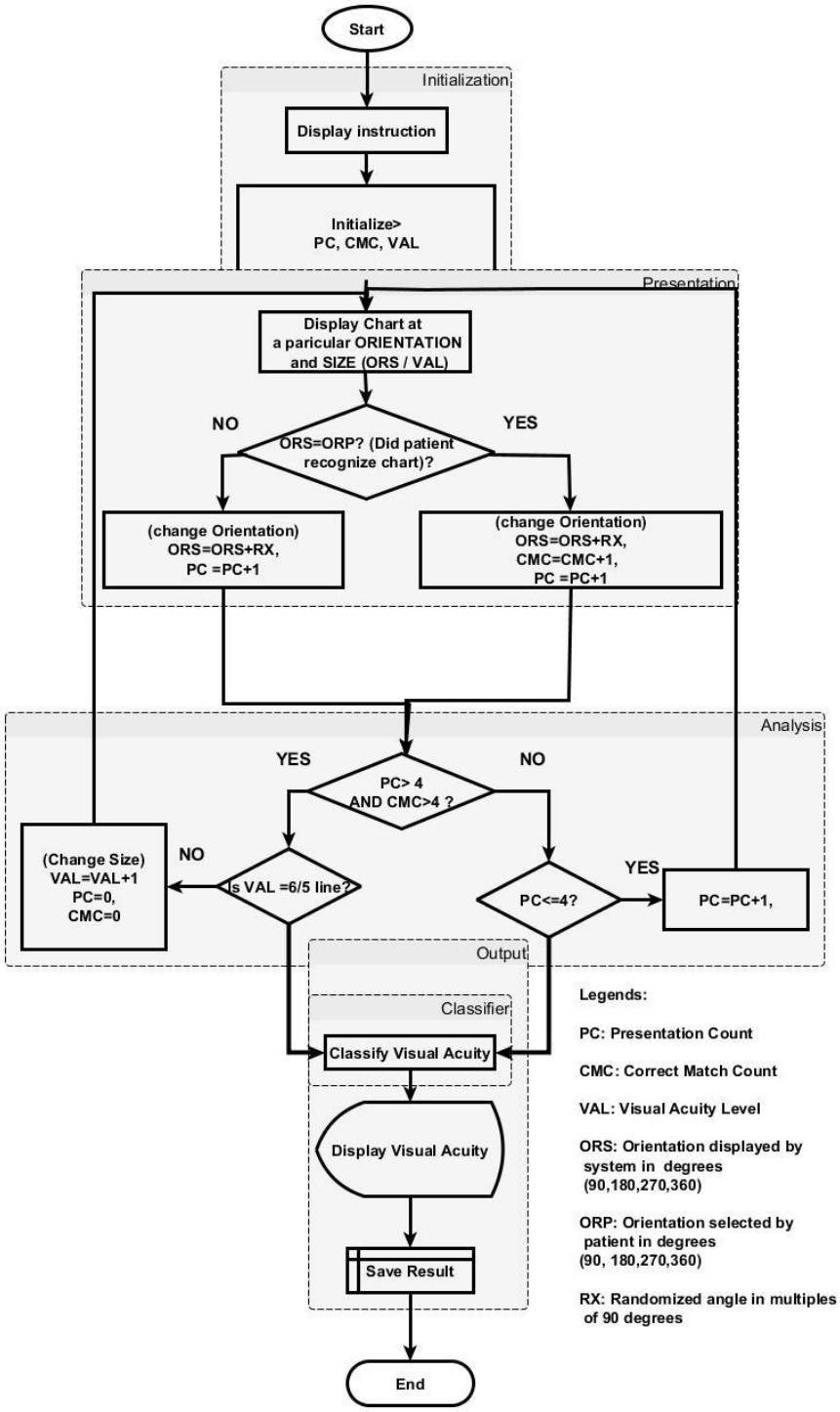


Figure 3.27: Visual Acuity Logic Model

3.8.6 Utility module

Figure 3.28 shows the utility module used by CFRMFEDD. This module is designed to give the user services that are not always performed on each program run. Such services include the following:

- Registration of new patients
- Addition of new diseases, symptoms, signs, risk factors and treatment to database
- Deletion of existing diseases, symptoms, signs, risk factors and treatment from database
- Password and log-in management
- Demo and simulation
- Learning facility
- Default System settings (Default Test distance, default certainty factors, etc)

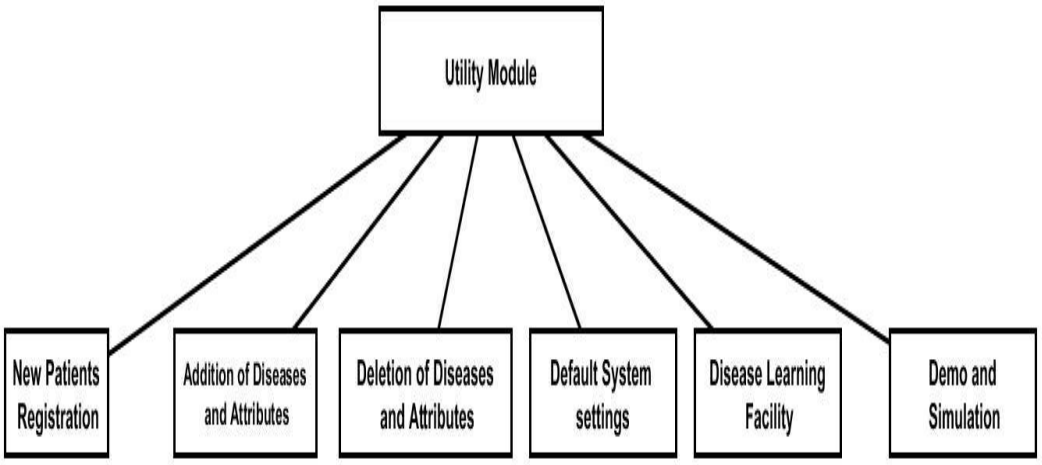


Figure 3.28: CFRMFEDD utility module

3.8.7 Use Case Diagram

Use case diagram is an important tool in software engineering used to expose the relationship between the various entities in the system. The use case diagram for CFRMFEDD is shown in Figure 3.29

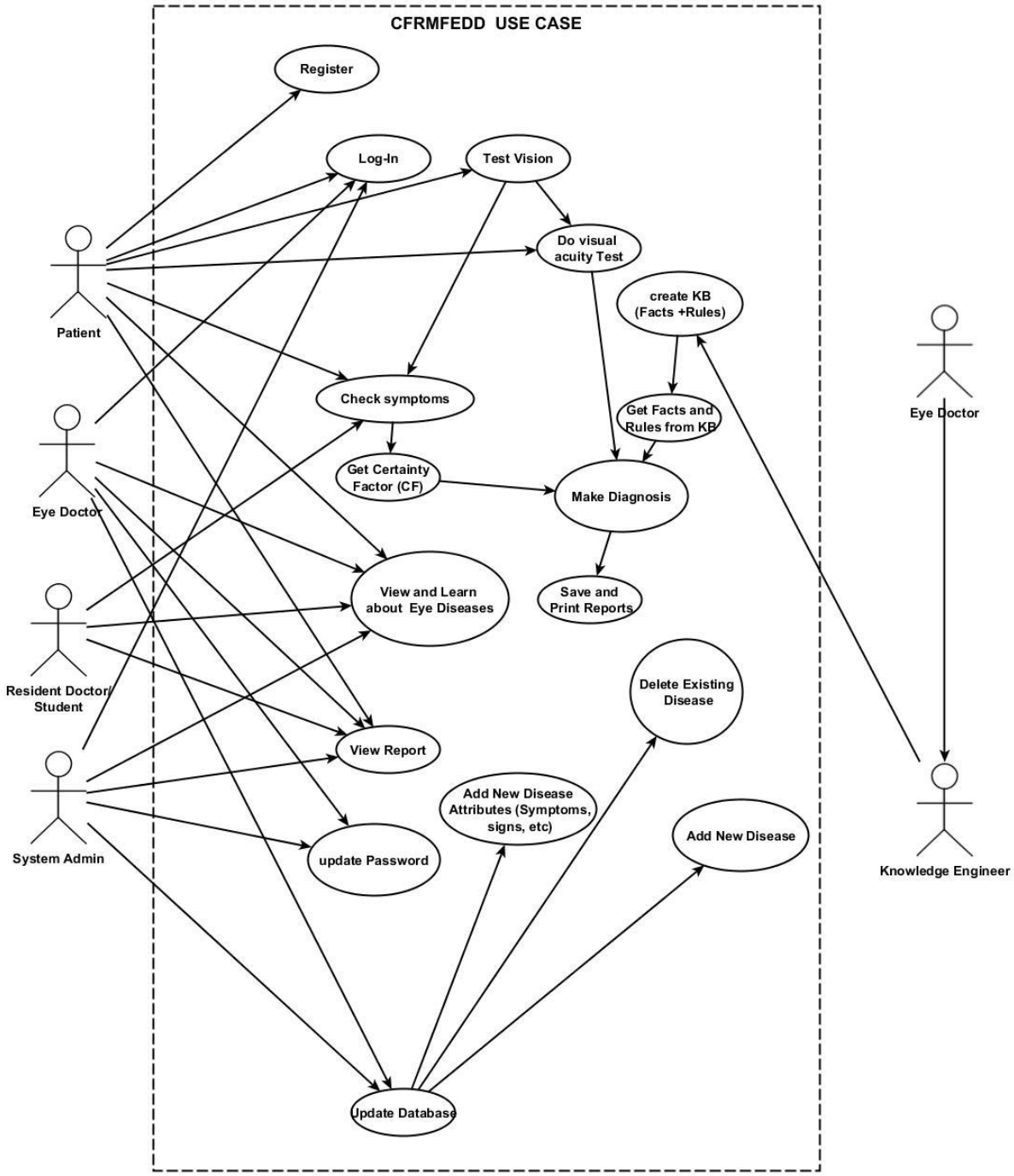


Figure 3.29: Use case Diagram of CFRMFEDD

3.8.8 Use Case Description

Use case description is a rendering of the list of actions and events stipulating the various interactions between the system users and the system. The user consists of the primary actors and supporting actors. In CFRMFEDD the primary actors are the Doctor and the Patient while the supporting actors are Medical Assistant, Knowledge Engineer and the System admin. The details of the various interactions between CFRMFEDD and the actors are hereby shown.

CFRMFEDD Use Case Description
Name: Diagnose Eye Disease **Id**: UC-01 **Description** Patient through help of medical assistant logs-in into the system and selects “Eye test”. System measures visual acuities of the patient. System asks diagnostic questions. Patient selects symptoms that match his/her complaints by selecting Yes or No. Patient also provides Degree of Belief or certainty factor for every question he answers. System uses the previous answers/positive symptoms, the certainty factors provided by both patient and doctor, to ask more diagnostic questions. System provides diagnosis after validating the symptoms provided by the patient with the measured visual acuity or stops when the symptoms provided by the patient are in conflict with the visual acuity measured or when there is no matching disease from the knowledge base. The system displays, saves, prints out test result or delivers medical advice.

Level: high level

Primary Actor

1. Patient
2. Eye Doctor (domain expert)

Supporting Actors

1. Medical Assistant
2. Knowledge engineer
3. System admin

Stakeholders and Interests

1. Eye doctors (domain expert) – Provides the necessary information and relationship on eye diseases, signs, symptoms, risk-factors, treatment and certainty factors for each disease definition.
2. Knowledge Engineer- converts the information supplied by the eye doctor (domain expert) into facts and rules in the knowledge base.
3. Medical Assistant – helps the patient to use the system by interpreting some questions that require further explanation or entering the necessary patient's response.
4. System Admin – has total system view privileges and can add, delete data or update the database.

Pre-Conditions

1. User must log-in to the system as either a patient, student or doctor/admin
2. System must have been loaded with appropriate eye disease knowledge base

Post Conditions

Success end condition

1. Diagnosis is made.
2. Result is displayed, printed and/or saved

Failure end condition:

No diagnosis is made

Minimal Guarantee

No diagnosis is made if the patient's symptoms are inconsistent with the measured visual acuity or the calculated joint certainty factor is too low or below default value for any meaningful diagnosis.

Trigger

1. User selects "patient mode" and logs-in by supplying relevant details before he can conduct valid eye test with the system.
2. User selects "Demo mode" and proceeds to learn relationships between eye diseases, symptoms, signs, risk-factors, treatment options, experiment with symptoms-checking and view disease images but cannot carry out valid eye test.

Main Flow / Success Scenario

1. User selects "patient mode" and logs-in with his/her ID but if new patient, provides relevant biodata information.

2. System registers patient's data into medical database/folder for new patients or retrieves patients folder for old patients
3. System prompts for selection of type of service desired
4. Patient selects "Eye test"
5. System displays test instruction and asks patient to close one eye and stay 3m from screen
6. System displays test chart "E" facing either Left, Right, Up or down orientation
7. Patient clicks appropriate arrow button having same orientation with displayed E
8. System rotates the E into another orientation in a random fashion and may also reduce the size of target.
9. Patient selects the appropriate button corresponding to the new orientation, only if he has seen the target
10. Process 6-9 continues until when patient clicks wrong arrow button or fails to click correct arrow button for a consecutive number of times (as determined by the system)
11. System displays visual acuity result for eye tested
12. System prompts user to repeat process 6-10 for the fellow (yet to be tested) eye.
13. System transfers control to symptoms checker
14. System displays instruction on how to use symptoms-checker
15. System displays first symptom question
16. Patient selects Yes or No and also selects certainty factor level (range:0%-100%)
17. System displays further symptom questions based on patient's initial answer(s).
18. System displays tentative diagnosis using the selected symptoms, the visual acuity result and the certainty factor gotten from both the patient and the doctor
19. System displays final test result which states the result of diagnosis and medical advice.

20. System saves the test summary into patient's medical folder/database and also prints out result

Alternate /Extensions/Exception flows

1a. In step 1, if user selects "Demo mode", the system will permit user to practice with system but will not save any eye test done under this mode

4a. In step 4, if the patient selects "browse eye disease", the system will display information about various eye diseases and their characteristics including the disease images.

19a. In step 19, if the answers given so far by patient could not lead to any known eye disease in the knowledge base the system will ask the patient to repeat process 15-18 or quit

Variations

The test for visual acuity measurement may be done at 2m or 1m if the patient does not see the first target at 3m but the assistant/user has to set test distance accordingly

Assumptions

1. The medical assistant assists the patient to use the system
2. Or the patient is medically-knowledgeable

Special Requirements

1. User must log-in as a patient in order to carry out valid eye test
2. Patient must have at least 6/120 vision in the best eye
3. There must be an assistant who is readily available to provide or explain some of the input requests made by the system
4. The test must be done in illuminated environment

3.9 Specifications

The various specifications used in the design of CFRMFEDD are hereby shown.

3.9.1 Database Development Tool

The database development tool used in the design of CFRMFEDD is MYSQL 5.7 Database Management System (DBMS) which is based on relational database model (See Appendix B17).

In a nutshell using MYSQL offers the following advantages:

- It is a Database Management System.
- The databases are relational
- It is object oriented
- It can connect effectively to logic programming software such as prolog.
- It has a Secured Socket Layer (SSL) and Secured Shell (SHH) security plug-ins
- The software is Open Source, hence cheap and easier to acquire
- Its Database Server is very fast, reliable, scalable, and easy to use.
- Its Server can work efficiently in client/server or embedded systems.
- A large amount of contributed MySQL software is available.

3.9.2 Database Design and Structure

Typically a database comprises tables, records, fields (attributes). The tables store data about the entities. The entity is the object which we want to store data about. Each entity is represented by a table, each table is composed of records, each record is composed of fields or attributes and each field (attribute) contains data item as depicted in CFRMFEDD database structure (See Figure 3.30). In addition, constraints can be set on the database objects for proper control of data management issues.

The entities used in CFRMFEDD and their corresponding tables are.

- Patient (patientInfo)
- Eye Disease (eyeDisease)
- Symptom (symptom)
- Sign (sign)
- Risk factor (riskFactor)
- Treatment (treatment)
- Eye Test (eyeTest)

Each field is defined by the following attribute properties:

- Name
- Data type
- Data size
- Description

Tables are connected to one another through primary keys and foreign keys relationship.

A detailed database structure is illustrated in ER database model (See Figure 3.31)

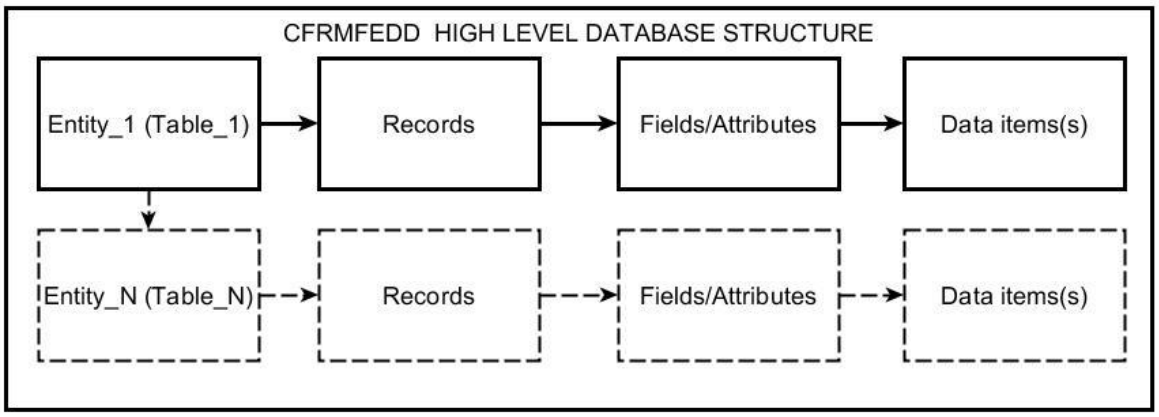


Figure 3.30 CFRMFEDD Database structure

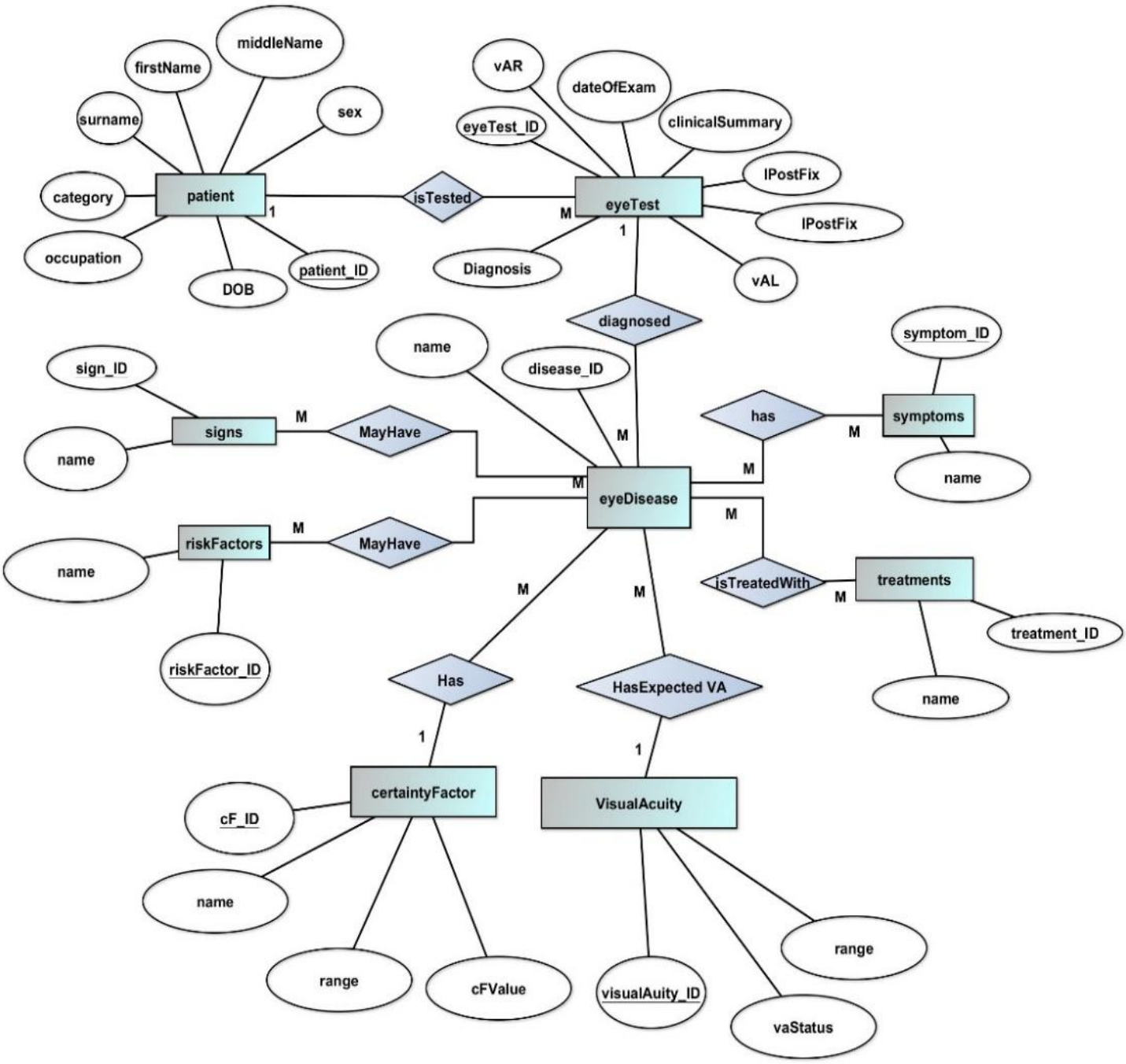


Figure3.31: CFRMFEDD E-R Database model

3.9.2.1 CFRMFEDD Database Tables

CFRMFEDD database tables consists of several tables (Tables 3.12 -3.20), each of which stores data used by each programming entity.

Table 3.12: PatientInfo

S/N	Field	Type	Data Size	Data Format	Description	Example
1	Id	Smallint	4	# # # #	Patient Identification/Folder No	1211
2	SurName	Varchar	20	XXX ……	Surname	Enechi
3	FirstName	Varchar	20	XXX…..	Firstname	Gilbert
4	MiddleInitial	Char	1	X	MiddleName initial	O
5	Sex	Char	1	M|F	Sex	M
6	DOB	Date		YYYY-MM-DD	Date of Birth	2001-02-11
7	Occupation	Varchar	20	XXX…..	Occupation	Trader
8	Category	Varchar	10	XXX….	Assisted or not assisted patient	Assisted

Table 3.13: EyeDisease

S/N	Field	Data Type	Data Size	Data Format	Description	Example
1	Id	Smallint	4	####	Disease Identification Code	1234
2	Name	Varchar	50	XXX….	Name of disease	Glaucoma
3	SymptomCodes	VarChar	50	[#,#,#,..]	List of Symptom codes	[10,01,23]
4	SignCodes	Varchar	50	[#,#,#,..]	List of Sign codes	[03,11,32]
5	TreatmentCodes	Varchar	50	[#,#,#,..]	List of Treatment codes	[01,50]
6	RiskFactorCodes	Varchar	50	[#,#,#,..]	List of Risk Factor codes	[44,5,55]
7	Picture	LongText	unlimited		Disease image	
8	CertaintyFactorCode	TinyInt	1	#	certainty factor code for the disease	1
9	ExpectedVisualAcuityCodes	VarChar	20	[#,#,#..]	List of Expected Decimal Visual Acuity codes for the disease	[1,4,3..]
Table description: stores relevant information ofvarious eye diseases.						

Table 3.14: Symptom

S/N	Field	Data Type	Data Size	Data Format	Description	Example
1	Id	Smallint	3	###	Symptom Identification code	110
2	Name	Varchar	100	XXX….	Name of Symptom	Headache
Table description: stores the names and corresponding codes of various disease symptoms.						

Table 3.15: Sign

S/N	Field	Data Type	Data Size	Data format	Description	Example
1	Id	Smallint	3	###	Sign Identification code	123
2	Name	Varchar	100	XXX…..	Name of Sign	Blurring of Distant Vision
Table description: stores the names and corresponding codes of various disease signs.						

Table3.16: RiskFactors

S/N	Field	Data Type	Data Size	Data format	Data Description	Example
1	Id	Smallint	3	###	RiskFactor Identification code	222
2	Name	Varchar	100	XXX…..	Risk factor name	Slanting of head
Table description: stores the names and corresponding codes of various disease Risk Factors.						

Table 3.17: Treatment

S/N	Field	Data Type	Data Size	Data Format	Data Description	Example
1	Id	Smallint	3	####	Treatment Identification code	123
2	Name	Varchar	100	XXX…..	Treatment name	Rinse eye with clean water
Table description: stores the names and corresponding codes of various disease treatment regimen.						

Table 3.18: EyeTest

S/N	Field	Data Type	Data Size	Data Format	Data Description	Example
1	Id	Smallint	5	#####	Test Identification No	12345
2	VisAR	Char	3	###	Visual Acuity for Right eye	60
3	VisAL	Char	3	###	Visual Acuity for Left eye	36
4	RpostFix	Char	2	+|- #	Visual Acuity Post fix for Right eye	-2
5	LpostFix	Char	2	+|- #	Visual Acuity Post fix for Left eye	+3
6	Report	Varchar	255	XXX……	Report summary	You have simple myopic astigmatism and…

7	DateOfExam	Date		YYYY-MM-DD	Date of exam	1989-06-25
8	PatientID	Varchar	4	####	Patient ID	1234
9	DiagnosisCode	Varchar	50	####...	Disease identification code	1234…
Table description: stores the reports of various eye tests done for all the patients.						

Table3.19: CertaintyFactor

S/N	Field	Data Type	Data Size	Data Format	Data Description	Example
1	Id	Smallint	3	#	Certainty factor Identification Code	101
2	Name	VarChar	20	XXX….	Certainty Factor Name	Not Certain
3	Range	Char	9	#.## - #.##	Range of certainty factor values	0.00 - 0.19
4	CFvalue	Double		#.#	Representative CF Value	0.6
Table description: stores the classification of certainty factors.						

Table3.20: VisualAcuity

S/N	Field	Data Type	Data Size	Data Format	Data Description	Example
1	Id	Smallint	3	#	Visual Acuity code	222
2	Range	Char	11	#.### - #.###	Range of Visual acuity	1.200 – 0.533
3	VAStatus	VarChar	30	XXX…..	Vision status	Very Poor
Table description: stores the classification of visual acuity and vision status.						

3.9.2.2 CFRMFEDD Database Schema

Figure 3.32 shows the database schema of CFRMFEDD. It illustrates the channel of relationships between one entity and another especially through Primary Key (PK)-Foreign Key (FK) complex.

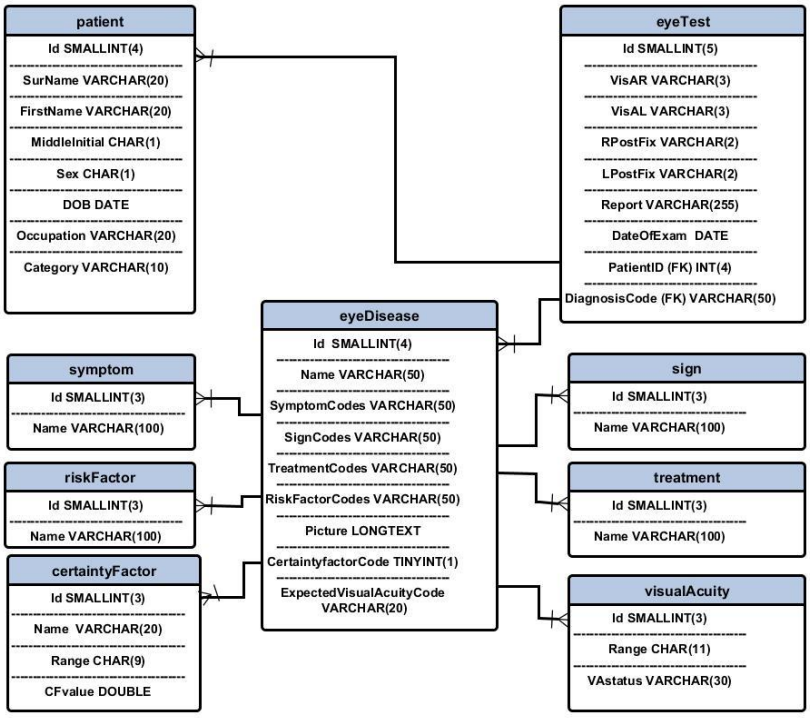


Figure3.32: CFRMFEDD Database Schema

3.9.3 Mathematical specifications

The following formula was used in determination of joint/combinational probability certainty factor.

CF [h,e] = MB [h,e] – MD [h,e] ……..[1]

Where, CF [h, e] represents the certainty factor and MB [h, e] describes the degree of confidence in the hypothesis h, if given evidence e (between 0 and 1), MD [h, e] describes the degree of distrust of hypothesis h, if given evidence e (between 0 and 1).

Case of Single-Rule-Single-Evidence

If e then h (CF rule)

CF[h,e] = CF(e) x CF(rule) ……...[2]

Case of Single-Rule-Multiple-Evidence with conjunction

IF e1 AND e2 ... AND en THEN h (CF rule)

CF(h,e) = min[CF(e1),CF(e2),...,CF(en)]*CF(rule) ……..[3]

Case of Single-Rule-Multiple-Evidence with disjunction

IF e1 AND e2 ... OR en THEN h (CF rule)

CF(h,e) = max[CF(e1),CF(e2),...,CF(en)]*CF(rule) ……..[4]

Case of Multiple Rule combination

IF h1 AND h2 THEN h3 (CF rule)

CF(h3) = CF(h1) + {CF(h2)[100-CF(h1)]/100}..…. ……..[5]

Since it will be inconvenient for providers of CF values (doctors and patients) to provide probability values in real numbers, an equivalent human-intelligible terms as earlier shown in Table 2.1 was used (Bogdan , 2006). The system automatically maps the terms back to the equivalent CF value.

3.9.4 Program Module Specification

In expert system based programs like CFRMFEDD, the inference engine represents the coding section of the project. Therefore, the following classes, modules and predicates were used in the design of CFRMFEDD. This is summarized in Table3.21. Also A tree-view of all the classes, modules and predicates used in CFRMFEDD are shownin appendicesB1-B16.

Each Class in visual prolog is organized into **class interface definition, class declaration** and **class implementation**. The actual codes that are used by the classes are found as clauses in the various predicates in the class implementation section.

Customized classes are those classes which were built from the native class-templates by the programmer.

The main customized classes of CFRMFEDD are shown in Table 3.21 and discussed briefly in the following sessions.

Table 3.21: Summary of modules designs used in CFRMFEDD

Class Name	**class implementation**	**Type**	**No of Predicates**	**Class Purpose**
addEyeDisease	addEyeDisease.pro	Class	32	adds new eye disease to database
addNewDiseaseAttributes	addNewDiseaseAttributes.pro	Class	11	Adds New symptoms, signs, risk factors and Treatment
askDialog	askDialog.pro	Class	7	gets password from user
biodataForm	biodataForm.pro	Class	10	registers new patient
browseDiseaseAttributes	browseDiseaseAttributes.pro	Class	4	displays Symptoms, signs, risk factors and treatment
deleteManager	deleteManager.pro	Class	8	delete existing disease from database
symptomChecker1	symptomChecker1.pro	Class	18	symptom check and

				diagnose eye conditions
myReport	myReport.pro	Class	24	displays result of eye testing for viewing and/or printing
patientLogIn	patientLogIn.pro	Class	10	logs in a patient for eye testing
testMyVision	testMyVision.pro	Class	39	tests the visual acuity of a patient
welcomePage	welcomePage.pro	Class	12	displays useful information and instruction to the user
Routine	routine.pro	class	30	provides re-useable codes often needed by other classes
Taskwindow	taskwindow.pro	Class	71	provides customized GUI functions for menu-driven tasks
Total		**13**	**287**	

3.9.4.1 taskwindow class

Name of class: taskwindow

No of predicates: 96 (See Appendix B1)

Purpose: provides customized GUI functions for menu-driven tasks.

Description: This class contains all the predicates, clauses and facts that are necessary to sustain menu-driven events/actions and database loading and manipulations.

The general algorithm for displaying the system GUI and responding to user actions are as shown below.

LOAD taskwindow form

DISPLAY form Title

LOAD and CONNECT database

CLOSE previously loaded Database

OPEN the loaded database for access

SET Timer

SET WindowState to MAXIMIZED THEN

RESPOND to Menu-driven user actions

3.9.4.2 welcomePage class

Name of class: welcomePage

No of predicates: 12 (See Appendix B2)

Purpose: Provides the template for displaying user instructions and other event-specific messages.

Description: This class contains all the predicates, clauses and facts that are necessary to display relevant instructions to the user on how to use and navigate the system.

The general algorithm for displaying the user instructions is as shown below.

SELECT Message Source

IF message is from:

“WELCOMEPAGE” OR

“TESTMYVISIONPAGE” OR

"DIAGNOSTICS" OR

"ABOUTEYEDIAGNOSTICS" OR

"REPORTBUGS"   OR

"ABOUTTHEAUTHOR"

THEN set Message AND

DISPLAY Message

3.9.4.3 askDialog class

Name of class: askDialog

No of predicates: 7 (See Appendix B3)

Purpose: To give log-In access to Doctor or System Admin

Description: This class contains all the predicates, clauses and facts that are necessary to give log-in access or denial to the doctor or system Administrator. Logging-in as a doctor/System admin gives the user reserved access privileges for adding, removing or updating the database.

The general algorithm for login-access is shown below.

DISPLAY Login Password Fields

VALIDATE [Password] Entry

CHECK if entered [Password] matches known password in database

GIVE access if match is found

DENY access otherwise

3.9.4.4 addNewDiseaseAttributes class

Name of class: addNewDiseaseAttributes

No of predicates: 11 (See Appendix B4)

Purpose: To add new Symptoms or Signs or RiskFactors or Treatmentto the database

Description: This class contains all the predicates, clauses and codes that are used to add new eye disease-attribute to the database. It displays add-disease-attribute input form earlier designed. This form contains a single adaptable list box which can display any of the four disease-attributes depending on the attribute the user has selected to add. For any disease-attribute such as "Signs" to be referenced, it must first of all be added into the database.

The general algorithm for adding new disease-attribute is as shown below.

Enter new Disease-AttributeName

Rule out that the new attributeName is not already existing

Select [ATTRIBUTE] from AttributeList

If NO ERROR THEN

Save [ATTRIBUTE] …..

If AttributeType is Signs THEN save into signsCode FactsDatabase

REPEAT for each of the attribute types

3.9.4.5 addEyeDisease class

Name of class: addEyeDisease

No of predicates: 32 (See Appendix B5)

Purpose: To add new eye disease to the database

Description: This class contains all the predicates, clauses and codes that are used to add new eye disease to the database. It displays add-new-disease input form earlier designed. This form contains sections for selection of disease attributes which include symptoms, signs, risk factors, treatment options and image for the disease about to be added. For any disease to be referenced, it must first of all be registered into the database.

The general algorithm for adding new disease is as shown below.

Enter new DiseaseName

Rule out that the new name is not already existing THEN

Select [SYMPTOMS] from SymptomsList

Select [SIGNS] from SignsList

Select [RISKFACTORS] from RiskFactorsList

Select [TREATMENT] from TreatmentList

Select [DISEASE IMAGE] from file

If NO ERROR THEN

Save [SYMPTOMS] into diseaseSymptoms FactsDatabase

Save [SIGNS] into diseaseSigns FactsDatabase

Save [RISKFACTORS] into diseaseRiskfactors FactsDatabase

Save [TREATMENT] into diseaseTreatment FactsDatabase

3.9.4.6 biodataForm class

Name of class: addEyeDisease

No of predicates: 10 (See Appendix B6)

Purpose: To add new patient's information to the database

Description: This class displays a registration input form earlier designed for entering the biodata of new patient. The biodata includes, FirstName, Surname, Initials, Age, sex, etc. This registration protocol is mandatory for any new patient who wishes to test his vision.

The general algorithm for adding new patient is as shown below.

Display AddNewPatientForm

Get Selections from the displayed fields

Validate entries made

Save [FIELD ENTRIES] into patientsBioData FactsDatabase

3.9.4.7 patientLogIn class

Name of class: patientLogIn

No of predicates: 7 (See Appendix B7)

Purpose: To give log-In access to Patient

Description: This class contains all the predicates, clauses and facts that are necessary to give log-in access or denial to the patient. Logging-in as a patient enables him or her to carry out eye test.

The general algorithm for login-access is shown below.

DISPLAY LISTBOX for patient to select his/her names

DISPLAY ID field for patient to enter his Folder/ID No.

VALIDATE [ID NO] Entry

CHECK if entered [ID NO] and Selected names MATCH any record in database

GIVE access if match is found

Otherwise set DEMO mode to TRUE.

3.9.4.8 testMyVision class

Name of class: testMyVision

No of predicates: 39 (See Appendix B8)

Purpose: Visual acuity measurement.

Description: Tumbling-E is presented to the patient at four different orientations (Left, Right, Up and Down) and at different sizes. The patient clicks an arrow corresponding to the orientation of E. For instance, if E is facing up, the patient is expected to click UP arrow. Testing is automatically halted when patient can no longer identify the orientation of presented-E correctly by pressing the wrong keys consecutively. Testing is done per eye. The visual acuity is finally saved in the database.

Algorithm :

IF E-orientation is X

AND correctLastButtonOrientationClicked is X

AND acuityOfE_beforeFailure is Y

THEN

PatientAcuity is Y

3.9.4.9 symptomChecker1 class

Name of class: symptomChecker1

No of predicates: 19 (See Appendix B9)

Purpose: Symptoms checking and partial tentative disease diagnosis.

Description: list of symptoms are presented to the patient for selection and then using the selections made, the list of unlikely diseases are eliminated systematically while the list of likely diseases are kept. The process continues until when one solution is found or when no solution is found or when further processing could not lead to any goal.

Algorithm:

Facts:

SymptAA, SymptBB, SymptCC, SymptDD are symptoms of Eyedisease-X,

SymptBB, SymptCC, SymptDD, SymptEE are symptoms of Eyedisease-Y,

Rules:-

IF **HasSymptomsBB**

AND **HasSymptomsCC**

AND **HasSymptomsDD**

THEN

Patient has **Eyedisease-X**

OR **Eyedisease-Y**

3.9.4.10 diagnostics class

Name of class: diagnostics

No of predicates: 19 (See Appendix B10)

Purpose: Outputs final disease diagnosis.

Description: The class outputs the final disease diagnosis by comparing the result of visual acuity measurement and the tentative partial diagnosis earlier made during symptom checking. It also calculates the certainty factor associated with the diagnosis.

Algorithm:

Get visual acuity result from testMyVision class

Classify the visual acuity result

Get the [tentative partial diagnosis] result from SymptomsChecker1 class

Using the [classified visual acuity] and [Tentative Diagnosis result] calculate the CERTAINTY FACTOR

Output DIAGNOSIS with the associated CERTAINTY FACTOR.

3.9.4.11 myReport class

Name of class: myReport

No of predicates: 27 (See Appendix B11)

Purpose: Displays the patient's test report from the database for viewing or printing.

Description: The class displays the test reports for a selected patient. Also all the test reports and records related to a particular patient could be displayed in multiple pages.

Algorithm:

Gather all the test records related to a given patient

Display the records in a form

For multiple records, display page navigation buttons

3.9.4.12 deleteManager class

Name of class: deleteManager

No of predicates: 8 (See Appendix B12)

Purpose: Deletes an existing disease from the database.

Description: The class provides platform for removing or deleting existing disease from the database.

Only the user who logs-in as doctor or system administrator could carry out this delete operation.

Algorithm:

Get user password

If user is registered doctor or system admin THEN

Display list of all existing eye diseases from the database

Confirm delete request from user the second time

Delete the selected disease and all its attributes from the database

Update database.

3.9.4.13 browseDiseaseAttributes class

Name of class: browseDiseaseAttributes

No of predicates: 4 (See Appendix B13)

Purpose: Displays the list of eye diseases, symptoms, signs, risk factors and treatment.

Description: The class displays only eye disease and disables other attributes if user logged-in as a patient. But if user logged-in as a doctor/system admin, then display of disease attributes could also be enabled.

Algorithm:

Get user password

If user is registered patient THEN

Enable only disease viewing and corresponding images

If user is registered doctor or system admin THEN

Enable disease viewing and corresponding images

Enable Symptoms viewing

Enable Signs viewing

Enable Risk-factor disease viewing

Enable Treatment viewing

3.9.4.14 routine Class

Name of class: routine

No of predicates: 30 (See Appendix B15)

Purpose: Common pool class for provision of routine functions

Description: This class contains all the common predicates, clauses and codes that are repeatedly required by other classes. Most of the important services provided by this routine are conversion services. This involves converting diseases, symptoms, signs, risk factors and treatment to codes and vice versa as it is programmatically safer to work with codes to ensure consistency, save memory demand and minimize errors.

3.9.4.15 main module

Name of class/module: main

No of predicates: 2 (See Appendix B16)

Purpose: loads system executable file (.exe)

Description: The class loads CFRMFEDD executable file at startup.

Algorithm:

Display taskwindow

Load main::run (Goal)

3.9.5 Input/output specifications

The various input and output specifications used in the design of CFRMFEDD are shown below.

3.9.5.1 Input specification

The input design specifies the WHAT MUST input to the system and the interface through which such data input is made possible. In this dissertation, the design includes the screens or forms which are used to collect data from the user through text input, option buttons, check boxes and drop-down list boxes.

3.9.5.1.1 Input Mode

The input modeisthe channel through which communication to the system can be actualized. These include the following:

a) Use of keyboard or mouse
b) Use of Forms and Controls by typing, clicking or double-clicking. The controls include option buttons, check boxes, drop-down list boxes and command buttons.
c) Input Forms are evoked through interactive menu-driven navigation system.

3.9.5.1.2 User Input Interface Forms

The user input interface forms were designed using Visual Prolog 7.0 enterprise edition and the following input forms were designed:

a) Patient Registration Input Form(See Figure 3.33)
b) Eye Disease Registration Input Form (See Figure3.34)
c) Eye Disease-Attributes Registration Input Form (See Figure 3.35)
d) Eye Disease Delete Input Form (See Figure 3.36)
e) Patient Log-In Input Form (See Figure 3.37)
f) Admin/Doctor Input Log-In Form (See Figure 3.38)
g) Visual Acuity Test Input Form (See Figure3.39)

h) Symptoms Checking Input Form (See Figure3.40)

i) Change Password input Form (See Figure 3.41)

3.9.5.1.3 Patient Registration Input Form

The patient registration input form (See Figure 3.33) is used to register a new patient into the system. The registration is done through the help of an assistant. The following information about the patient is registered:

a) Surname,

b) First Name,

c) Middle Name

d) Sex

e) Age

f) Occupation

g) The user Type (auto-filled)

h) Patient ID/Folder No (auto-filled)

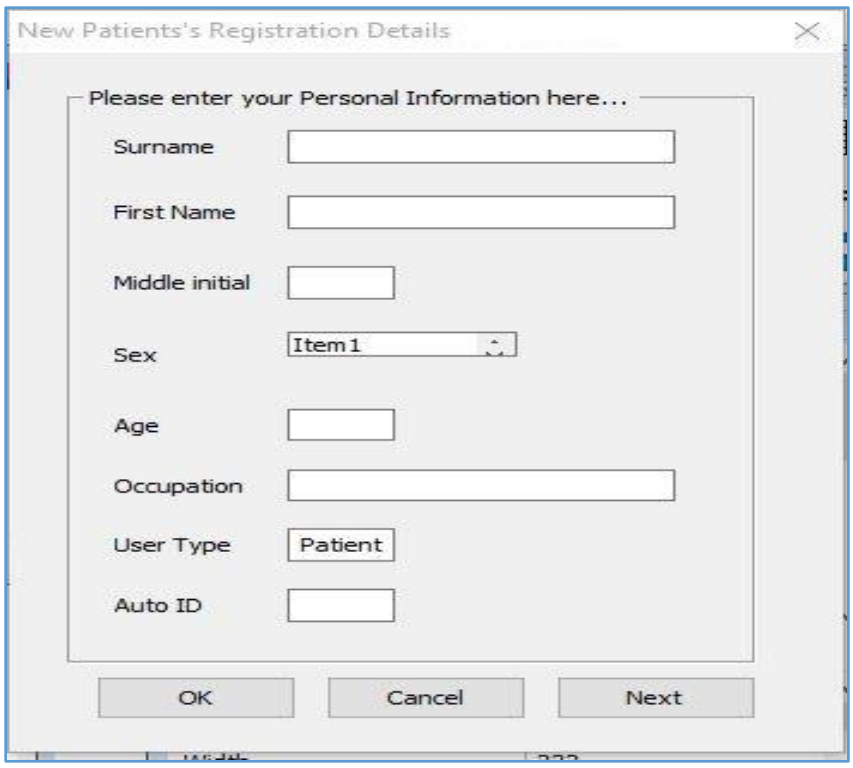


Figure 3.33: Patient Registration Input Form

3.9.5.1.4 Eye Disease Registration Input Form

New eye disease is added into the database through this form (See Figure 3.34). The following disease information are entered into the system:

a) The Name of Eye disease

b) The Symptoms of the disease

c) The Signs of the disease

d) The Risk factors of the disease

e) The Treatment regimen of the disease

f) The certainty factor associated with the disease

g) The image of the disease

Only item (a) above is typed in as text, the rest of the input is done through selection from a pull down list. Selection of exact set of symptoms for already existing disease in the database is not allowed as this will tantamount to duplication of eye disease with another name. Only a system administrator or doctor has access to this form.

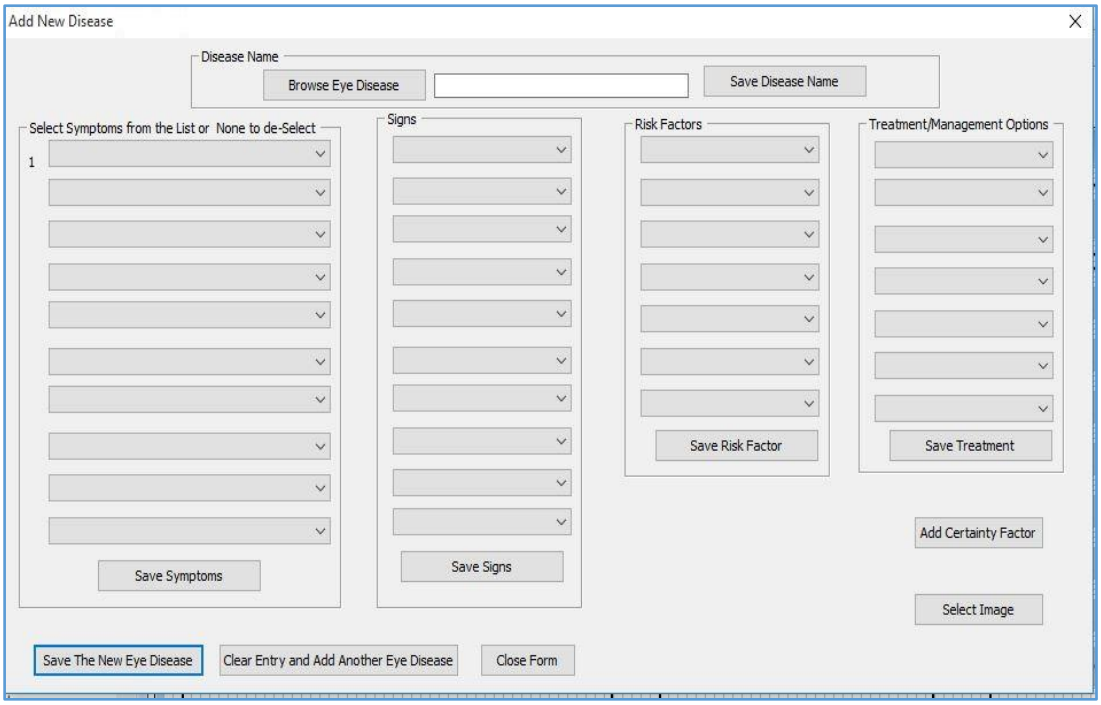


Figure 3.34: Add-New-Eye-Disease Input Form

3.9.5.1.5 Eye Disease-Attributes Registration Input Form

This form (See Figure 3.35) is used to register new disease attributes into the database. Such disease attributes include the following:

a) The Symptoms

b) The Signs

c) The Risk factors

d) The Treatment regimen

Duplication of any of the above attributes in the database is not allowed. Only a system administrator or doctor has access to this form

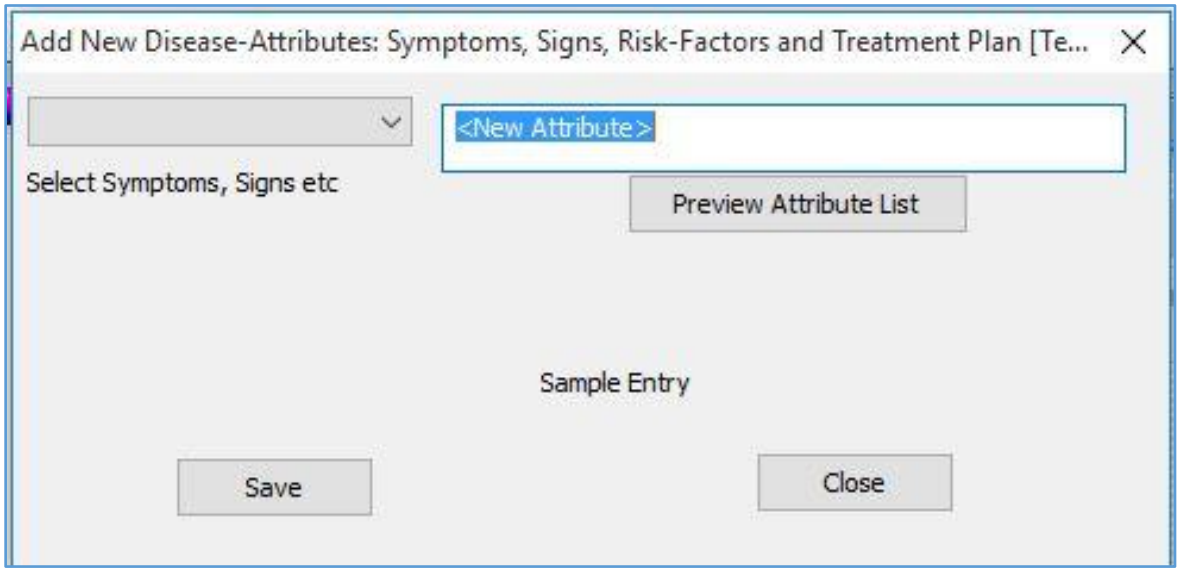


Figure 3.35: Add-New-Eye-disease-attributes Input Form

3.9.5.1.6 Eye Disease Delete Input Form

This form(See Figure3.36) is used to delete existing an eye disease from the database. Two levels of confirmatory warnings are presented to the used before the disease is finally deleted from the database. Only a system administrator or doctor has access to this form

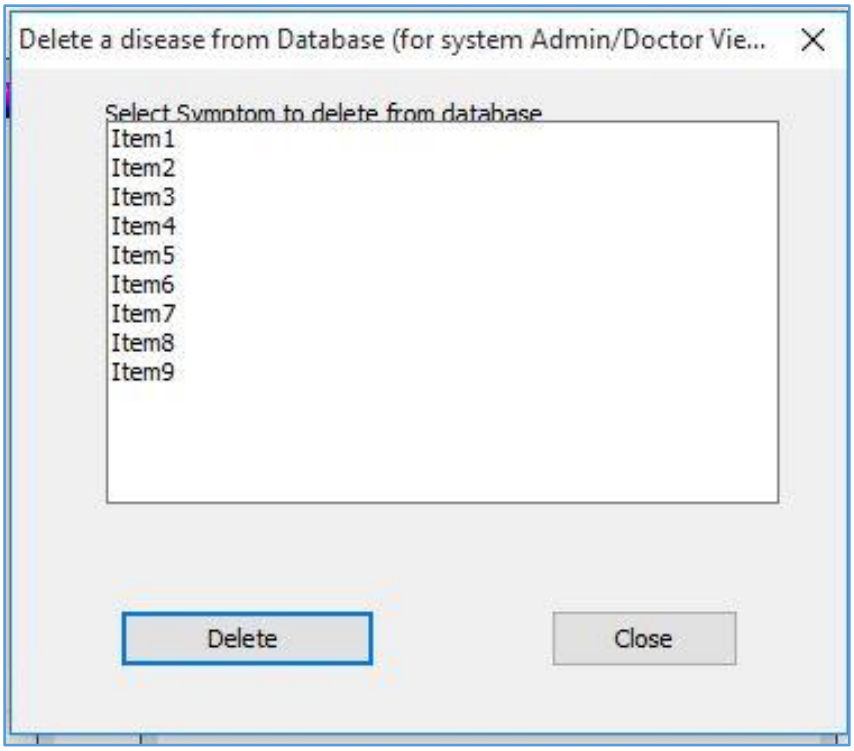


Figure 3.36: Delete-existing-Eye Disease Input Form

3.9.5.1.7 Patient Log-In Input Form

This form(See Figure 3.37) is used for logging-in a patient. For successful log-in to occur, the patient through the help of assistant must supply correctly the following information:

a) Surname, First Name and Middle Initial

b) ID

The name is simply selected from a pull-down listwhile the ID No must be typed. When a user is logged-in as a patient, he will be given the following view/action privileges:-

a) Carry out visual acuity test

b) Participate in symptoms-checking

c) View eye disease pictures, signs, symptoms, risk factors and treatment options

d) View/Print test reports related to him/her only

Also a new patient is allowed to register by clicking the <New patient> button.

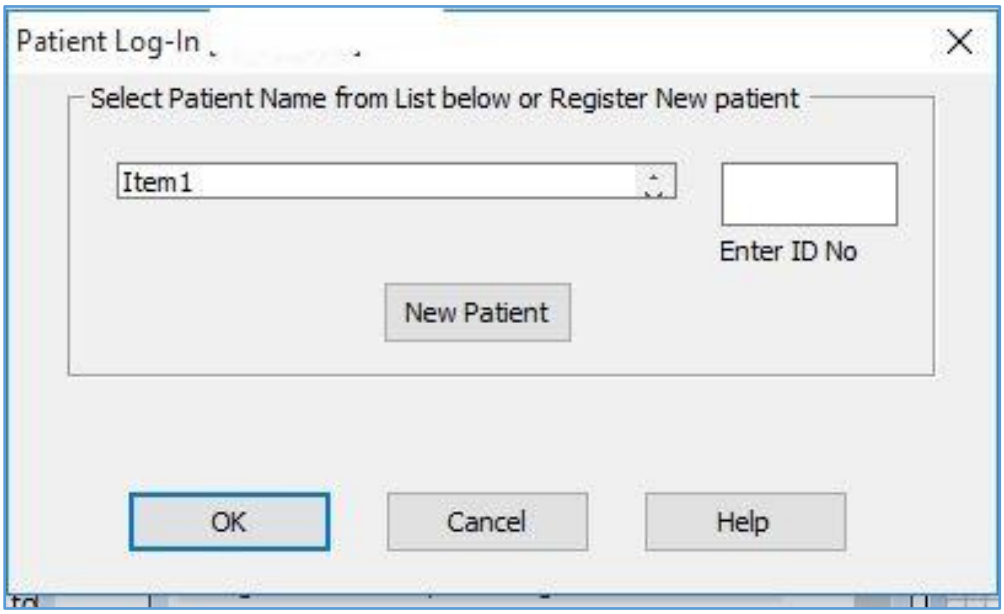


Figure 3.37: Patient Log- in Input Form

3.9.5.1.8 Admin/Doctor's Log-In Input Form

This form(See Figure 3.38) is used for logging-in as system Admin/Doctor. For successful log-in to occur, the user through the help of assistant must supply correctly the following information:

a) Admin Password

When a user is logged-in as an Admin/Doctor, he will be given unrestricted privileges including:-

a). Carry out visual acuity test

b) View eye disease pictures, signs, symptoms, risk factors and treatment options

c) View/Print test reports related to any patient

d) Add or delete eye disease

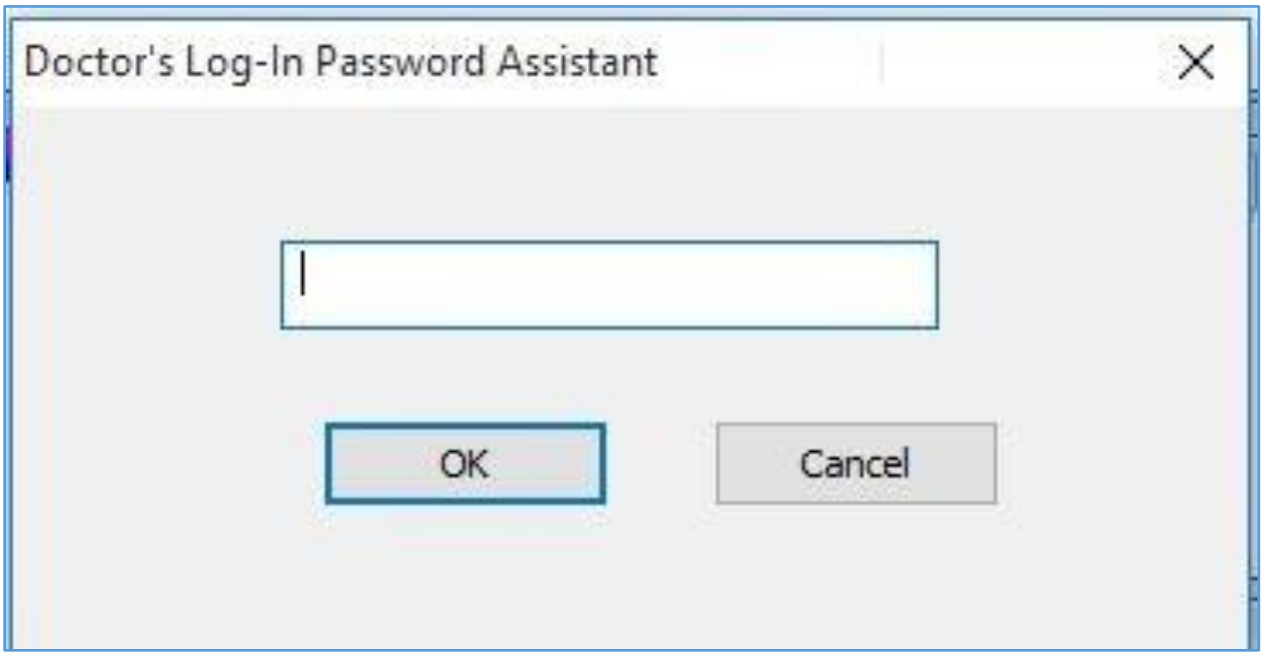


Figure 3.38: Admin/Doctor's Log-In Input Form

3.9.5.1.9 Visual Acuity Test Input Form

The visual acuity test input form (See Figure 3.39) is used to receive patient's response during the measurement of visual acuity. Only users who log-in as patient can save the test result whereas other users can only use the test as a demo but cannot save the result. A saved result of the test is automatically forwarded to symptoms-checker for further processing.

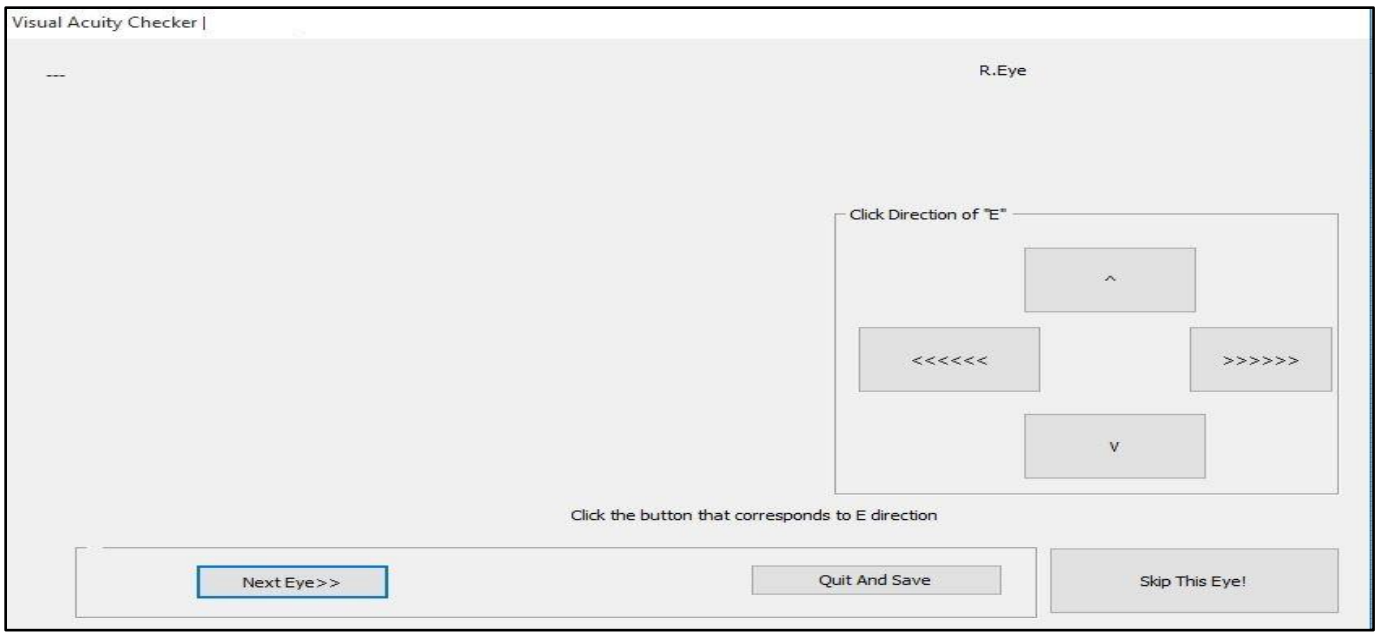


Figure 3.39: Visual Acuity Test Input Form

3.9.5.1.10 Symptoms Checking Input Form

The Symptoms checking input form (See Figure 3.40) is used to receive patient's symptoms. It serves as a consultation panel between the system and the patient. Only users who log-in as patient can view and save the result after consultation. However, users who log-in as Admin/Doctor can view and practice with the consultation panel as a learning tool but cannot save the result thereafter for diagnosis. Entering of symptom is simply through clicking of <YES> or <NO> button as a response to the diagnostic question displayed by the system. Afterwards a <NEXT> button is clicked for more questions.

The following information are supplied by the user during a typical consultation session:

a) Symptoms complained by the user

b) Certainty factor associated with each symptom provided

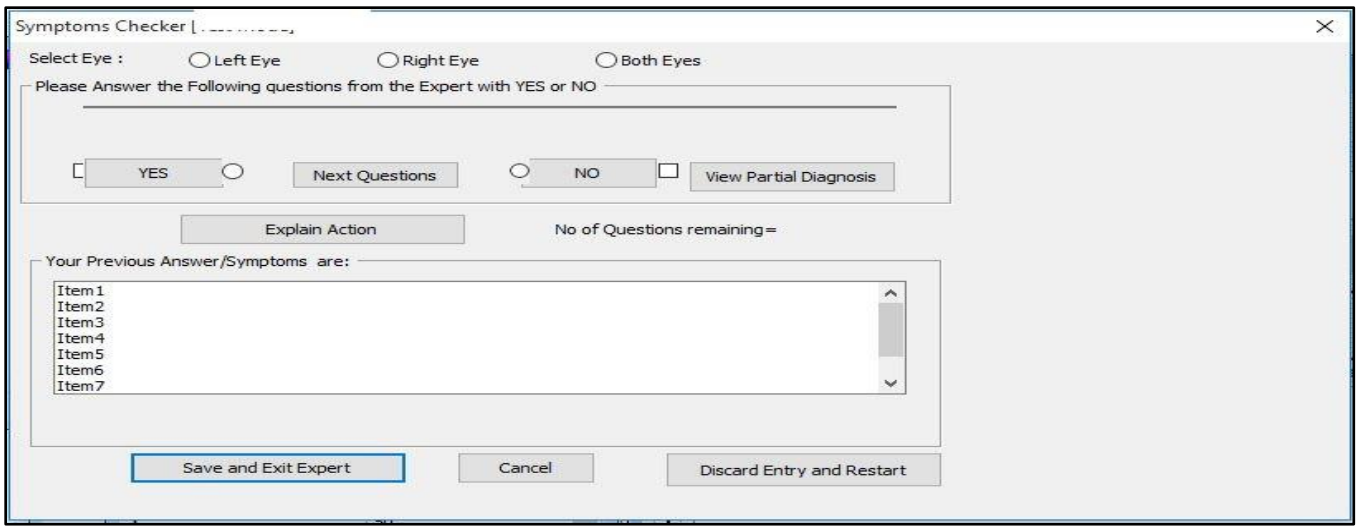


Figure 3.40: Symptoms Checking Input Form

3.9.5.1.11 Change Password input Form

For security reasons, the doctor or system admin is allowed to change his/her password at will. This is to prevent unwarranted intrusion into the sensitive section of the database. The user must have to successfully provide the old password and repeated new password before password change could be effected.

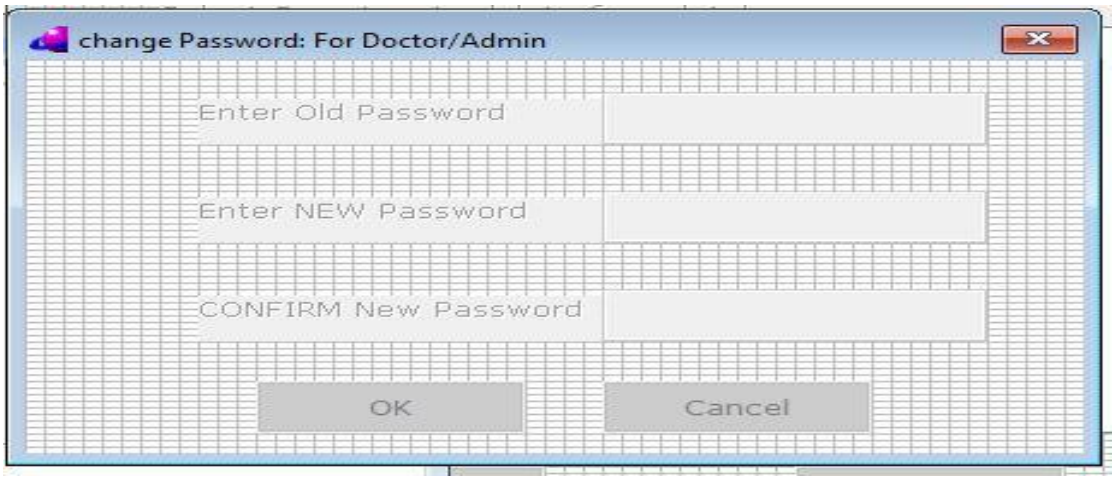


Figure 3.41: Change password input form

3.9.5.2 Output Specification

The output design specifies WHAT the system shall and MUST output and the interface through which such data output is made possible. In this dissertation, the output design includes the screens or forms which are used to output data from the system in form of test reports, screen displays and hard-copy print-outs.

The output from the system includes:

a) Displays, reports and print-outs
    i. Test results, errors, warnings, messages and other instructions are displayed on the computer screen
    ii. Test report is sent to Printer for print out
    iii. Test result is saved to database
b) The user selects output from the system through various Forms and Controls by typing, clicking or double-clicking.
c) Output Forms are evoked through interactive menu-driven navigation system and include the following:
    i. Disease-Attributes Browsing Output Form
    ii. Eye Disease Browsing Output Form
    iii. Diagnosis Output Form
    iv. Cumulative Test Report Output Form
    v. Welcome Page Output Form

3.9.5.2.1 Output interface Forms

The following output Forms were designed:

a) Disease-Attributes Browsing Output Form(See Figure 3.42).

b) Eye Disease Browsing Output Form(See Figure 3.43).

c) Diagnosis Report Output Form (See Figure 3.44).

d) Cumulative Test Report Output Form(See Figure 3.45).

e) Welcome Page Output Form (See Figure 3.46).

3.9.5.2.1.1 Disease-Attributes Browsing Output Form.

Disease-Attributes Browsing Output Form (See Figure3.42) is used to display the list of disease attributes from the database. Such disease attributes include the following:

a) The Symptoms list

b) The Signs list

c) The Risk factors list

d) The Treatment regimen list

Only users who log-in as doctor/Admin can view this form as the patients do not need to know this list in advance as to avoid supplying memorized information.

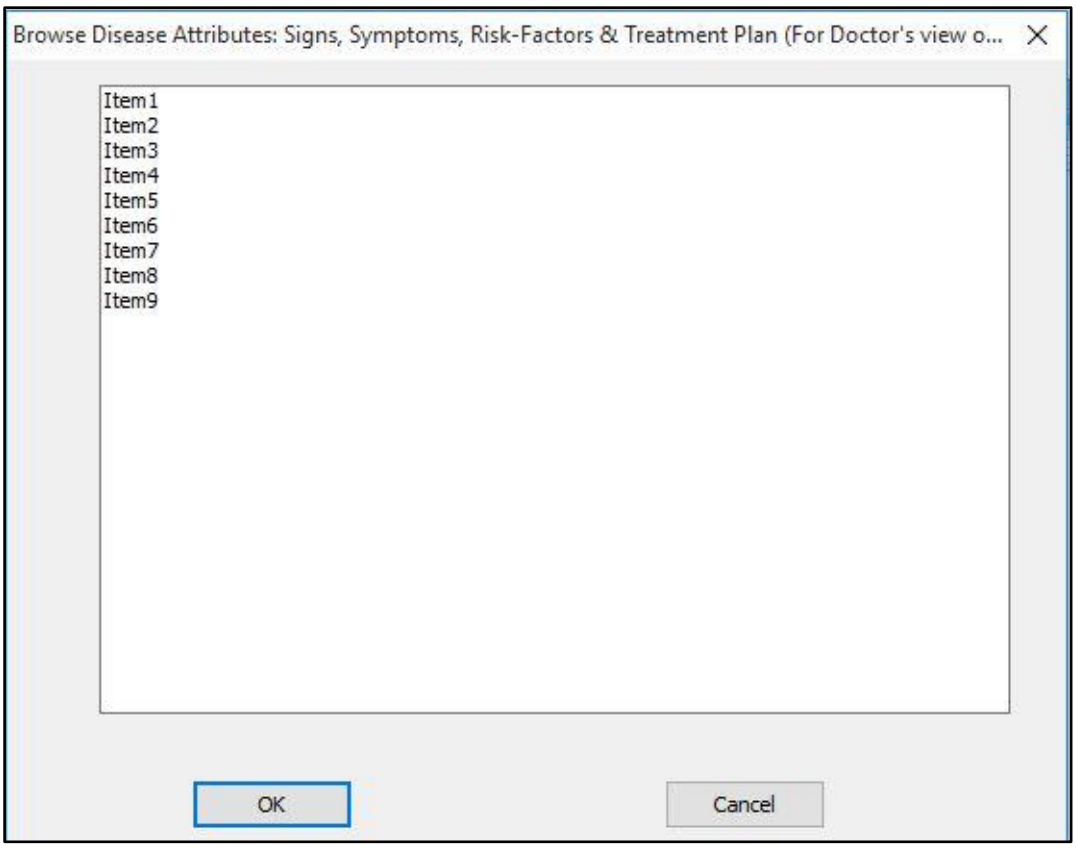


Figure3.42: Disease-Attributes Browsing Output Form

3.9.5.2.1.2 Disease Browsing Output Form.

Disease Browsing Output Form (See Figure3.43) is used to display the list of eye disease from the database. For each selected disease from the list, the following information is displayed:

a) The Symptoms of the disease

b) The Signs of the disease

c) The Risk factors of the disease

d) The Treatment regimen of the disease

e) The picture of the disease

Viewing of this form is accessible to any user of the system as learning about eye diseases is one of the fundamental facility provided by CFRMFEDD.

Figure3.43: Disease Browsing Output Form

3.9.5.2.1.3 Diagnosis Report Output Form

Diagnosis report output form (See Figure3.44) is used to display final diagnosis made by CFRMFEDD. The view of this form is only accessible to users who logged-in as patients and have also undergone eye test.

The following information is displayed:

a) The name of eye disease diagnosed with associated certainty factor (for single disease diagnosis)
b) The names of eye diseases diagnosed with associated certainty factors (for multiple disease diagnosis)

c) Inconclusive diagnosis when the certainty factor and/or visual acuity gotten from the patient do not yield to any known eye disease in the database.

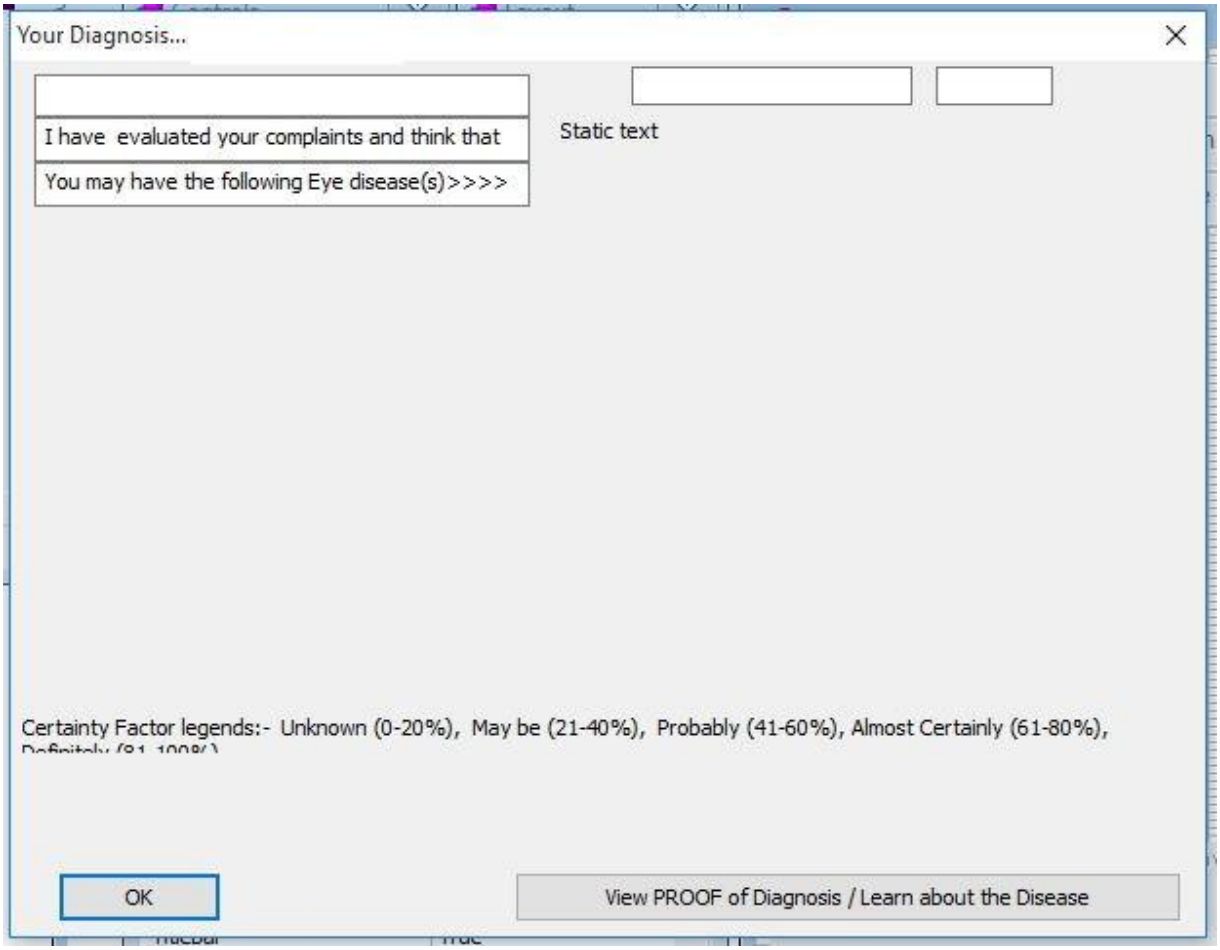


Figure3.44: DiagnosisReport Output Form

3.9.5.2.1.4 Cumulative Test Report Output Form

Cumulative Test Report Output Form(See Figure 3.45) is used to display all the tests done by each patient in all his/her consultations with CFRMFEDD. The view of this form is only accessible to users who logged-in as either patients or Admin/doctor. A patient can only view those results that pertain to

him/her while the Admin/doctor has global view of all the results of the patients. This ensures information protection and security.

The following information is displayed:

a) Patient Name :Surname, First name, Middle Name
b) Age,
c) Sex,
d) Occupation,
e) Patient category
f) Patient ID No

For each date of eye examination, the following information are also displayed:

a) Visual Acuity and vision status for Right eye
b) Visual Acuity and vision status for Left eye
c) The symptoms complained an associated diagnosis made
d) Recommendations/ Health Advice

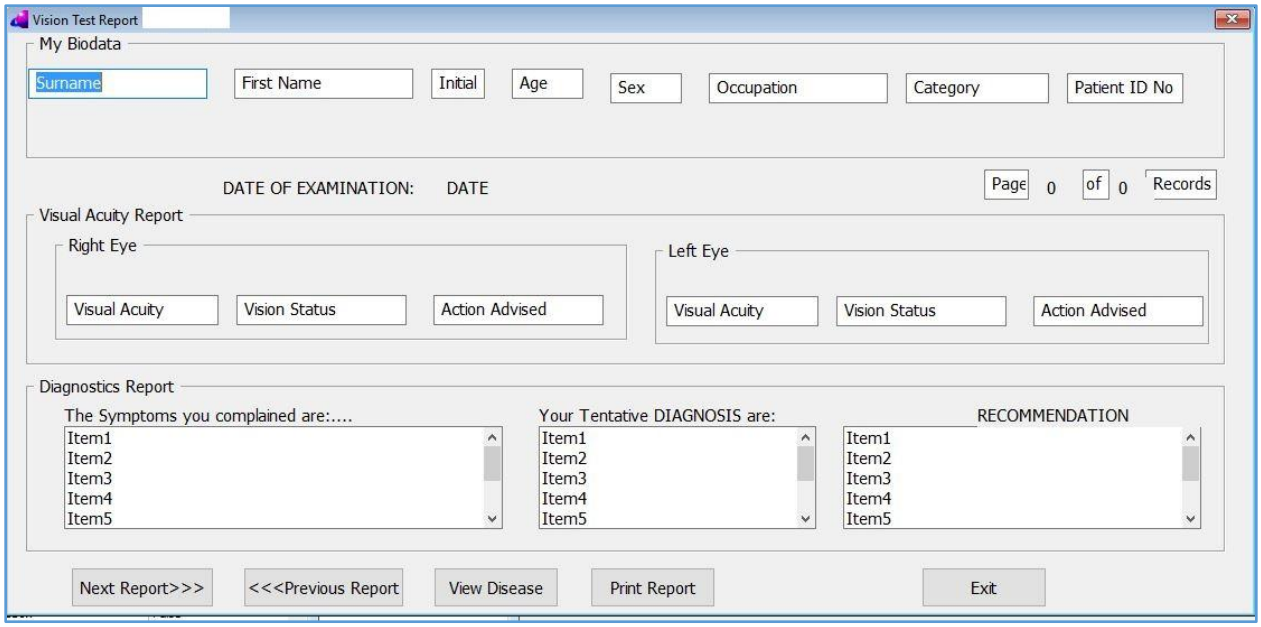


Figure 3.45: Cumulative Test Report Output Form

3.9.5.2.1.5 Welcome Page Output Form

Welcome page output form (See Figure 3.46) is designed to be the first welcome portal to the user. Brief but necessary user instruction is displayed here. It gives the user a sense of direction on what he expects to do with CFRMFEDD.

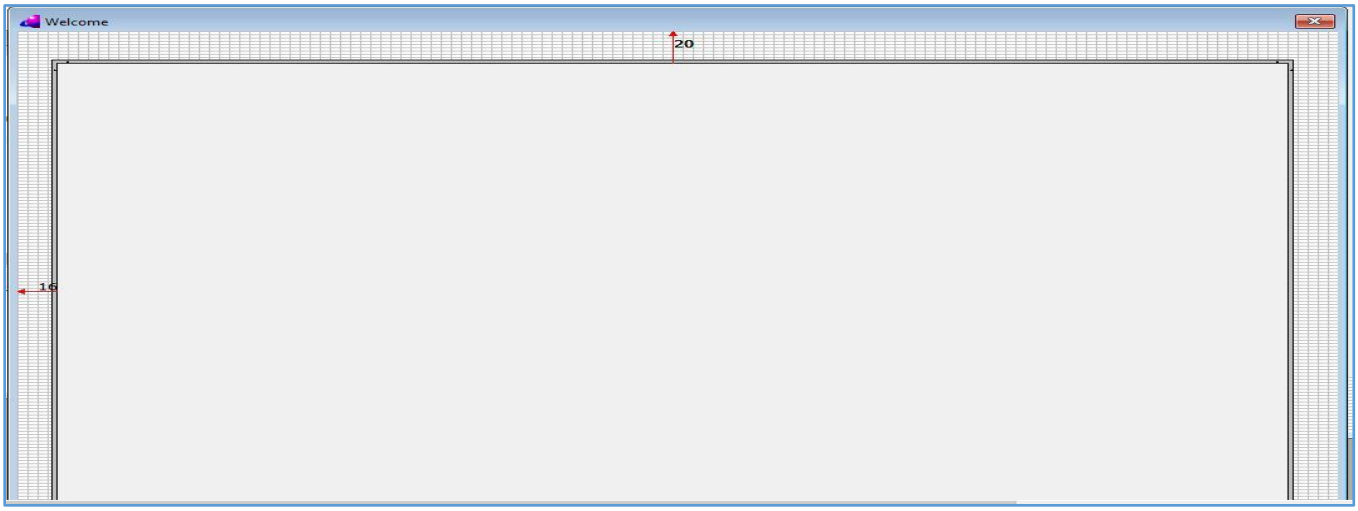


Figure 3.46: Welcome page output form List of Nu

3.9.6 Application Algorithm

Application Algorithm in this study constitutes a sequence of actions or steps to be taken from input to output for CFRMFEDD application. .

3.9.6.1 Pseudo codes

This is a step by step platform-independent verbal rendition of the application algorithm

1. START
2. Display Welcome Message
3. GET User Log-In Information
4. Select Type of User
5. User is PATIENT
6. Enable application view for patient
7. Enable all patient's menu items and controls
8. Disable all non-patient's menu items and controls
9. User is STUDENT
10. Enable application view for student
11. Enable all student's menu items and controls
12. Disable all non-student's menu items and controls
13. User is DOCTOR/ADMIN
14. Enable application view for Doctor/Admin
15. Enable all Doctor/Admin menu items and controls

16. Disable all non-Doctor/Admin's menu items and controls

17. WAIT for Action (Event Driven)

18. User selects < TEST MY VISION>

19. <Automated Visual Acuity Tester>

20. Display Instruction for Testing Visual Acuity

21. [Ask patient to close one eye and stay 3m away from screen]

22. Initialize count for presentation, correct match and visual Acuity line

23. Display 4 directional arrows and other control buttons

24. Display one E-character of 6/120optotype size at random orientation

25. Wait for user response

26. User clicks one directional arrow button

27. IF the button clicked is the same orientation with the displayed character THEN

28. Increment Presentation counter

29. Increment correct match counter

30. IF Presentation counter >4 and Correct match counter >4 THEN

31. Reduce size of Character to next smaller level

32. Go back to Step 24

33. ELSE

34. IF Presentation counter >4 THEN

35. OUTPUT result (Display Visual Acuity of current line)

36. SAVE result for the current eye

37. [Repeat similar test for fellow eye]

38. Go back to Step 24

39. Transfer control to symptoms checker

40. ELSE

41. Increment Presentation counter

42. Go back to Step 24

43. END IF

44. END IF

45. ELSE

46. Increment Presentation counter

47. Go back to Step 24

48. END IF

49. Transfer control to symptoms checker

50. <Symptoms checker>

51. Display associated Test instruction to user

52. Initialize list of complained symptoms, list of available symptoms, list of tentative diagnosis

53. Populate list of available symptoms with all the symptoms in the knowledge base

54. Display the first symptom question from list of available symptoms and allow patient to select Yes or No

55. IF patient selects YES THEN

56. Allow patient to select certainty factor (CF) of the symptom (S) complained of

57. Store CF together with S in a list of complained symptoms

58. <pre-processing>

59. Get all diseases from knowledge base that have complained symptoms

60. Calculate the combined certainty factor for each disease-symptom combination

61. Extract only the disease sets that have CF more than set goal

62. IF disease list in Step 61 is EMPTY THEN

63. Report [**NO DIAGNOSIS]**

64. ELSE

65. Extract all the symptoms of the CF disease listed in step 61

66. Remove duplicate symptoms

67. Remove Queried symptom (S) from Step 61

68. Overwrite list of available symptoms with list got in Step 62

69. IF list of Available symptom is EMPTY THEN

70. IF list of Tentative diagnosis is EMPTY THEN

71. Report **[NO DIAGNOSIS]**

72. ELSE

73. IF list of Tentative diagnosis has more than one member THEN

74. Report [**MULTIPLE DISEASE DIAGNOSIS]**

75. ELSE

76. Report **[SINGLE DISEASE DIAGNOSIS]**

77. END IF

78. END IF

79. ELSE

80. Go back to Step 54

81. END IF

82. ELSE

83. [Patient selected NO]

84. Remove queried symptom (S) from list of available symptoms

85. Go back to Step 54

86. END IF

87. Display result

88. IF user selects <**EXPLAIN> THEN**

89. Backtrack and show all the symptoms of diagnosed disease

90. Compare the symptoms got in Step 89 with the complained symptoms

91. END IF

92. Save Diagnosis

93. Print Diagnosis (optional)

94. User selects <ADD NEW PATIENT> [enabled for Doctor/Admin] only

95. Display Add-New-Patient form

96. Get Biodata information from patient

97. Save (Register) the new patient into patients database

98. User selects <CHANGE PASSWORD> [enabled for Doctor/Admin] only

99. Display Change-password form

100. Get old password from user

101. IF entered password exists in database THEN

102. Get New Password from user

103. Confirm New password from User

104. IF New password and Confirm Password are the same THEN

105. Replace old password with New password in the database

106. ELSE

107. Display warning message “ Password mismatch”

108. END IF

109. ELSE

110. Display warning message “ Password does not exist”

111. END IF

112. User selects <UPDATE DATABASE> [enabled for Doctor/Admin] only

113. User selects <ADD NEW DISEASE ATTRIBUTES> [enabled for Doctor/Admin] only

114. Display Add-New-Disease-Attributes form

115. Prompt for attribute type [Ex: Symptom, sign, etc.]

116. Prompt for attribute name or select from attribute list [Ex: headache]

117. Save new attribute into database

118. User selects <DELETE EXISTING DISEASE> [enabled for Doctor/Admin] only

119. Display Delete-Existing-Eye-Disease form

120. Prompt for disease name to delete or select from disease list

121. Confirm delete request for 1st time

122. Confirm delete request for 2nd time

123. Delete requested disease and all its attributes from database

124. User selects <ADD NEW DISEASE> [enabled for Doctor/Admin] only

125. Display Add-New-Disease form

126. Prompt for new disease name

127. Prompt for symptoms from symptoms list

128. Prompt for signs from signs list

129. Prompt for risk factors from risk factors list

130. Prompt for treatment from treatment list

131. Prompt for disease image from image file address

132. Add new disease and its attributes into the disease database

133. User selects <BROWSE EYE DISEASE> [enabled for ALL users]

134. Display Browse-Eye-Disease form

135. Display disease list

136. Display the attributes for each disease selected from the list

137. User selects <VIEW MYREPORT> [enabled for active user]

138. Display Report form for the active (current) user only

139. User selects <VIEW OTHER'S REPORT> [enabled for Doctor/Admin]

140. Select the patient from existing patients' list

141. Display Report form for selected patient

142. END

3.9.7 **CFRMFEDD Data Dictionary**

A data dictionary is a collection of descriptions of the data objects or items in a data model for the benefit of programmers and others who need to refer to them. Tables 3.22 represents such collections used in CFRMFEDD.

Table : 3.22 CFRMFEDD Data Dictionary

Entity Name	Entity Description	Column Name	Colum Description	Data Type	Length	Primary /Foreign key	Nullable	Unique
PatientInfo	Person who presents with eye symptoms and is tested for diagnosis	Id	Unique Patient No	Char	6	Primary key	Not Null	True
		SurName	Last Name	Varchar	20		Not Null	falls
		FirstName	First Name	Varchar	20		Not Null	False
		MiddleInitial	Middle Name Initial	Varchar	1		Not Null	False
		Sex	Sex	Varchar	1		Not Null	False
		DOB	Date of Birth	Date	10		Not Null	False
		Occupation	Occupation	Varchar	20		Not Null	False
		Category	Assisted or not assisted patient	Varchar	10		Not Null	False
EyeDisease	Eye Disease	Id	Unique Disease code	Char	6	Primary key	Not Null	True
		Name	Name of Disease	Varchar	20		Not Null	True
		SymptomsCode	Symptoms code	Varchar	50		Not Null	False
		SignsCode	Sign code	Varchar	50		Null	False
		TreatmentsCode	Treatments Code	Varchar	50		Null	False
		RiskFactorsCode	Risk Factors Code				Null	False

				Varchar	50			
		Picture	Disease picture	Text	Unlimited		Null	True
		CertaintyFactorCode	Certainty Factor Code	Char	3		Not Null	False
		ExpectedVisualAcuityCode	Expected visual acuity code	Char	3			
Symptom	Symptom of eye disease	Id	Unique symptom code	Char	5	Primary key	Not Null	True
		Name	Name of Symptom	Varchar	30		Not Null	True
Sign	Sign of eye disease	Id	Unique sign code	Char	5	Primary key	Not Null	True
		Name	Name of Sign	Varchar	30		Not Null	True
RiskFactor	Risk factor of eye disease	Id	Unique Risk Factor code	Char	5	Primary key	Not Null	True
		Name	Name of Risk factor	Varchar	30		Not Null	True
Treatment	Treatment plan/advice of eye disease	Id	Unique Treatment code	Char	6	Primary key	Not Null	True
		Name	Name of Treatment	Varchar	30		Not Null	True
EyeTest	Report of Eye Test done on a patient for each consulting session	Id	Unique Test code	Char	7	Primary key	Not Null	True
		VisAR	Visual acuity for Right eye	Char	3		Null	False
		VisAL	Visual acuity for Left eye	Char	3		Null	False
		RpostFix	Acuity Post fix for Right Eye	Char	2		Null	False
		LpostFix	Acuity Post fix for Left Eye	Char	2		Null	False
		Report	Summary report of Diagnosis	Varchar	255		Null	False
		DateOfExam	Date of eye	Date	10		Not Null	False

			consultation					
		PatientID	Patient Identification No	Char	6	Foreign key	Not Null	False
		DiagnosisCode	Diagnosed disease code	Char	6	Foreign key	Null	False
CertaintyFactor	Certainty factor rating and calibration	Id	Unique certainty factor code	Char	3	Primary key	Not Null	True
		Name	Certainty Factor Title	VarChar	20		Not Null	True
		Range	Certainty Factor range	Char	9		Not Null	True
		CFValue	Certainty Factor value	Real	3		Not Null	True
VisualAcuity	Visual Acuity Classification	Id	Unique visual acuity code	Char	4	Primary key	Not Null	True
		Range	Visual acuity range	Char	9		Not Null	True
		VAStatus	Visual Acuity status	VarChar	20		Not Null	True

3.10 CFRMFEDDSystem Flowchart

System flowchart is useful tool in software engineering often deployed to expose the process logic of the entire system. Figure 3.47 shows the system flowchart of CFRMFEDD. The program starts with welcome message/instruction display, checks password for log-in or registers new user, delivers visual acuity test, asks diagnostic questions, analyses all the input data and responses, outputs diagnostic results and stops.

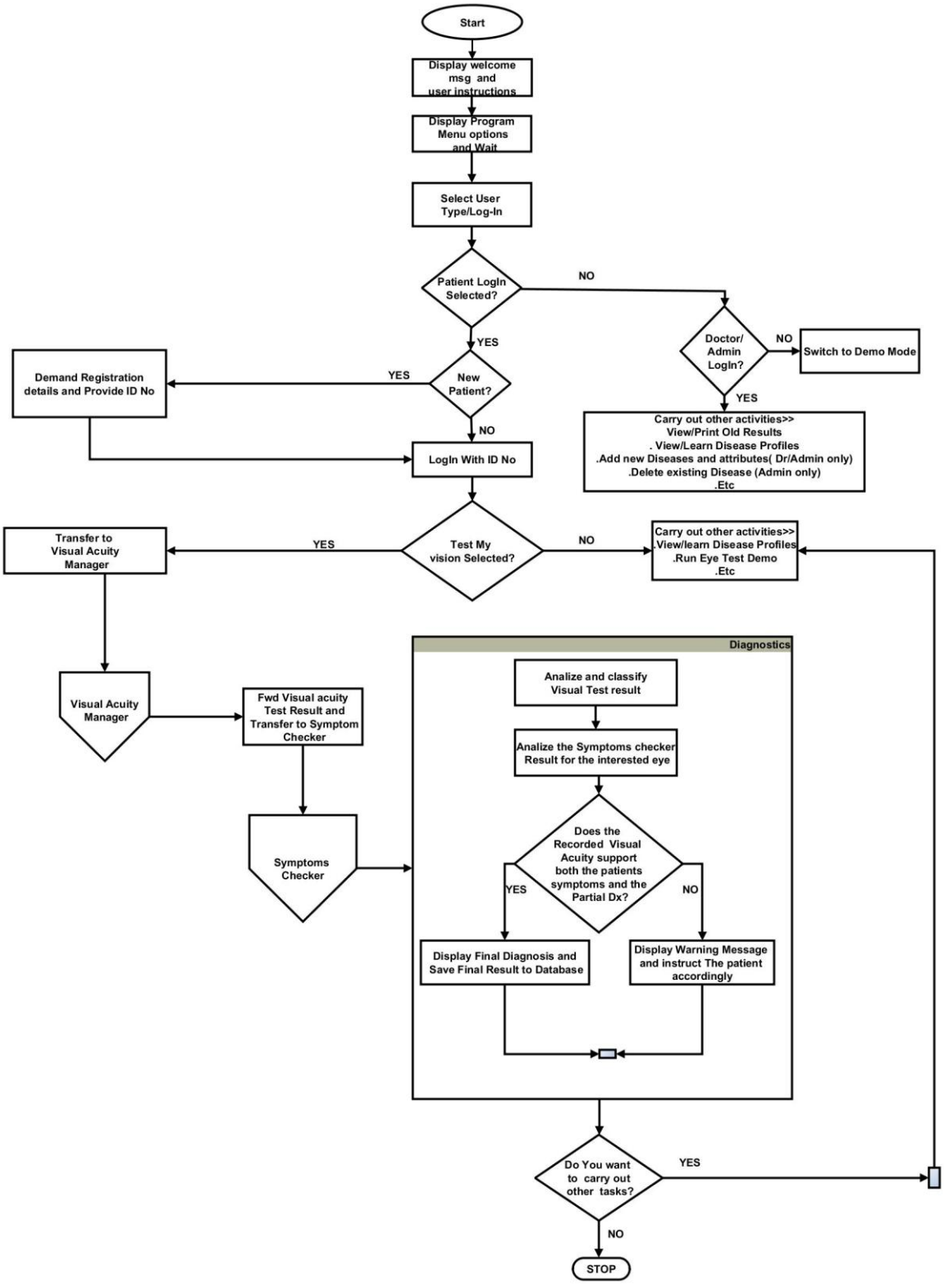


Figure 3.47: System flowchart

CHAPTER FOUR

SYSTEM IMPLEMENTATION

4.1 New System Requirement

Any software program must run under a particular environment. This environment includes both hardware and software environment. These environments have dimensions in terms of minimum configurations necessary to host the software program. The minimum hardware and software requirements needed to implement CFRMFEDD are therefore as follow:

4.1.1 Hardware Requirement

a) System type: x64-based PC

b) Processor: Intel(R) Pentium(R) CPU B960 @ 2.20GHz,

c) Core(s), 2 Logical Processor(s)

d) Physical Memory (RAM): 4.0GB

e) Total physical memory: 3.98GB

f) Total virtual memory: 7.89GB

g) Hard disk drive 100GB

h) USB: Intel(R) USB 2.0 Extensible Host Controller

i) Ports: Serial/Parallel

j) Input Keyboard: Standard PS/2 Keyboard/wireless

k) Input Pointing device: Synaptics PS/2 Port TouchPad/wireless

l) Display Adapter: Intel(R) HD Graphics

m) Display Adapter RAM: 1.76 GB (1,888,380,928 bytes)

n) Screen Color table Entries: 4294967296

o) Screen Resolution: 1366 x 768 x 59 hertz

p) Resolution Bits/Pixel: 32

q) Sound device: PNP

4.1.2 Software Requirement

CFRMFEDD was developed with visual prolog codes. Since visual prolog codes/programs are compiled to bytecodes and thereafter run through a virtual machine, in essence, CFRMFEDD is platform-independent. This implies that compiled visual prolog programs can virtually run in many operating systems as they do not require additional interpreters. However since CFRMFEDD also runs MYSQL codes for database management, it is therefore necessary to have an operating system that integrates the two languages.

Both Visual prolog programming interface (VPI) and MYSQL codes are recognized by windows operating systems, therefore for implementation purposes, the following versions of Microsoft windows operating systems were considered.

a) Windows 2000

b) Windows NT/XP

c) Windows Vista

d) Windows 7

e) Windows 8

f) Windows 8.1

g) Windows 10

Among all the operating systems enumerated above, Microsoft windows 10 was selected as the operating system of choice and used for both the design and actual implementation of CFRMFEDD.

Generally, Microsoft windows operating system have the following features:

a) It has ubiquitous user interface
b) It has multi-tasking features
c) Development will be faster
d) Software support: Windows offers a huge user base to any manufacturer of software. Consequently, majority of commercial and even non-commercial software available are designed to run primarily with Windows. In addition it provides the following possibilities:
    i. Some common libraries (COM, activeX, DLL, etc) can be shared
    ii. User training and adaptation period will be minimal as many users are already familiar with windows platform
    iii. It will be compatible for installation in many user systems
    iv. It will be easier for system upgrade in future
e) Hardware support: windows OS is compatible with the largest combination of PC hardware which includes the following:
    i. Motherboards
    ii. Processors
    iii. Memory chips
    iv. Expansion cards
    v. USB devices
    vi. Internal disk drives of PATA and SATA
    vii. Future devices and standards yet to be designed

f) User familiarity: The concept of windows programming and its usage which has become enshrined in software packages such as EXCEL, WORD, POWERPOINT, ACCESS, PUBLISHER, ONE NOTE, etc, has become very popular amongst various categories of computer users such that any system which lacks an atom of windows-compatibilities is bound to face acceptability challenges.

In fact, in the very words of Cawley et al. (2010), "Windows is a hugely popular OS - and not without reason. While some versions are perhaps not as popular as others, they're all extremely good systems, capable of managing system resources, multitasking and much more".

In addition to the above general features of MS windows, Michael(2014) summarized the new features of windows-10 as follow:

a) Two update modes : User and Admin can allow or lock software upgrades
b) Unified app store: Here windows and windows phone apps are unified into one
c) Modern app windows: The windows desktop takes the looks of modern apps
d) Snap enhancements: The quadrant arrangement permits snapping of 4 apps at a go
e) Multiple desktops view are possible
f) New task view button allows easy switching between open files and desktops.
g) Enhanced Search-the-web tool
h) Recent files button displays lists of recently used files
i) Enhanced Built-in, multi-factor authentication.
j) BitLocker containers: encrypted data can now easily move between devices
k) Enhanced Built-in mobile device management (MDM)
l) Personal and business data can now be separated with ease.

4.2 System Testing

System testing involves the integration of all the modules, interfaces and classes and thereafter deployed in a real life environment. Typically the diagnosis made by the doctors were used to compare with diagnosis generated by the system for the same patients.

4.2.1 Test Plan

Test plan typically involved the unit and system testing and finally testing the system in real life situation using eye center as test environment. The system was tested for functionality, accuracy, reliability and stress/overload.

Unit testing involved the separate testing of individual components of the system which included the modules, classes and interfaces, etc. During the unit testing, almost all the system components worked effectively as expected, however the few errors noticed in some units were corrected and retested until consistent satisfactory result was achieved.

4.2.2 Test Data

An eye center with basic eye examination facility was selected for testing the system. The diagnosis and the visual acuities of patients who consulted the eye doctors were used to compare with the results generated by the system on the same patients. Typically, the test data were extracted from the following sources:

a) 191 Patients
b) 10 eye doctors
c) 1 eye center
d) 20 medical students and Assistants

e) Expected visual acuity and diagnostic results were extracted from the patient's medical folders as recorded by the eye doctors

The system was tested for reliability, accuracy and stress/overload during performance evaluation. Patients below 3 years and those who did not give their consent were excluded from participation.

4.2.3 Actual Test Result versus Expected Test result

In software system testing, the actual result as the name suggests is the real result that was generated from the system while the expected result is the correct known result. Table 4.1 shows the result of system functionality test during which the entire system was tested as a single unit while at the same evaluating its sub-components to ensure that the system met with the aspirations and objectives of the designer.

The test evaluated the following aspects of the program:

- Program start-up
- Logging-in (as a patient and as a doctor/system admin)
- Adding new disease attributes (Signs, symptoms, treatment, risk factors and images)
- Adding new eye diseases
- Deleting existing eye diseases
- Running visual acuity test
- Running symptoms checking/ diagnosis
- Registering new patients
- Changing admin password

Table 4.1: Actual versus Expected tests result

Sno	Test Data	Actual Result	Expected Result
1	Start up	Program Taskwindow (main window) was displayed, then followed by display of Welcome page with relevant user instructions	Program Taskwindow (main window) will be displayed, then followed by display of Welcome page with relevant user instructions
2	Logging-In as a patient	When [Log-In as a patient] sub-menu was clicked, [Patient Log-In] Dialog box was displayed allowing patient to select his name from listbox and then enter his/her ID No or Register if New. When the patient entered correct ID No and hit Ok button, control was transferred to system @ ready mode with the patient's name displayed on top of window task bar and some menu items/sub-items that were irrelevant to patient use were disabled while relevant items were enabled but when the patient entered wrong ID No, his input was rejectedwith appropriatewarning message.	If [Log-In as a patient] sub-menu is clicked, [Patient Log-In Dialog] box will be displayed allowing patient to select his/her name from listbox and enter his/her ID No or Register if New. On hitting Ok button, If ID No entered matches the Patient's name then control will be transferred to system @ ready mode with patient's name displayed on top of window's task bar and some menu items/sub-items that are irrelevant to patient use disabled while relevant items will be enabled, otherwise entered ID will be rejected and the patient informed with Alert icon sign.

3	Logging-In as a doctor/admin	When [Log-In as a Doctor/Admin] sub-menu was clicked, [Doctor's Log-In] Dialog box was displayed allowing the doctor to enter his registered password. When the doctor entered correct password and hit Ok button, control was transferred to system @ ready mode with the doctor's name displayed on top of window task bar and all the menu items/sub-items were enabled but when the doctor entered wrong password, his input was rejected with appropriate alert message.	If [Log-In as a Doctor/Admin sub-menu is clicked,[Doctor's Log-In] Dialog box will be displayed allowing the doctor to enter his/her registered password. On hitting Ok button, If password entered matches the one in database then control will be transferred to system @ ready mode with doctor's name displayed on top of window task bar and all the menu items/sub-items will be enabled otherwise entered ID will be rejected and the patient informed with Alert icon sign.
4	Adding New Disease Attributes (Signs, Symptoms, Risk Factors, Treatment options)	On clicking [Add New Disease Attributes] sub-menu item, [Add New Disease Attributes] dialog box was displayed allowing the user to select the attribute to add. When attempt was made to add already registered attribute, the system rejected entry and prompted the user with appropriate message. However, on successful entering of new disease	On clicking [Add New Disease Attributes] sub-menu item, [Add New Disease Attributes] dialog box will be displayed allowing the user to select the attribute to add. If attempt is made to add already registered attribute, the system will reject entry and prompt the user with appropriate message. On successful entering of new disease attribute and

		attribute and at click of Save button, appropriate message was displayed informing user that addition was successful. Also on clicking [Preview Attribute] button, a drop down list of all the registered disease attribute of the same class was displayed	at click of Save button, appropriate message will be displayed informing user that addition is successful. Also on clicking [Preview Attribute] button, a drop down list of all the registered disease attribute of the same class will be displayed
5	Adding New Disease item	On clicking [Add New Disease] sub-menu item, [Add New Disease] dialog form was displayed allowing the user to select the attributes to add. When attempt was made to add already registered disease, the system rejected entry and prompted the user with appropriate message. On successful entering of new disease and at click of [Update Entry] button, appropriate message was displayed informing user that addition was successful. Also on clicking [Browse Eye Disease] button, a drop down list	On clicking [Add New Disease] sub-menu item, [Add New Disease] dialog form will be displayed allowing the user to select the attributes to add. If attempt is made to add already registered disease, the system will reject entry and prompt the user with appropriate message. On successful entering of new disease and at click of [Update Entry] button, appropriate message will be displayed informing user that addition is successful. Also on clicking [Browse Eye Disease] button, a drop down list of all the

		of all the registered eye diseases was displayed	registered eye diseases will be displayed
6	Deleting existing eye disease	On clicking Delete Existing Eye Disease] sub-menu item, a [password checker] dialog box was displayed. Un successful entering of correct password, a [delete Existing Disease] dialog box was displayed allowing the user to select the disease name to delete from database. Two separate successive confirmatory messages were presented to the user to cancel delete request or to proceed with delete action. On selection of deletable disease and at click of [Delete disease] button, appropriate message was displayed informing	On clicking Delete Existing Eye Disease] sub-menu item, a [password checker] dialog box will be displayed. Un successful entering of correct password, a [delete Existing Disease] dialog box will be displayed allowing the user to select the disease name to delete from database. Two separate successive confirmatory messages will be presented to the user to cancel delete request or to proceed with delete action. On selection of deletable disease and at click of [Delete disease] button, appropriate message will be

		user that deletion was successful. Automatically the selected disease and its linkages were deleted from the database.	displayed informing user that deletion is successful. Automatically the selected disease and any linkages will be deleted from the database.
7	Visual Acuity Checking	On clicking [Visual Acuity Checker] sub-menu item, an instruction page was displayed. On clicking [Ok] button, [Visual Acuity Examination interface] was displayed with one uppercase E facing right orientation. The right eye was occluded, when the user clicked a correct directional button, the E tumbled to another orientation and progressively the size of E was reduced until the minimum size of E is displayed then the test halted and the result was displayed	On clicking [Visual Acuity Checker] sub-menu item, an instruction page will be displayed. On clicking [Ok] button, [Visual Acuity Examination interface] will be displayed with one uppercase E facing right orientation. While one eye is occluded, If the user clicks any of the directional button correctly, the E will tumble to another orientation and progressively the size of E will be reduced until the minimum size of E is displayed then the test will halt and the result

		and saved. On the contrary, whenever the user clicked the wrong orientation button, the system beeped and further clicking of wrong directional buttons terminated the test and visual acuity result was displayed and saved. The process was repeated for the fellow eye.	displayed and saved. On the contrary, if the user clicks the wrong directional button, the system will beep audible sound and continuous clicking of wrong directional buttons will terminate the test and visual acuity result will be displayed and saved. The process is repeated for the fellow eye.

8	Symptoms Checking/Diagnosis	On clicking Symptoms Checker] sub-menu item, an instruction page was displayed. On clicking [Ok] button, [Symptoms checker] interface was displayed with various buttons disabled except the [select eye] radio button. When an eye was selected, the first diagnostic question was displayed and [Yes] and [No] buttons were enabled. Clicking [Yes] or [No] button as a means of answering the question caused further diagnostic questions to be displayed depending on previous answers. The consultation terminated when all the relevant questions were exhausted or when the answers already chosen had led to known diagnosis. Also the user clicked at [Show partial diagnosis] button, he was able to peruse the list of possible diseases that have matching symptoms. At the end of the consultation, the result was saved and control was	On clicking Symptoms Checker] sub-menu item, an instruction page will be displayed. On clicking [Ok] button, [Symptoms checker] interface] will be displayed with various buttons disabled except the [select eye] radio button. When an eye is selected, the first diagnostic question will be displayed and [Yes] and [No] buttons will be enabled. Clicking [Yes] or [No] button as a means of answering the question will cause further diagnostic questions to be displayed depending on previous answers. The consultation will terminate when all the relevant questions are exhausted or when the answers already chosen had led to known diagnosis. Also the user can click on [Show partial diagnosis] button to peruse the list of possible diseases that have matching symptoms. At the end of the consultation, the result will be saved and control is transferred to

		transferred to diagnostic manager. The Diagnostic manager generated the final diagnosis with attached certainty factor	diagnostic manager. The Diagnostic manager will use both the previous results of the visual acuities and the symptoms checker result to generate the final diagnosis with attached certainty factor
9	Registering new patient	On clicking [Register New Patient] sub-menu item, a new patient registration Dialog box was displayed allowing patient to enter his/her biodata. At conclusion of data entry and at the click of [Ok] button a unique ID No was automatically generated and assigned to the user	On clicking [Register New Patient] sub-menu item, a new patient registration Dialog box will be displayed allowing patient to enter his/her biodata. At conclusion of data entry and at the click of [Ok] button a unique ID No will be automatically generated and assigned to the user

		while the entered information was saved into the database.	while the entered information will be saved into the database.
9	Changing Doctor's/Admin Password	On clicking [Change Password] sub-menu item, a [Change Password] Dialog Box was displayed. User was prompted to enter Old Password, New Password and Confirm Password respectively. When the user entered incorrect data as old password and/or when New password and Confirm Password entry were not the same, access was denied and appropriate message was displayed. However, on making valid entries and at the click of [Ok] button the new password automatically was saved.	On clicking [Change Password] sub-menu item, a [Change Password] Dialog Box will be displayed. User will be prompted to enter Old Password, New Password and Confirm Password respectively. If the old password is incorrect and/or both New password and Confirm Password are not the same, then access will be denied and appropriate message displayed to the user. However, on valid entries and at the click of [Ok] button the new password will automatically replace the old password.

4.2.4 Performance Evaluation

The following evaluation tools were used to analyze the results generated by the domain experts (eye doctors) as compared with the actual results generated by the system.

a) Accuracy Test
b) Reliability/Repeatability test
c) Stress overload test

4.2.4.1 Accuracy Test

This test measures the agreement of results generated byCFRMFEDDwiththat generated by domain experts on the same patients and therefore indirectly tests the validity and accuracy of the new system.

To evaluate this test, the diagnostic results generated by the system were compared with that made by the eye doctors on the same patients. Bland-Altman Agreement tool for numerical data was used for analyzing the visual acuity results while Cohen's Kappa agreement tool for categorical data was used for analyzing the diagnostic results.

4.2.4.1.1 Accuracy test for diagnosis

Here the actual diagnosis made by CFRMFEDD was compared with that made by the domain experts on the same patients. From the results collated with respect to the system's performance, using Cohen's kappa analysis of agreement for categorical data, the test of accuracy for the diagnosis made by the new system revealed K-value of 0.827 and rated as almost perfect agreement (Tables 4.2&4.3).

Table 4.2: Cohen's Kappa Cross tabulation for Diagnosis

			Diagnosis by Domain Experts		
			No Disease	Yes Disease	Total
Diagnosis by CFRMFEDD	NoDisease	Count	6.0	1.0	7.0
		Expected Count	1.2	5.8	7.0
	YesDisease	Count	1.0	32.0	33
		Expected Count	5.8	27.2	33.0
	Total	Count	7.0	33.0	40.0
		Expected Count	7.0	33.0	40.0

Table 4.3:Cohen's Kappa Symmetric Measures for diagnosis

		Value	Asymp. Std. Error[a]	Approx. T[b]	Approx. Sig.
Measure of Agreement	Kappa	0.827	0.119	5.229	.000

	N of Valid Cases	**40**			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Since the K value is **0.827** there is "**Almost Perfect Agreement**" (refer to Table 3.4) in diagnosis between the new system (CFRMFEDD) and the domain experts

4.2.4.1.2 Accuracy test for visual acuity measurement

Here the actual visual acuity measured by CFRMFEDD was compared with that measured by the domain experts on the same patients. Using Bland-Altman analysis of agreement for numerical data, the test of accuracy for visual acuity measurement made by the new system revealed P-value of 0.041682(See Figure 4.1 and Table 4.4) which implies that the visual acuity measurement by the new system is significantly accurate.

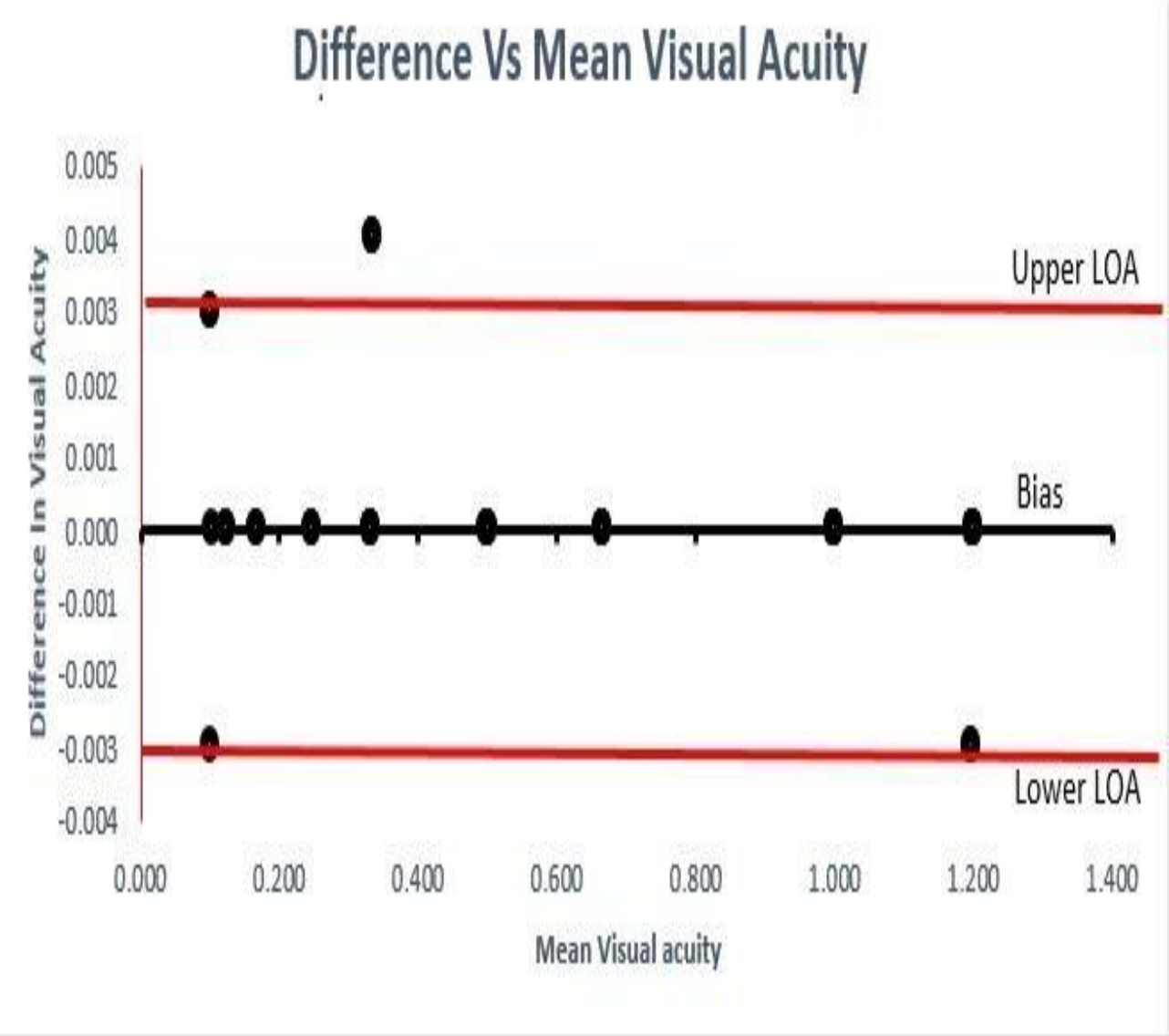


Figure 4.1: Bland-Altman Scatter plot of Difference in Visual Acuity Versus Mean Visual Acuity for accuracy test

Table 4.4: Bland-Altman Analysis of Agreement for visual acuity Accuracy test

Descriptive Statistics on difference in Visual acuity measurement	
Bias (Mean Diff)	0.00013
Standard Dev.	0.00140
Upper LOA	0.00287
Lower LOA	-0.00262
Observations	40

*LOA: Limit of Agreement

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F/ P-Value*
Regression	1	8E-06	8E-06	4.443681	0.041682
Residual	38	6.84E-05	1.8E-06		
Total	39	7.64E-05			

Using Bland-Altman Regression Plot at 95% confidence, P-value = **0.041682**

Since the P-value (**0.041682)** is < 0.05, we could infer that there is no significant disagreement between the visual acuity measured by the new system and that measured by domain experts.

4.2.4.2 **Reliability/Repeatability Test**

This measures the consistency of a machine, instrument or system to produce same result when repeated under the same condition. In this case, it is the degree at which CFRMFEDD will yield the same result when it is repeated on the same patients more than once.

To evaluate this test, a first and second (repeated) visual acuity tests were run with CFRMFEDD on the same patients under the same condition (the same environment and personnel). Bland-Altman agreement tool for numerical data was used for analyzing the visual acuity results of the first test and the repeated test. This revealed P-value of 0.0000375 (See Figure 4.2 and Tables 4.5) which implied that measurements done with the new system are repeatable and reliable.

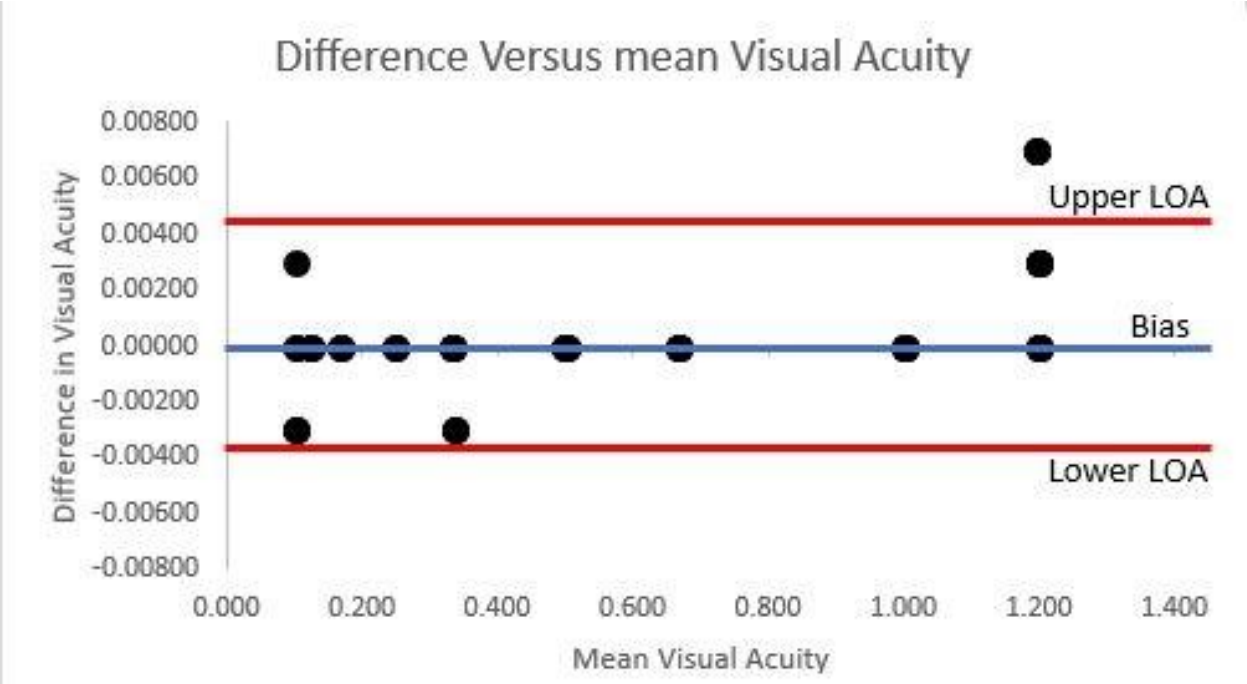


Figure 4.2: Bland-Altman Scatter plot of Difference in Visual Acuity Versus Mean Visual Acuity for reliability test.

Table 4.5: Bland-Altman Analysis of Agreement for visual acuity Reliability test

Descriptive Statistics	
Bias/Mean diff	0. 00035
Upper LOA	0. 004365589
Lower LOA	-0. 003665589
SD	0. 00204877
Observations	60

ANOVA

	Df	*SS*	*MS*	*F*	*Significance F/* ***P-value***
Regression	1	6.34E-05	6.34E-05	19.9386063	**3.75E-05**
Residual	58	0.000184	3.18E-06		
Total	59	0.000248			

Using Bland-Altman Regression Plot at 95% confidence, P-value = **0.0000375**

Since the P-value (**0.0000375)** is < 0.05, we could infer that there is no significant disagreement between the first visual acuity measurement and repeated measurements.

4.2.4.3 Stress/Overload Test

This measures how efficient the system could withstand stress or database overload without failing.

To evaluate this test, the system was used by the medical students, the assistants and the eye doctors on patients from morning till time of close of work daily for 1 working week, registered as many new patients as possible, ran as many eye tests and demos as possible, etc. For each day, the number of hours

used, the number of patients registered, the number of tests done, the number of system failures (if any), etc, were noted. These data were analyzed at the end of the week (Table 4.6).

Table 4.6: Stress/Overload test result

Days	**No of New Registration**	**No of Eye tests done**	**Patients that needed assistance during test**	**No of New Diseases added**	**No of Hrs used**	**No of System failures**	**Remark**
Day1	20	15	15	11	10	1	System hanged due to file read error when user attempted to load **.txt** file as disease image instead of .**jpg** file. This was corrected in code from ***.*** to ***.jpg** so that only jpg files will be loaded
Day2	15	10	13	14	11	0	Nil of note
Day3	18	12	14	10	11	0	Nil of note
Day4	21	12	17	13	12	0	Nil of note
Day5	17	13	13	15	10	0	Nil of note
Total	**91**	**62**	**72**	**63**	**54**	**1**	**Initial error**

							encountered was corrected

As evident from the stress/overload test (Table 4.6), during the 1 week (5-days) system test, a total of 91 new patients were registered, 62 eye tests were done, out of which 72 patients required technical assistance during the test, 63 new eye diseases were added to the database, a total of 54 system hours were used but 1 system failure was recorded. The system failure was as a result of the user (doctor) loading **glaucoma.txt** file instead of **glaucoma.jpg** during addition of new eye disease. This error was corrected from the code by changing file opening parameter from ***.*** to ***.jpg.**

One shall note that system testing and evaluation are cyclic tasks that continue throughout the life cycle of the system. It is interesting to remark that all the bugs, errors and malfunctions noted during the testing and evaluation of the new system were successfully corrected and fixed. In summary, therefore the new system performed as expected.

4.2.5 Limitations of the System

The following system limitations were noted

a. The system requires involvement of medical assistant in most cases
b. Persons under three years and those who are not mentally sound may not effectively be tested with the system
c. The input consoles rely on the standard keyboard and mouse configuration and some category of patients may not visualize these consoles due to button size unless helped by the assistant
d.

4.3 Program Development

Any computer system requires a suitable environment in which to operate. Such environment forms an inevitable part of the program development. One of the most important aspects of this environment is the programming language.

4.3.1 Choice of programming language

The choice of programming language chosen for any system is partly dependent on the task the system is expected to perform. CFRMFEDD is an expert system and therefore requires logic programming. Visual prolog 7.5 was chosen as the programming language while MYSQL was chosen as the database management language.

4.3.2 Language Justification

Visual prolog was chosen as the programming language because it has the following features:

a) It is based on logic programming with emphasis on Horns clause
b) It is highly declarative (Declare WHAT you want and leave the HOW to the inference engine)
c) It is object-oriented.
d) It has programmer-friendly Graphical user interface and menu design tools
e) It is strongly typed.
f) It has algebraic data types.
g) It utilizes pattern matching, instantiation and unification.
h) It has inbuilt controlled non-determinism.
i) It has a fully integrated fact databases.

j) It compiles its program into byte-codes during packing and therefore its generated program is platform-independent.

k) It uses a standard database structure in which facts and rules can be stored to or loaded from a external database.

Since the first release of visual prolog 1.0 in 2010, the language has metamorphosed rapidly through several versions (totaling 10 versions till date) to come to its latest release version 7.5 build in 2015. Visual prolog combines the traditional benefits of Prolog Development Community (PDC) and Turbo prolog with the best features of object-oriented concepts to deliver the best logic programming environment to its user.

Furthermore, MYSQL was chosen as database language due to the following reasons:

a) It is a relational database management system

b) It is windows-OS compliant

c) It is object oriented

d) It can connect effectively to logic programming software such as prolog.

e) It is Open Source software

f) It can handle both small and large amount of Database

4.3.3 Program Implementation Details

In the previous chapter (system design), the various disease attributes such as signs, symptoms, risk factors and treatment plan as provided by the knowledge experts and from the ophthalmology textbooks and journals were used to design the structure of both the knowledge base and the database. In this section, the various attributes are appropriately numbered and coded.

4.3.3.1 Implementing Database Tables

The database Tables designed in chapter 3 is now implemented in Tables 4.7 – 4.13 using MYSQL. Afterwards, the database was connected to visual prolog 7.5 through Open Database Connectivity (ODBC) and finally the Tables were populated with data.

Table 4.7> **Symptoms**_Implemented

Table 4.8> **Signs**_Implemented

Table4.9> **Riskfactors**_Implemented

Table4.10> **Treatments**_Implemented

Table4.11> **Eyedisease**_Implemented

Table4.12> **Certaintyfactor**_Implemented

Table4.13> **Visualacuity**_Implemented

Table 4.7: Symptoms_Implemented

Code	Symptom
001	Sunlight disturbance
002	Excessive tearing
003	Blur distant vision
004	Constant blurring of near vision
005	Constant eye redness
006	Burning eye sensation
007	Eye itching
008	Foreign body sensation
009	Grittiness or sandy sensation

010	Color vision defect
011	Moderate eye pain
012	Severe eye pain
013	Double vision while two eyes are open {diplopia}
014	Dryness of eyes
015	Light glare
016	Black spot in vision which disappears when looked at {Floater}
017	One eye suddenly became blind
018	Excessive blinking
019	Mild to moderate headache
020	Cloudiness of vision
021	Crossing of eyes
022	Constant eye irritation
023	Intermittent eye irritation
024	Eyelid drooping {ptosis}
025	Constant eyelid inflammation
026	General eye discomfort
027	Intermittent eye inflammation
028	Involuntary jerky to and fro movement of the eyes
029	Side vision loss
030	One blind eye
031	Pain on rotation or movement of eye

032	Diminution of vision in one eye
033	Redness of eyelid
034	Intermittent redness of the eye
035	Narrowing of eye or frowning of face to see
036	Difficulty swallowing
037	Dizziness
038	Nausea
039	Bleeding in the eye
040	Bluish hue of part or entire white of eye ball
041	Tingling; pain or loss of sensation in foot and finger {peripheral neuropathy}
042	Recent blurring of distant vision
043	Poor distant vision that have defied spectacles; drugs; surgery {Low vision}
044	Intermittent blurring of near vision
045	Recent blurring of near vision
046	Blurring of near vision that is not correcTable with spectacle drug or surgery
047	Hazy vision at the center
048	Eyelid bump or inflammation
049	Clear near vision
050	Crusting of eyelashes
051	Difficulties in eye movement or double vision
052	Difficulty reading in dim light

053	Pains around the eyes associated with eye movement
054	Difficulty to read near prints without spectacle even though one is below 35 years
055	Trouble using contact lens
056	Double vision in affected eye only {monocular diplopia}
057	Drowsiness/sleepiness when reading
058	Eye deviation {squint/strabismus}
059	Greenish-yellowish eye discharge
060	Stringy or mucus eye discharge
061	Sticky or crusty eye discharge
062	Dense eye discharge
063	Eye fatigue
064	Eye irritation that worsens with smoke or wind
065	Eye pain that starts from moderate then to severe
066	Eye poking habit
067	Eye tenderness
068	Intermittent eyelid inflammation
069	Eyelid tenderness
070	Flashes of light especially in one eye
071	Frequent changes of eye glasses
072	Growth of flesh on white eye that does not extend to the black eye

073	Growth of flesh on white eye that extends to the black eye
074	Image distortion
075	Vision improvement at dusk
076	Vision improvement at near but later gets worse
077	Vision improvement with increased light
078	Inability to recognize faces from distance
079	Twitching or uncontrollable movement of eyelid {eyelid spasm}
080	Inward turning of eyelid
081	Keyhole-shaped pupil
082	Loss of depth perception
083	Loss of night vision that started gradual
084	Loss of side vision that started recently
085	Mis-alignment of one eye at straight gaze
086	Outward turning of eyelid
087	Pain around the eyes
088	Pain in the eyelid
089	Pink eye
090	Poor adaptation to light changes
091	Poor vision at best eye even after exhausting other therapeutic interventions
092	Poor vision at night or dim light
093	Vision problem that started at one eye and later progressed to the other eye

094	Eyeball protrusion or bulging
095	Have reading difficulty unless the print is pushed away from face
096	Red patch on white eye
097	Severe redness of the eye
098	Difficulty in read in dim light but improves with brighter light
099	Roving eye movement
100	Dark spot or flashes of light
101	Color vision challenge and can only see in shades of color
102	Color challenge and can only see in black and white
103	Issues when looking at light source as rings/halos surrounding the light
104	Sensation of having something in the eye
105	Sense of fullness of the eyes
106	Slanting of objects and images
107	Stinging eye sensation
108	Sudden loss of vision in both eyes
109	Swelling of areas surrounding the eyes
110	Transient loss of vision in one eye
111	Incontinence
112	Unequal pupil sizes
113	Visible whiteness between the black part of eyeball and upper eyelid

114	Amurosis fugax
115	Vision problem that started suddenly
116	Occasions of seeing things other normal people don't see {hallucination}
117	Weakness of eye muscles
118	White eye discoloration
119	White spot on the transparent part of the eye {cornea opacity or scar}
120	One-sided throbbing headache
121	Severe headache
122	Headache that worsens with physical activity
123	Slurred/impaired speech
124	Occasions of bumping into object while walking
125	General body muscle weakness
126	Hypertension
127	Inability to carry out activities of daily living
128	Shortness of breath
129	Vomiting
130	Weakness of extremities especially the hand and leg

Table 4.8: Signs_Implemented

Code	**Sign**

001	Against motion retinoscopic reflex
002	Bleeding under the conjunctiva
003	Eccentric fixation
004	Enlarged fundus images
005	Esodeviation inward crossing of eyes
006	Exodeviation outward deviation of eyes
007	Flattened cornea
008	Large eye bulb
009	Minimized fundus images
010	Not available
011	Nystagmus
012	Oblique disc
013	Obvious sharply outlined bright area over the sclera
014	Ocular torticollis
015	Positive lab result
016	Pushing away reading materials
017	Small eye bulb
018	Squinting
019	Steepened cornea
020	White reflex in childs eye
021	With retinoscopic reflex motion

022	Nystagmus
023	Nystagmus in albinism
024	Progressive tunnel vision

Table4.9: RiskFactors_Implemented

Code	Risk factors
001	Absence of the iris
002	Age
003	Age related macular degeneration
004	Albinism
005	Anophthalmia
006	Atherosclerosis
007	Autoimmunity
008	Baby handlers
009	Battens disease
010	Being a woman
011	Being over 60 yrs
012	Bells palsy
013	Bleeding disorder
014	Blockage narrowing of carotid arteries
015	Blood cloth

016	Blood clotting disorder hemophilia
017	Blow trauma to the eye
018	Brain injury
019	Brain tumor
020	Cancer of the eye
021	Cat eye syndrome
022	Cataract
023	Cataract acquired
024	Certain anti-glaucoma drugs acquired
025	Changes in retinal nerve cells
026	Charge syndrome
027	Chemical burns
028	Congenital cataracts
029	Contact lens wearing
030	Corneal disease
031	Corneal trauma
032	Coughing
033	Cross eye strabismus
034	Diabetes
035	Diabetic retinopathy
036	Disorders from relevant extra-ocular nerves

037	Disorders in brain stem nuclei of extra-ocular nerves foville syndrome
038	Disorders in white matter tract connecting the relevant nuclei multiple sclerosis
039	Dorsal midbrain disorders parinauds syndrome
040	Dry eye syndrome
041	Dystonia
042	Elevated blood cholesterol level
043	Extra-ocular muscle problems
044	Eye disease
045	Eye irritation
046	Eye rubbing
047	Eye trauma
048	Eye trauma or surgery
049	Eye tumors
050	Eyelid coloboma
051	Eyelid disorders ie ectropion
052	Eyelid irritation
053	Farmers
054	Fatigue
055	Gender
056	Glaucoma

057	Graves disease
058	Having laser surgery
059	Head nodding
060	Head trauma
061	Heart problems
062	High anisiekonia
063	High blood pressure
064	High anisometropia
065	High cholesterol
066	Hot oven workers
067	Hyperopia
068	Hypertension
069	Hypertensive retinopathy
070	Hyperthyroidism
071	Incomplete development of the optic nerve
072	Advancing age
073	Industrial workers
074	Infection caused by herpes virus
075	Infections
076	Infections around the eye or orbital cellulitis
077	Intra-ocular lens problems

078	Irritants
079	Lack of adequate sleep
080	Lebers amaurosis
081	Long term duration of diabetics
082	Low vitamin-a diet
083	Macular edema
084	Microphthalmia
085	Migraine
086	Morning glory syndrome
087	Mostly older men above 60
088	Mostly young adult women under 40
089	Myopia acquired
090	Not available
091	Narrow filtration angle
092	Nerve infection
093	Neuro-muscular junction problem myasthenia gravis
094	Nystagmus
095	Optic atrophy
096	Orbital tumor
097	Other medical disorders

098	Parkinson disease
099	People within 40-50yrs
100	Physical exertion
101	Pingueculla
102	Poorly controlled diabetics
103	Poorly controlled hypertension
104	Positive familiar genetic history of astigmatism
105	Positive familiar genetic history of myopia
106	Positive family history of same condition
107	Positive family history of amblyopia
108	Positive family history of ARMD
109	Positive family history of coloboma
110	Positive family history of glaucoma
111	Prenatal exposure to certain toxins alcohol
112	Presence of autoimmune disease
113	Prolonged exposure to UV light
114	Pterigium
115	Race
116	Rare blood disorders
117	Renal coloboma
118	Restrictions from the orbit grave's disease

119	Retinal detachment
120	Retinitis pigmentosa
121	Retinitis pigmentosa congenital
122	Short sightedness
123	Sickle cell anemia
124	Side effects of medication
125	Sleep apnea
126	Smoking
127	Sneezing
128	Some eye problems such as glaucoma, ARMD, cataracts, diabetic retinopathy
129	Spasms in retinal blood vessels
130	Straining vomiting
131	Stress
132	Taking medications that cause dry eye
133	Thiamine deficiency
134	Thyroid disease
135	Tobacco smoking
136	Tourette syndrome
137	Toxic envenomation
138	Toxins
139	Trauma in the eye

140	Tumors
141	Ultra-violet light
142	Uncorrected refractive error
143	Undergoing radiation therapy
144	Unequal refractive errors in both eyes
145	Use of alcohol tobacco or coffee
146	Usher syndrome congenital
147	Ushers syndrome
148	Vitamin-a deficiency acquired
149	Weakness of eye muscle
150	Welders
151	Women more affected than men

Table 4.10: Treatments_Implemented

Code	Treatment
001	Anti-cholinesterase; neostigmine
002	Anti-epileptic drugs
003	Anti-malarial medications
004	Anti-rejection medications
005	Anti-VEGF drug for wet ARMD
006	Anti-VEGF eye injections avastin lucentis eylea
007	Anti-viral drugs

008	Antibiotic eye drop
009	Antihistamine and steroids
010	Apply cold compress or ice block
011	Artificial tears and lubricants
012	Artificial tears eye drop
013	Aspirin
014	Avoid night movement
015	Balanced diet rich in anti-oxidants
016	Bed rest
017	Beta blockers
018	Bifocal spectacle
019	Blood thinners
020	CCTV
021	Check and monitor eye pressure on daily basis
022	Clean affected eye regularly
023	Cleaning of eyelid margins with antibiotic solution
024	Conservative treatment
025	Contact lenses
026	Corneal refractive laser surgery
027	Corrective lenses
028	Corrective lenses if due to refraction
029	Corticosteroids

030	Cosmetic masking contact lens
031	Dark filters
032	Dilatation of the eyes for anterior uveitis type;
033	Dilating eye drops
034	Do nothing but monitor
035	Drug injections into the eyeball
036	Early intervention is mandatory to prevent vision loss
037	Elective surgery on patient request or when other remedies have failed
038	Electronic talking devices
039	Elevate head at 40 degrees during sleep
040	Environmental modifications
041	Eye movement training
042	Eye surgery if due to strabismus
043	Filters
044	Fusion training orthoptic exercises
045	Genetic counseling
046	Home remedy
047	Hot compress
048	Immunosuppressive drugs
049	Improve eyelid hygiene
050	Laser photocoagulation

051	Laser surgery for macular edema
052	Laser surgery or therapy
053	Learn to use color cues
054	Low vision for dry ARMD
055	Low vision aids
056	Magnifiers
057	Mobility training
058	No cure treatment is based on vision enhancement only;
059	No treatment except low vision management for congenital nyctalopia
060	No treatment for inherited color blindness
061	No treatment is required if mild; just observe
062	No treatment is required; just observe
063	Non aspirin b NSAIDs
064	Ocular lubricants
065	Pain relief drugs
066	Patch one eye
067	Patch the affected eye
068	Photochromic lenses
069	Photodynamic therapy
070	Pilocarpine or brimonidine to constrict pupil

071	Polaroid or anti-reflective lenses
072	Prescription eye medications
073	Prism glass
074	Proper hygiene
075	Quit smoking
076	Restricted eye movement
077	See an eye doctor immediately
078	See eye doctor if swelling and pain do not subside after few days
079	See eye doctor immediately if condition is not due to trauma blow
080	Seek medical help immediately
081	Special contact lens
082	Spectacle or contact lenses
083	Steroid eye drug to control inflammation
084	Steroid injections into the eyeball
085	Strict BP control only in mild cases
086	Strict sugar control only in mild cases
087	Sun hats
088	Surgery
089	Systemic drugs
090	Systemic steroids may often be used
091	Telescopes

092	Tetanus injection in certain cases
093	Thorough irrigation of eye with clean water
094	Topical antibiotics many times a day if infected by bacteria
095	Topical antiviral many times a day if infected by virus
096	Topical steroids or NSAIDs if not infectious
097	Treat infectious type with appropriate drug such as antibiotics antiviral antifungal etc;
098	Treat non-infectious type with steroid
099	Treat underlying cause
100	Treatment of underlying conditions for acquired nyctalopia
101	Tricyclic anti-depressants
102	Tumor necrosis factor alpha TNF
103	Use topical antibiotics if infectious
104	Vit b12 supplementation
105	Vitrectomy
106	Warm water eyelid massaging
107	Wear special color contact lenses
108	Not available
109	No cure
110	Daily intake of 15;000 iu or 4;5mg of vitamin-a palmitate might help in some cases

Table 4.11: EyeDisease_Implemented

Code	Eye Disease	Symptom Codes	Sign Codes	Treatment codes	Risk Factor Codes
001	Myopia	3, 6, 35	1, 4, 6, 8, 18, 19	25, 26, 82	104
002	Hyperopia	1, 2, 3, 4, 7, 19, 37	5, 7, 9, 17, 21	25, 26, 82	105
003	Astigmatism	1, 2, 3, 4, 7, 19, 37, 106	12, 12, 14	25, 26, 82	31,101,104,114
004	Presbyopia	4, 19, 52, 57, 95	16	25, 82	2, 67
005	Conjunctivitis	1, 2, 5, 6, 7, 9, 59, 61, 68, 93	15	7, 8, 9, 22	89
006	Foreign body	1, 2, 5, 9, 18, 26, 31	10	8, 80, 93	53, 72, 149
007	Cataract	1, 15, 49, 56, 71, 76	3, 11, 18, 20	43, 88	47, 66, 149
008	Floaters	16	10	34, 41	34, 44, 47, 50
009	Corneal abrasion	1, 2, 8, 35	10	8, 33, 43, 65, 92, 93	8, 54, 73, 150
010	Eyelid inflammation	1, 3, 4, 6, 9, 14, 25, 33, 50	10	23, 74, 106	90

	blepharitis				
011	Red eye	1, 2, 3, 4, 5, 18, 26, 31	10	80	90
012	Dry eye syndrome	1, 2, 6, 18, 55, 60, 63, 64, 104, 107	10	12, 72, 81	10, 59, 72, 82, 132, 143
013	Stye	2, 8, 33, 48, 69, 88	10	8, 22, 47	90
014	Entropion	2, 8, 11, 80	10	12, 49, 64, 88	89
015	Blepharospasm	11, 79	10	12, 49, 64, 88	12, 41, 45, 53, 55, 79, 98, 100, 123, 131, 136, 145
016	Glaucoma	3, 4, 12, 15, 17, 38, 108, 121, 124	10	72, 88, 89	91,110,139
017	Black eye	87,109,118	10	10, 46, 78, 79	17
018	Sub-conjuctival hemorrhage	9, 23, 96	2, 13	62	13, 32, 46, 49, 63, 97, 127, 130
019	Amblyopia lazy eye	21, 23, 32, 105	2, 13	28, 42, 44	27, 33, 63, 63, 107
020	Pterigium	6, 7, 8, 27,	10	24, 37, 83	39, 77, 112

		34, 44, 73			
021	Pinguecula	6, 7, 8, 27, 34, 72	10	24, 83	39, 78, 113
022	Diabetic retinopathy	3, 4, 17, 100, 103	10	6, 52, 55, 84, 86, 105	42, 63, 81, 102, 125
023	Hypertensive retinopathy	42, 45, 84, 126	10	6, 51, 85	103
024	Nyctalopia	77, 90, 92	10	14, 59, 100	23, 24, 89, 121, 146, 148
025	Low vision visual impairment	29, 91, 127	10	20, 38, 40, 56, 57, 91	3, 4, 30, 35, 56, 69, 95, 119
026	Strabismus	13, 21, 32, 82, 85	10	27, 44, 73, 88	61,142,144,149
027	Age related macular degeneration armd	1, 10, 47, 74, 78, 98, 116	10	5, 15, 50, 54, 69, 71, 75	64,108,135,141
028	Proptosis exophthalmos bulging eyes	5, 11, 14, 30, 94, 113	10	11, 99	58, 70, 96
029	Color blindness	10,101,102	10	53, 60, 71, 99, 107	47,105,124,128
030	Uveitis	1, 3, 4, 5, 11, 16, 22	10	31, 32, 36, 97, 98	7, 47, 75, 138, 140

031	Scleritis	1, 2, 3, 4, 5, 12, 13, 40, 51, 67	10	36, 90, 96, 98, 98, 99	99,112,151
032	Corneal ulcer	1, 2, 5, 9, 12, 25, 62, 119	10	10, 77, 94, 95, 95	27, 29, 40, 52
033	Hyphema	1, 2, 20, 30, 39, 65	10	16, 21, 39, 61, 61, 63, 76, 83, 99	16, 20, 48, 74, 77, 123
034	Cone-rod dystrophy	10, 28, 29, 66, 75, 83, 99	10	25, 45, 55, 58, 58, 68, 82	9, 80, 105, 120, 147
035	Ophthalmoplegia	3, 4, 13, 24, 36, 53, 58, 125	10	66, 73, 99, 104, 104	18, 19, 36, 37, 38, 39, 43, 76, 85, 93, 118, 133, 134, 137
036	Ocular migraines	1, 38, 70, 110, 120, 122, 129	10	2, 13, 17, 101, 101	25,129
037	Ocular sarcoidosis	1, 3, 4, 11, 97	10	3, 4, 29, 62, 62, 102	2, 56, 106, 115
038	Retinal vascular occlusion rvo	17,115	10	19, 35, 52, 62, 62	6, 11, 14, 15, 34, 56, 62, 65, 68, 83, 116, 126
039	Myasthenia gravis	3, 4, 13, 24,	10	1, 19, 35,	87, 88

		36, 117, 123, 128, 130		48, 48, 52	
040	Iris coloboma	1, 30, 81	10	30, 55, 68, 87, 87	5, 21, 22, 26, 51, 57, 84, 86, 94, 109, 111, 117, 119, 122
041	Aides pupil	1, 15, 54, 112	10	18, 30, 68, 68, 70, 71	92
042	Nystagmus	1, 28, 43, 46	10	25, 55, 68	1, 4, 28, 60, 71
043	Ectropion	2, 5, 6, 14, 22, 86, 89	10	12, 49, 64, 88	90
044	Retinitis pigmentosa	83, 29, 42	24	155,156	106

Table4.12: CertaintyFactor_Implemented

ID	Name	Range	CFValue
1	Unknown	0.00 - 0.20	0.20
2	Maybe	0.21 - 0.40	0.40
3	Probably	0.41 – 0.60	0.60
4	Almost certain	0.61 – 0.80	0.80
5	Definitely	0.81 – 1.00	1.00

Table4.13: VisualAcuity_Implemented

ID (Code)	Range (in Decimal Acuity)	VAStatus
1	1.200 – 0.533	Normal Vision
2	0.667 – 0.211	Mild Vision Loss
3	0.333 - 0.080	Moderate Vision Loss
4	0.100 - 0.036	Severe Vision Loss
5	0.050- 0.015	Profound Vision Loss
6	0.020 – 0.007	Near Total Vision Loss
7	0.010 – 0.00	Total Vision Loss

4.3.3.2 Implementing the Forms and Classes

The various classes are hereby implemented.

4.3.3.2.1 The taskwindow.cl

The taskwindow is the main window object that serves as a container for the entire system. It contains the menu system required for system navigation. The taskwindow is displayed at maximized mode on start up, but could also be minimized. This therefore allows other programs to run concurrently with the system. Some menu items such as Test distance and default certainty factor are set in this window. Taskwindow is implemented by Taskwindow.cl. This is shown in Figure 4.3

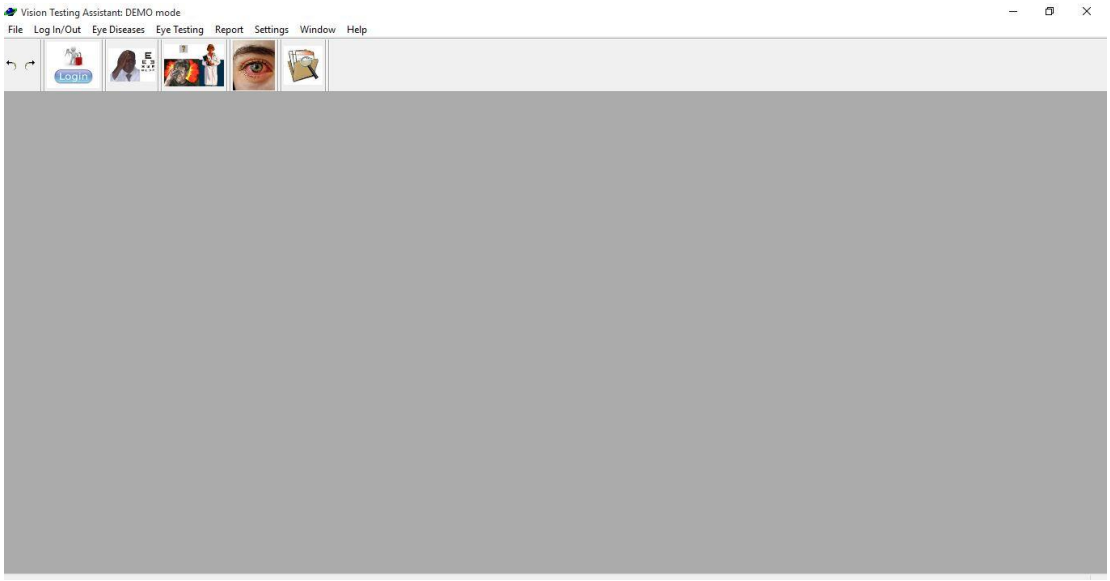


Figure 4.3: The taskwindow panel

4.3.3.2.2 The welcomePage.dlg

It is the duty of the taskwindow to display the welcome page on startup. The welcome page gives the user the initial introduction to the program. Also in order to simplify the complexity of CFRMFEDD, an in-context help format was used. However, the help menu contains further information about the program,

the author and contact directives. The help menu and welcome page were implemented with the form ***welcomePage.dlg***

4.3.3.2.3 *addNewDiseaseAttributes.dlg*

Data values for signs, symptoms, risk factors, treatment and diseases are added by the system administrator or eye doctor. To add these disease attributes, a special predicate, **tryToRegisterNewAttributesIntoDB(),** alias **AddNewDiseaseAttributes**manager is invoked which in synergy with two other predicates **createNewAttribute**() and **assertSymptomToDB**() will extract the relevant data entered by the administrator (user) and automatically append them into the appropriate sections of the database. This is implemented with the form ***addNewDiseaseAttributes.dlg***.

4.3.3.2.4 *addEyeDisease.dlg*

New eye disease must be added into the database before it is referenced in the system. The disease attributes which include signs, symptoms, risk factors and treatment are selected from list boxes. This is implemented with the form ***addEyeDisease.dlg.***

4.3.3.2.5 *bioDataForm.dlg*

New patient must register if he wishes to carry out any eye examination. This is implemented with the form ***bioDataForm.dlg***. During registration, biodata information are entered. On successful registration, a unique patient ID No is automatically generated and consequently assigned to the patient with a congratulatory message.

4.3.3.2.6 *patientLogIn.dlg*

A patient must log-in appropriately before using the system. This is implemented with the form ***patientLogIn.dlg***. Mismatch entry or wrong login input will provoke error message as shown.

4.3.3.2.7 *askDialog.dlg*

To be able to update the database, the user must first login as a doctor or system administrator. This is implemented with the form ***askDialog.dlg***. Updating database involves tasks such as adding new disease, symptoms, signs, risk factors, treatment options, deleting existing disease, etc. During login entry, the password entered is masked by the system with "****".

4.3.3.2.8 *dlgTestMyVision.dlg*

One of the fundamental functions of CFRMFEDD is to enable the user access the quality of his/her vision by carrying out visual acuity testing. This is implemented with the form ***dlgTestMyVision.dlg.***

4.3.3.2.9 *symptomsChecker1.dlg*

Another fundamental function of CFRMFEDD is to diagnose eye disease condition by allowing the user (patient) register his/her symptoms. This is achieved through series of guided differential diagnostic questions by which the patient is expected to select the suggestions made by the system that match his/her symptoms. This is implemented with the form ***symptomsChecker1.dlg***

4.3.3.2.10 *diagnostics.dlg*

The certainty factor represents the degree of confidence provided by both the patient and the doctor on the information they have provided. Certainty factor for the disease/rule/hypothesis is retrieved from the

knowledge base as provided by the doctor during knowledge acquisition while another certainty factor for the symptom/fact/evidence is provided by the patient during consultation session. The final combined probability or certainty factor is used together with the symptoms provided by the patient to make diagnosis. If the final CF is below a goal level, diagnosis will be halted otherwise diagnosis will proceed to conclusion. Concluded diagnosis must indicate the degree of associated certainty. Diagnosis with certainty factor is implemented in CFRMFEDD with the form ***diagnostics.dlg.***

4.3.3.2.11 *deleteManager.dlg*

Deleting existing eye disease from the database requires administrative permission. Only system Admin/doctor can carry out delete request. Also deleting any eye disease automatically deletes all references to that disease including the link address to the image location in the file. This is implemented with the form ***deleteManager.dlg.***

4.3.3.2.12 *browseEyeDiseases.dlg*

Often the patients and clinical students might be interested in learning about eye diseases along with their associated pictures, symptoms, signs, risk factors and treatment options. This request can also be invoked when “partial diagnosis button” is clicked during symptoms checking or when “show disease button” is clicked from the medical report form. Browsing eye disease is implemented with the form ***browseEyeDiseases.dlg***.

4.3.3.2.13 *browseDiseaseAttributes*

Often the doctor or the system admin may want to view the list of eye disease-attributes such as signs, symptoms, risk factors and treatment plans stored in the database. At the same time this information is not necessary for patient’s knowledge as it may lead to clamming of symptoms and consequent forgery

and/or memorization of symptoms. Consequently, the user must log-in as a doctor or system admin in order to view these information. This view is implemented with the form ***browseDiseaseAttributes.dlg.***

4.3.3.2.14 *myReport.frm*

All the tests undergone by each patient over a period of time can be viewed in a multi-page format. A patient can only view all the reports that concern him/her but could not view other patients' report. However, only the doctor/system admin has global view privileges of the entire tests and reports. This is enforced by patients logging in with their names and ID no. Also the reports can be printed out in hard copy. The report viewing and printing is implemented with the form ***myReport.frm.***

4.3.3.2.15 *changePassword.dlg*

It is possible that important database facts could be deleted or tampered with un-intentionally by unguided user or intentionally by a malicious user. In order to avoid such occurrences, access to critical segment of the system is protected with password. Only the doctor or system admin has the privilege or right to update, delete or modify the database. The doctor or system admin can therefore change his/her password at will as to ensure adequate data security at all times. The password management is implemented with the form ***changePassword.dlg.***

4.3.3.2.16 *routine.cl*

Some group of codes perform similar tasks routinely and repeatedly in various classes. For program efficiency, all repeatable codes, often called codes and codes that perform similar but not exactly the same tasks are packaged into a special class with relevant predicates for each service type. Classes request and retrieve desired computations from the routine via parameterized arguments. Routine tasks are implemented in routine.cl

4.3.4 Logic Programming

This is a programing paradigm that is rooted in formal logic which expresses facts as statement and rules as clauses to form set of sentences. It uses the techniques of first order predicate logic to represent knowledge, prove theory and satisfy a given goal. A special type of clause known as Horn clause (or definite clause) was copiously used during the program development. The Horn clause is composed of a Head and a Body, in which the head represents the inference or conclusion while the body represents the condition. Fact is also regarded as rule without a body in its simplest form. Rules and facts are also means of knowledge representation.

With the help of alphabets (variables, constants, symbols, connectives and quantifiers), axioms, facts and rules, logic programming is able to make inferences from given conditions.

Rule is represented with Horn clause as follow.

ruleName (0 or N Arguments):- fact_A (Arg, ..), LOGICAL OPERATOR, rule (Arg, ..).

In Horn clause-sentence, the LEFT side of the colon (:-) is the HEAD (also known as the logical CONCLUSION or INFERENCE) while the RIGHT side is the BODY (or the logical CONDITION). If the BODY is TRUE then HEAD is TRUE otherwise HEAD is FALSE.

Fact is represented as follow:

predicateName (0 or N Arguments).

Fact is always TRUE.

NOT is represented with the symbol "!", which serves as a negation of fact

An example of Horn clause using symptomAndCode()***fact,*** *getSymptomAndCode* ***predicate*** *andconvertSymptomCodesToList****() rule*** as applied in program code is as follow.

```
symptomAndCode("Dizziness",37).                    % Fact

getsymptomAndCode(Symptom, Code):-          % Predicate

        symptomAndCode(Symptom, Code).

convertSymptomCodesToList([],[]). % terminating base clause/rule


convertSymptomCodesToList([HeadSymCode|TailSymCode],[HeadSymList|TailSymList]):-  % Rule/Clause

      foreach BL = taskwindow::tryGetDiseasesAndSymptoms(), BL:getSymptomAndCode(HeadSymList,

                HeadSymCode) do %

                   strVariable:=HeadSymList

        end foreach,

      HeadSymList=strVariable,

  convertSymptomCodesToList(TailSymCode, TailSymList).
```

In the aboveprogram sample, SymptomAndCode() is a 2-nary argument **fact** which contains a symptom andits code, getSymptomAndCode() is a 2-nary **predicate**which gets this fact from database and then passes it on to a **rule** convertSymptomCodesToList() which uses a search argument to correctly return an equivalent code of any given symptom. The rule uses recursion to evaluate each member of the list until it gets a matching argument and then returns the code accordingly.

Using logic programming during the program development has the following advantages:

a) Knowledge representation does not depend on the implementation
b) Knowledge can be separated from the codes such that changes in machine architecture will not affect the underlying code.
c) Higher-order or meta-level knowledge can be represented at ease
d) It can be applied in non-computational tasks that require reasoning

4.3.5 **Program Testing**

This is code-level testing of the program which involves running a program with intention of finding bugs or to verify and validate that the program runs as it was intended or that the program has met the earlier specifications noted during the program design. The following testing strategies were used.

i) Static testing: Under this testing, the program is in static mode or is not running (not executing). During this stage, the program design, the program codes and other important documents were reviewed to ensure that they are accurate, consistent and did not contain any bug or logic errors.

ii) Dynamic testing: Under this testing, while the program is left running (or in execution mode), fictitious and invalid entries were intentionally made to verify whether the system will detect these errors or whether it will fail to detect it (evidence of bugs) as shown in Figures 4.4- 4.6.

Character Input error: In this stage, characters were typed where only digits are required or digits were typed where only characters are required. The system was observed to see what would happen.

Command click error: In this case, wrong command keys were clicked when they are not required. Again, the system was observed to see what would happen.

Password testing: Wrong passwords were intentionally entered to see whether the system will be cracked.

File opening error: In this case, during addition of new eye disease which requires a bmp file for selection of disease image, a non-bmp file was selected. The system was observed to see what would happen.

CFRMFEDD was tested in both static and dynamic mode. At the end of the program testing, some errors and bugs were encountered but were summarily corrected and fixed. The program finally worked as designed.

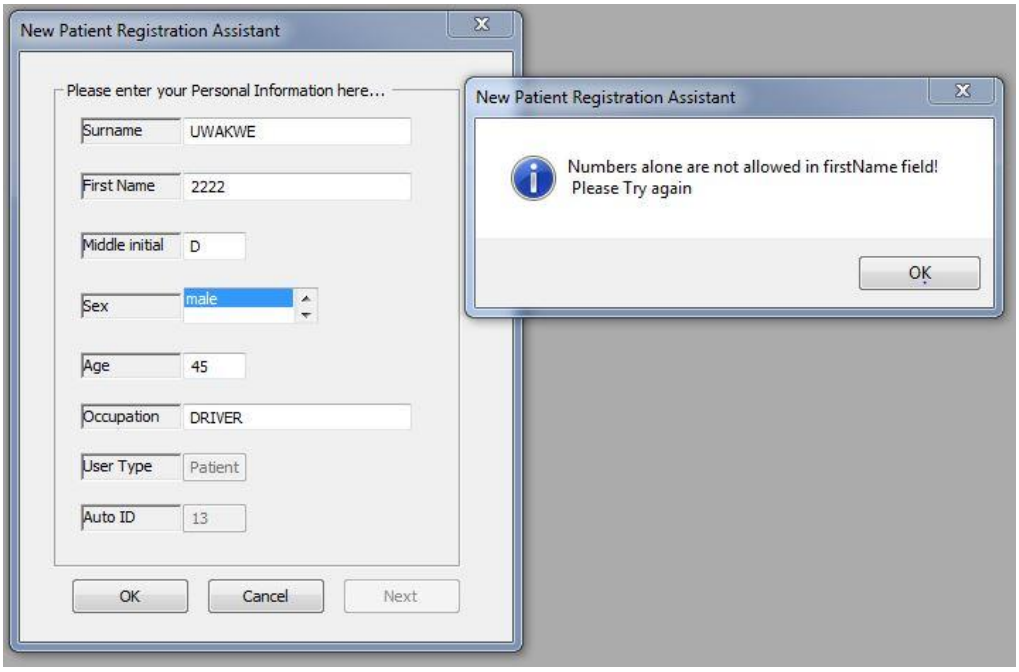


Figure 4.4: Testing character input bug

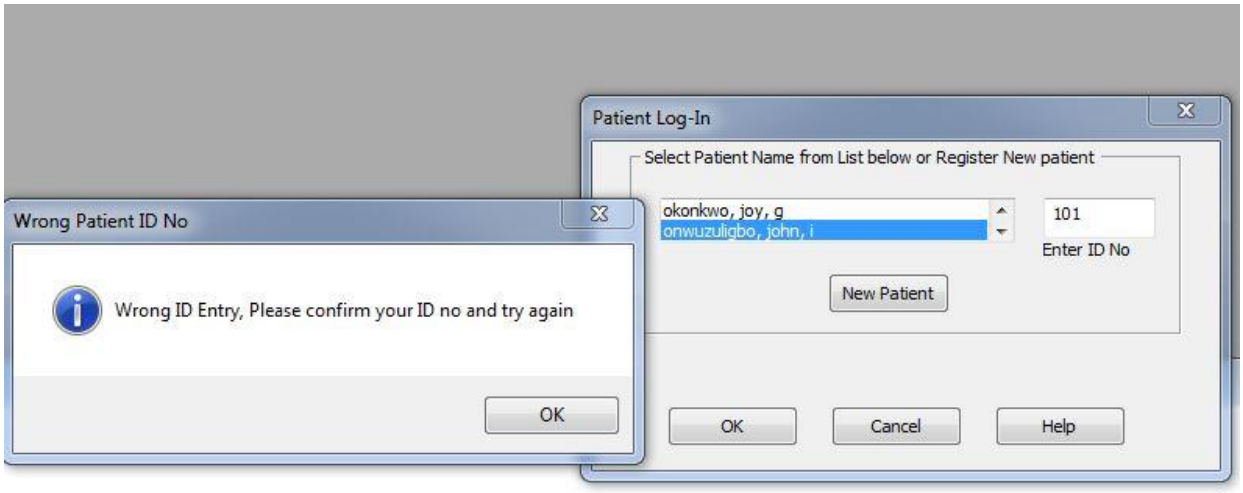


Figure 4.5: Testing Patient ID input

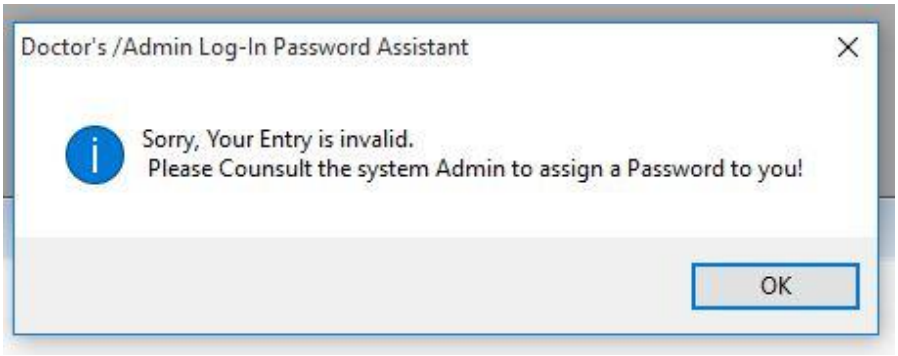


Figure 4.6: Testing Doctor's/Admin Password entry

4.3.6 Change over procedure

This is the process of converting from existing system to the new system. Some of the popular change over techniques are.

i. Direct change over
ii. Phase change over
iii. Parallel change over
iv. Pilot running

Out of the four options above, parallel change over procedurewas chosen as both the existing and new system would be made to run concurrently until when the existing system would be finally laid off. This includes duplicating data in both systems so that failure of new system will not cause catastrophic damage and recovery will be easier.

4.3.7System Maintenance

Maintenance is an integral part of system development life cycle. As the world keeps changing, so are the ways we do things. A system such as CFRMFEDD is a logical living project which must stay in tune with time. In the field of medicine, new diseases are discovered almost on daily basis and so are the treatment. Also as users continue to use CFRMFEDD, some bugs which hitherto were not discovered may tend to manifest with time. As the researcher continues to review this work, faster and better ways of data processing and presentation will become inevitable. All these expected changes and future development in the areas of expert system technology and artificial intelligence will therefore make it inevitable that this maiden version of CFRMFEDD will not last forever. Therefore, there will be need for version upgrade in future so as to reflect the changes in our changing world, views, medical knowledge, etc. The anticipated changes may affect the contents of current modules, database, rules and inference engine used in the design of this work.

4.4 System Security

System security includes all the structures built into the system to prevent malicious damage, intrusion or inadvertent use. System security applied was based on the following philosophy:

a) **Data security**: Important files, database and data are shielded from damage and corruption. Changes in database and objects are reserved for high-end users who understand the internal workings of the system.
b) **Patient's protection**: Medical information are made confidential by preventing access from other patients but permitting access to doctors and system administrators hence protecting patient's privacy.
c) **Enforcement of View privileges:** A user is permitted a system view that is relevant to him/her while at the same time hiding other patient's data from view.

d) **Log-in monitoring**: Usage is being monitored as only registered users can use the system effectively.

System security was implemented by using the following security tools:

i] **Log-in with Password**: Password is required only when the user wants to update database objects and data items or execute any of reserved system tasks. Since these tasks are critical in the system performance, only system admin or doctor is allowed access to these facilities. Such reserved tasks include the following:

a) Adding new symptoms
b) Adding new signs
c) Adding new risk factors
d) Adding new treatment plan
e) Adding new eye disease
f) Deleting existing eye disease
g) Viewing symptoms list
h) Viewing all the patients' medical records and test reports
i) Running visual acuity test or symptoms checkingon stand-alone mode without saving test result

Ii] **Log-in with unique ID No**: Any user who uses the system solely for running eye test is regarded as a patient and therefore must first register as a New Patient during which a unique Id No will be issued to him/her and subsequently can log-in with this No. The following views and tasks are permitted at patient-mode.

a) Registering as new patient
b) Viewing Signs list

c) Viewing risk factors list

d) Viewing treatment plan list

e) Running eye diagnostic suites (which includes both visual acuity checking and symptoms checking) with automatic saving of test result.

Iii] **Demo mode**: A user who did not log-in with password or ID No is regarded simply as a visitor and therefore can only navigate the system in demo-mode. This mode permits restricted views and tasks as follow:

a) Viewing Signs list

b) Viewing risk factors list

c) Viewing treatment plan list

d) Running visual acuity test at stand-alone mode without saving the test result

4.5 Training and Documentation

CFRMFEDD is easy to use and also user-friendly. However, since the system is event-driven, the following instructions are given based on the tasks (events) the user wants to perform. The system documentation includes the following user guide.

a) Loading and running eye test

b) Updating the database

c) Carrying out miscellaneous tasks

1 >> LoadingCFRMFEDD

- Click CFRMFEDD icon from the desktop

- A welcome page will show

2 Registering as a new patient

- @[Log-In/Out] menu, Click [Add New Patient…]
  - [New Patient Registration Assistant] form will show
  - Enter your Bio data information as requested
  - Click OK to Save and Exit form

3A] Logging-In as a PATIENT

- @[Log-In/Out] menu, Click [Log-In as a Patient]
  - [Patient Log-In] dialog box will show
  - If you are a NEW patient, click [New Patient] button and follow instruction
  - If you are OLD patient, Select your name from the list and Enter your ID No
    - Click Ok button to close dialog box and continue

3B] Logging-In as a DOCTOR

- @[Log-In/Out] menu, Click [Log-In as a Doctor]
  - [Doctor Log-In Assistant] dialog box will show
  - Enter your password as appropriate
  - Click Ok button to close box and proceed or Cancel button to go back

4. Running Eye Test as a PATIENT

- @[Eye Testing] menu, Click [Test my Vision as a Patient]

4a] **Running Visual Acuity Testing**

i. Visual acuity Instruction page will show, click Ok button to proceed

ii. Visual Acuity Test Form will show and uppercase E will be displayed with Beep

iii. Position yourself 3m away from the screen

iv. Close your left eye to test the RIGHT EYE

v. If the eye is blind or have low vision click [Skip this Eye] button

vi. Click arrow button that has the same orientation with displayed-E (with wireless mouse, extended cord mouse or human assistant)

vii. Orientation of E will change with a Beep

viii. Continue to click appropriate arrow key as you hear a beep or as E changes orientation and/or size

ix. When you did not see or cannot identify the orientation of E, click [NOT SEEN] button

- The system will automatically stop and score you as you click wrong arrow keys or [NOT SEEN] button for a number of times.

x. Click [Next Eye] button to test the fellow eye

xi. Repeat step (iv) to step (viii) for LEFT EYE

xii. Click [Quit and Save] button to save your test and proceed

- A message will appear informing you that your work is saved and that you are being transferred to symptoms checking Assistant

4b] Running Symptoms checking

Symptoms checker form will automatically display

A question will be displayed automatically. Your response shall be YES or NO.

iii. Select the eye you have complaints>> the options are Right, Left or Both

iv. Click [Next Question] button for next question to be displayed.

v. Continue answering questions until the system automatically stops

vi. You can preview interim/partial diagnosis by clicking [View Partial Diagnosis] button

vii. Click [Save and Exit Expert] button to proceed to final stage of diagnosis

viii. A message box will appear informing you that your test is now saved and is forwarded to Diagnostic Manager for final diagnosis.

ix. Or click [Discard Entry and Restart] button to discard all your previous choices and start symptoms checking afresh.

x. Or click [Cancel] button to exit the form without saving.

4c] Running Final Diagnosis with certainty factor

Diagnosis report will be automatically displayed by the diagnostic manager indicating the strength of the diagnosis with a certainty factor.

i. Click [View/Learn above diseases] button to view the attributes of the diagnosed eye disease.

ii. Click [Ok] button to close and exit the diagnosis report.

5. Running Eye Test as a Doctor

Running this mode does not allow you to save any test result to database but is only meant for academic and learning purposes (for medical students and resident doctors).

i. Repeat instructions in steps 4a or 4b above

6. Running Eye Test in Demo mode

Running this mode does not save any test result to database but is only meant for training you (patient) on how to carry out visual acuity test with the system.

i. Run step 4a (steps 4b and 4c are not enabled under this mode!)

7. Updating the database

Updating the database is only enabled for Doctor/System admin and includes the following tasks:

i. Adding new symptoms
ii. Adding new signs
iii. Adding new risk factors
iv. Adding new treatment plan
v. Adding new eye disease
vi. Deleting existing eye disease

7a] Adding new Disease attributes (steps)

1. Log-In as a doctor
2. Click File>>System Admin>>Update Database>> [Add New Disease Attributes…]
    a) Add New Attributes Form will show
3. To add new symptom
    a) Select Symptom from the pull down List box
    b) Enter the new symptom name in the name field
    c) Press preview button to see list of symptoms already in the database
    d) Click [Save] button to save your entry and exit

4. To add new Sign
    a) Select Sign from the pull down List box
    b) Enter the new Sign name in the name field
    c) Press preview button to see list of Signs already in the database
    d) Click [Save] button to save your entry and exit
5. To add new Risk Factor
    a) Select Risk Factor from the pull down List box
    b) Enter the new Risk Factor name in the name field
    c) Press preview button to see list of Risk Factor already in the database
    d) Click [Save] button to save your entry and exit
6. To add new Treatment plan
    a) Select Treatment from the pull down List box
    b) Enter the new Treatment name in the name field
    c) Press preview button to see list of Treatment plans already in the database
    d) Click [Save] button to save your entry and exit

7b] Addingnew Eye Disease (steps)

1. Log-In as a doctor
2. Click File>>System Admin>>Update Database>> [Add New Eye Disease…]
    a) Add New Eye Disease Form will show
3. Enter name of the new eye disease
    a) You may wish to click [view eye disease] button to see list of eye diseases already in the database so as to avoid duplication. Although the system will not allow duplicate names!
    b) Click [Save disease name] button to save your entry

4. Select Symptoms from the symptoms section and click [Save Symptoms]
5. Select Signs from the Signs section and click [Save Signs]
6. Select Risk factors from the Risk Factors section and click [Save Risk Factors]
7. Select Treatment from the Treatment section and click [Save Treatment]
8. Click [Select image] button to select the disease .Bmp image from a file location
9. Click [Update Entry] button to save and close form

7c] DELETING existing Eye Disease from database

WARNING: Diseases DELETED from database cannot be reversed!

1. Log-In as a doctor or system admin
2. Click File>>System Admin>>Update Database>> [Delete existing Eye Disease …]
    a) A log-in Password dialog box will show
    b) Enter your Admin password and click [Ok] button to Confirm request

    Delete disease manager/form will show
3. Select the Name of disease you wish to delete and click [Delete disease] button
    a) A first warning message will be displayed and allows you to cancel action or proceed
    b) If you click [Ok], asecond warning message will be displayed but also allows you to cancel action or proceed
    c) If you still click [OK] then the requested Disease will be deleted permanently from database.
    d) A message informing you that your request was successfully executed will be displayed.

8) Browsing eye diseases and Disease Attributes (steps)

To browse eye diseases:

1. Click Eye Disease >>
2. To see list of Eye disease and associated details, click [Browse Diseases..]

To browse diseases attributes (Signs, symptoms, Risk factors, treatment):

3. Log-In as a doctor or system admin
4. Click Eye Disease >>
5. To see list of Symptoms, click [Browse Symptoms List..]
6. To see list of Signs, click[Browse Signs List..]
7. To see list of Risk factors, click [Browse Risk Factors List..]
8. To see list of Treatment, click [Browse Treatment List..]

9) Viewing and/or Printing Reports (steps)

To View/Print a particular patient's Test results

1. Log in as a Patient
2. Click [Report] >> [View my Case Report..]

   Test Report Form will be displayed along with the results if you have undergone eye test for at least once
3. Click [Next Report] or [Previous Report] button to view appropriate reports
4. Click [View Disease] button to view the details of any highlighted disease
5. Click [Print Report] button to print out current report page

To View/Print all the patients' Test results

6. Log in as a Doctor
7. Click [Report] >> [View Others Case Reports..]

   A patient Log-In Form will be displayed

8. Select the patient to view from the displayed list
9. Click [Ok] button to close form and display Test Report Form
10. Repeat steps 3-4 above.
11. Click [Exit] button to close Report form

10) Setting the Test distance (steps)

The standard test distances for eye test are 6m, 3m and 1m. The default setting for CFRMFEDD is 3m.

To change the test distance from values other than default, take the following steps:

1). Click [Settings] >> [Test Distance Settings…]

Settings Options dialog box will display 3m, 1m and 6m in this order

2). SelectDistance of your choice and the box will close at your click.

4.6 Results and Analysis

The result of this dissertation represents the program output of CFRMFEDD. This is analyzed in figures 4.7-4.51. The welcome page(See Figure 4.7) is the first point of contact and interface with the user. It displays the menu from which the user can select the action he wants to execute. But most importantly, it describes briefly the purpose of the program and what the user is expected to see. The page is plain and devoid of distraction so that user may concentrate on message content. The message is displayed by using on-the-fly message box control which is closed by the user by simply clicking the <Ok> button. One of the good features of CFRMFEDD is its ability to update its database as new diseases and symptoms emerge without recoding the program. It is the duty of the doctor or system administrator to add or remove disease attributes such as signs, symptoms, risk factors, treatment, etc as the need arises. Also to protect un-intended deletion of knowledge base facts, the user must log-in as a doctor or system admin in order to add new disease attribute.

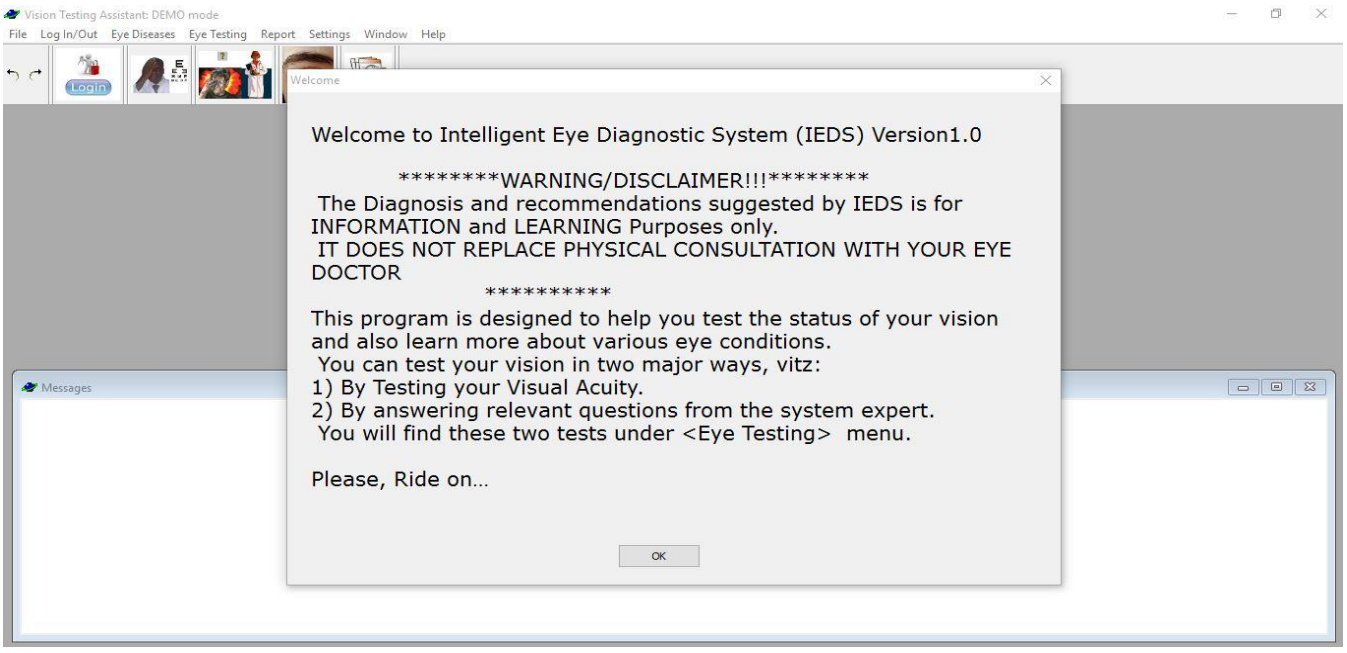


Figure 4.7: The Welcome page

In Figures 4.8 a user wanted to add new symptom by first selecting <symptom> as the attribute. Having selected <symptom>, the system provided an input box where the user can enter the <symptom name>. To avoid duplication of symptoms which however must later fail, the system provided a pull down list-box to enable user peruse all the symptoms that are already stored in the database (See Figure 4.9). Finally, new symptom entry was accepted with congratulatory message informing the user that his/her request was executed successfully (See Figure 4.10)

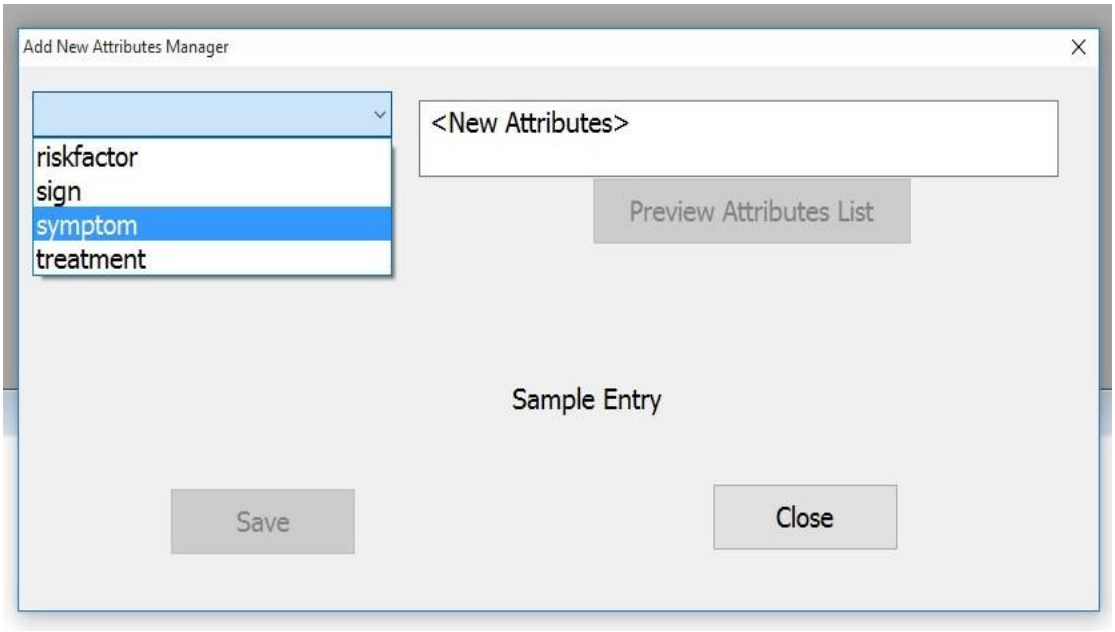


Figure 4.8: Selecting symptom as the disease attribute type for adding symptom into database

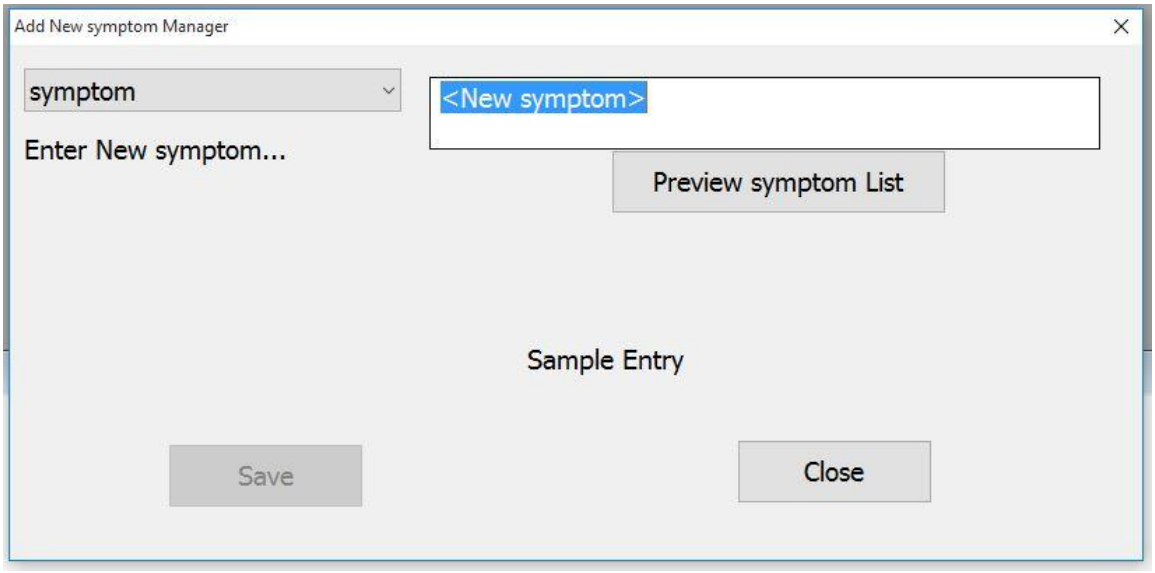


Figure 4.9: Entering new symptom into the database

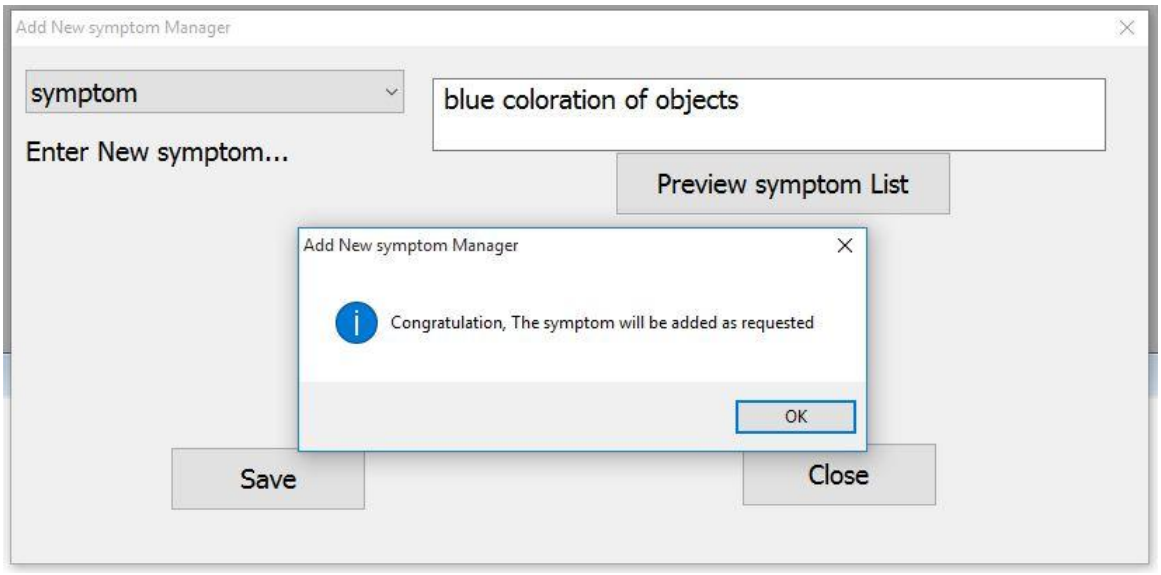


Figure 4.10: Successful addition of new symptom into database

Only doctor or system admin can add new disease into the knowledge base. Adding new eye disease involves linking all the attributes associated with the new disease such as the signs, symptoms, risk factors, treatment and disease images. However, the system must ensure that diseases are not duplicated in the database. Therefore, when the user enters a new <Disease Name>, the system searches its database to rule out duplication. If duplication attempt was trapped, the user will be prompted accordingly and allowed to change to another name. However, a pull-down list-box is provided so that user can browse all the disease names in the database. In Figure 4.11, a user wanted to add <glaucoma> as new eye disease. System check for duplication was negative hence the system then allowed the user to link all the necessary glaucoma attributes, starting with the symptoms and ending with the images. It is to be noted that no new attributes could be entered at this stage, therefore only pull down list-boxes for various attributes were presented and the user could only have to select from the list. The disease image was selected from a file in a given memory location.

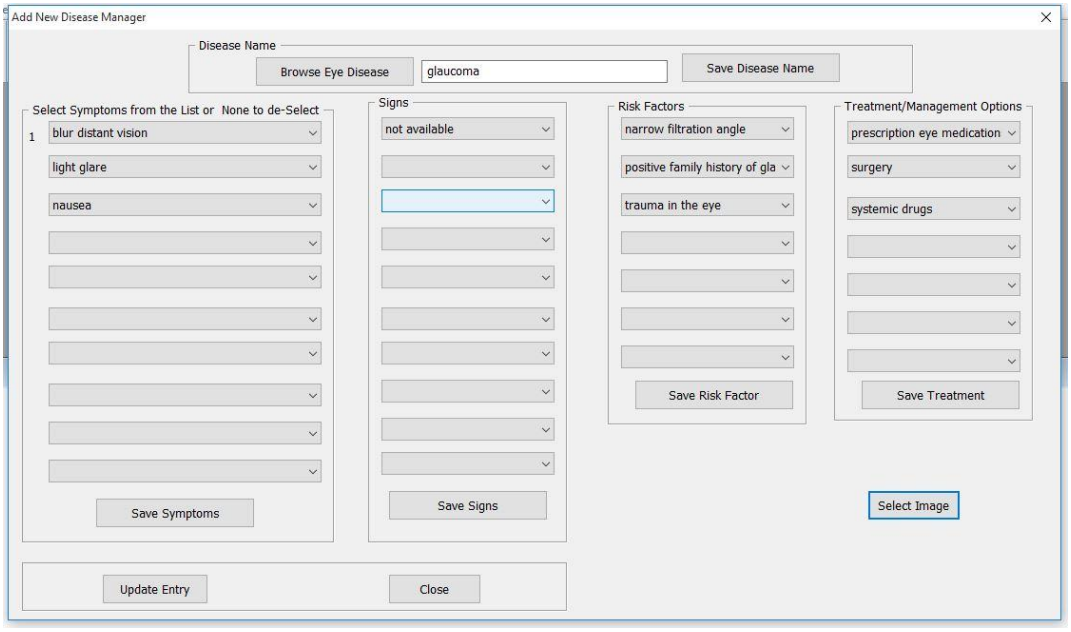


Figure 4.11: Adding new eye disease to database

In order to add new eye disease, the user is given opportunity to add the disease image as well. However, if the disease image is not readily available at the time of addition, the system will use object mask as image place holder. The user must have saved the desired disease image as.bmp file in a known memory location before a successful addition could be made as shown in Figure 4.12.

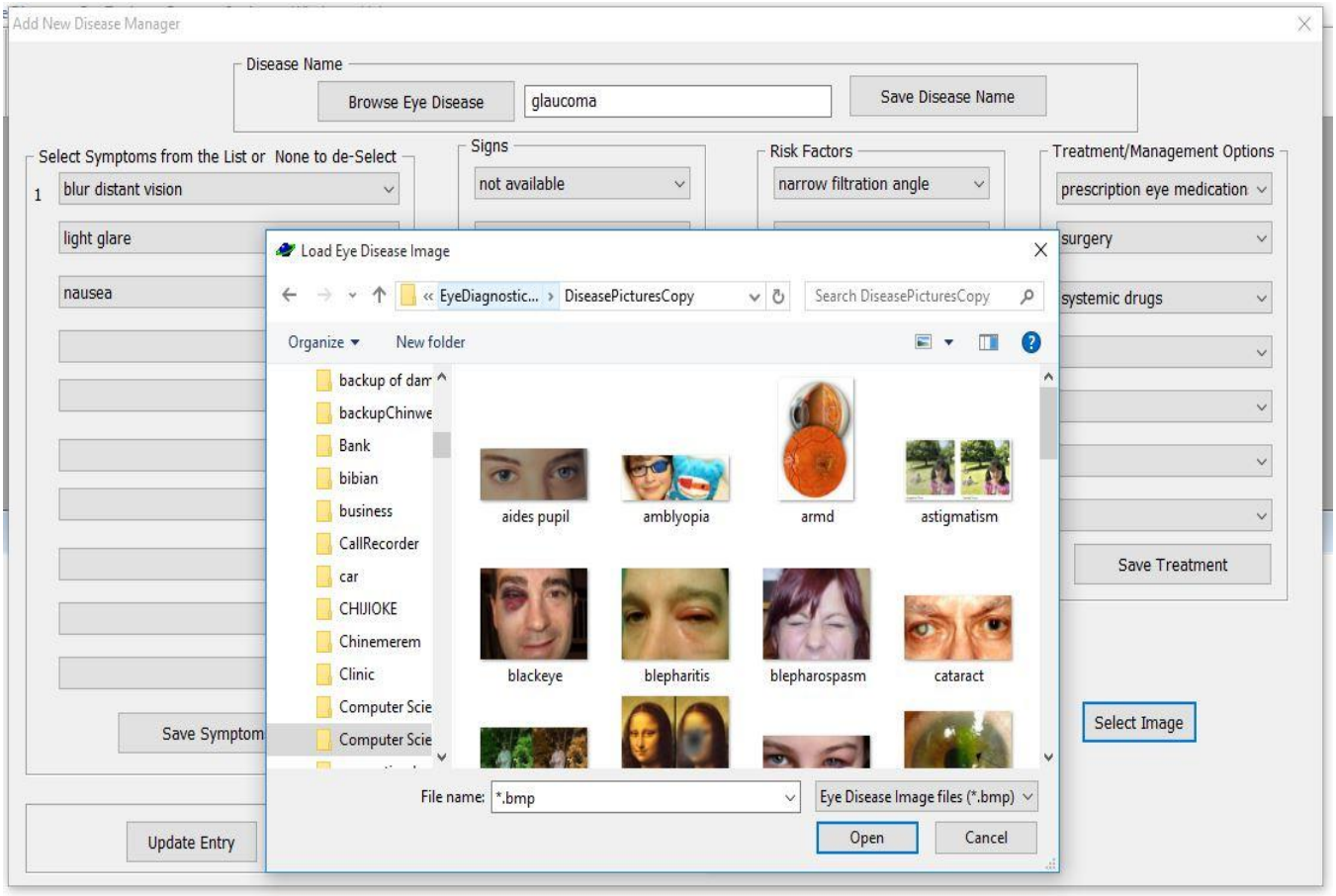


Figure 4.12: Associating disease image from file to the new eye disease

For a new patient to use the system the first time, he must first register his/her biodata information with the system and a unique ID No will be automatically issued to him/her as shown in Figure 4.13. On subsequent visits he can then log-in with his ID before using the system as shown in Figure 4.14.

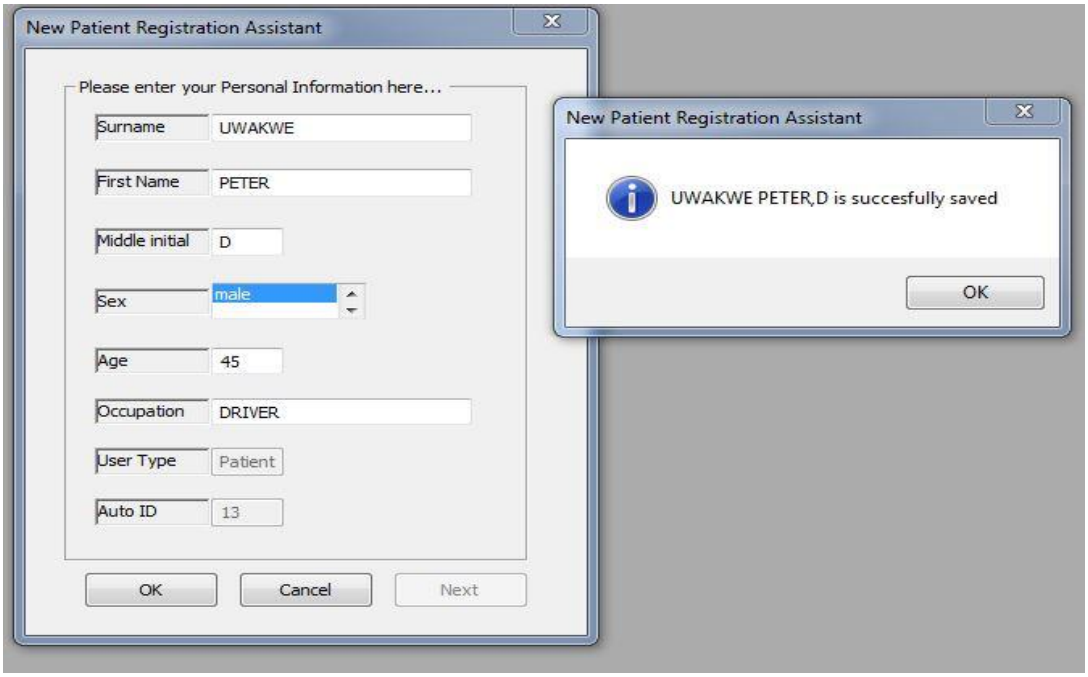


Figure 4.13: Registration of new patient

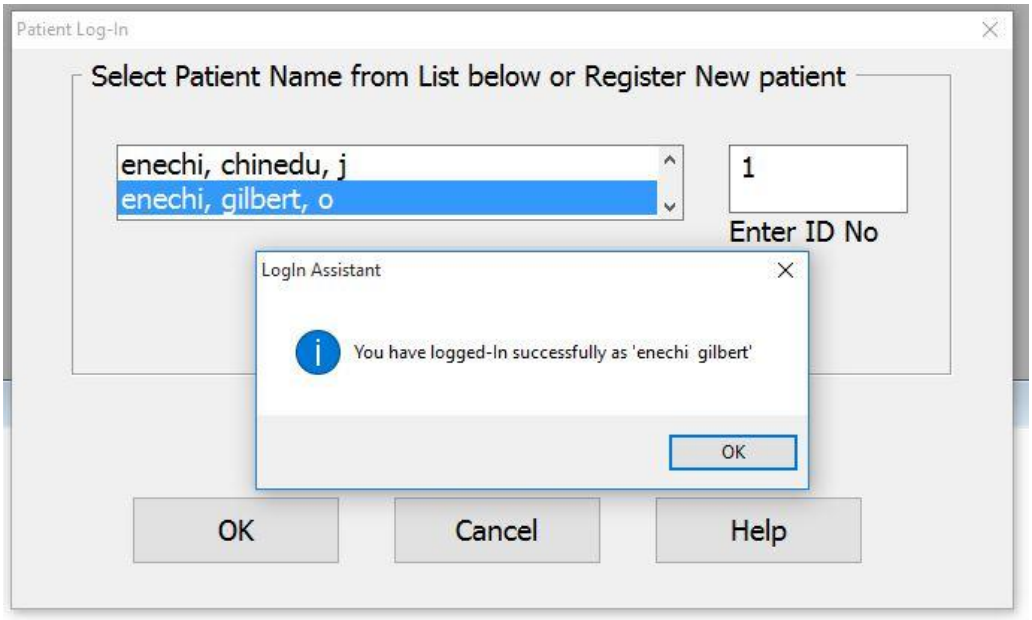


Figure 4.14: A patient attempting to log-in

Security management is an important aspect of a successful system especially in a multi-user environment. Easy and uncontrolled access to important system files and knowledge bases could spell doom for any system. Therefore, through proper enforcement of user privileges and views, access and modification of important system files are implemented through instrument of Password. Since it is only the doctor or system admin who have the privileges to modify the knowledge base, such a user must log-in with a password as shown in Figure 4.15.

Figure 4.15: Doctor/System admin LogIn session

The test distance for eye test can be set at program start-up as shown in Figure 4.16. The standard testing distances in the eye clinic are 6m, 3m and 1m. Each test distance has a corresponding visual acuity chart size. The default test distance at start-up used by CFRMFEDD is 3m. However, in situations where the patient could not see the largest acuity chart even at 3m, the default distance could be changed from 3m to 1m for that particular patient.

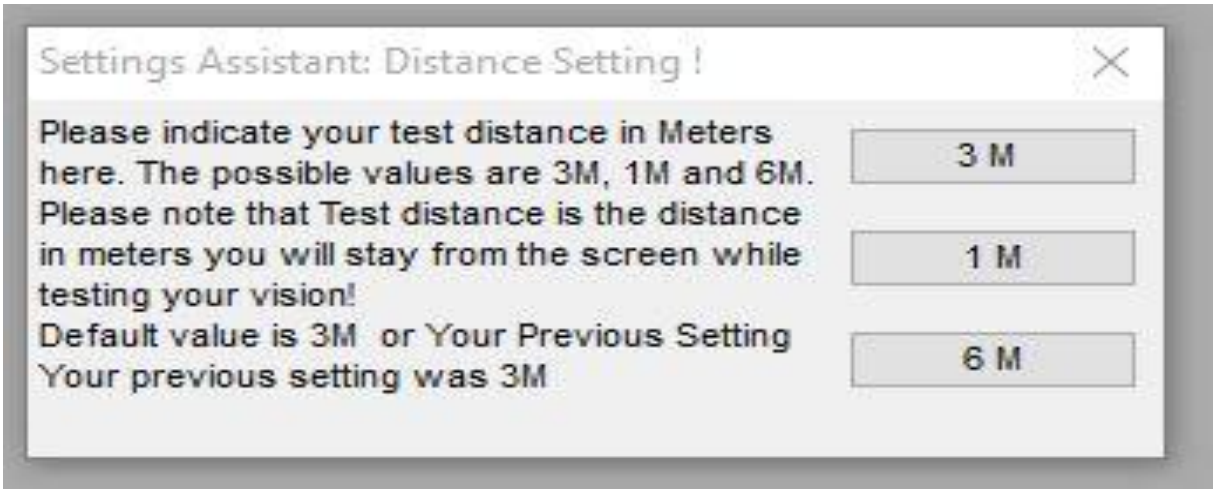


Figure 4.16: Setting of Test distance

Conducting eye test with CFRMFEDD involves two important stages. The first stage is the measurement of the patient's visual acuity while the second stage is answering the diagnostic questions (symptoms). To measure visual acuity, the system first displays necessary instruction on how to carry out the test (See Figure 4.17). Afterwards, a tumbling E-Character is displayed and patient is expected to click the arrow button that corresponds to the orientation of the displayed E (See Figures 4.18 & 4.19). The patient will continue to click the button as the E is changed in both orientation and size until at a point when the patient could no longer see the E very well. This point is detected by the system when the arrow clicked does no longer match with the orientation of E. However, the system will keep count of this failure until three consecutive times when the test will automatically halt and current reading is recorded (See Figure 4.19). It is mandatory that the two eyes are tested unless the patient clicks <Skip This Eye> button, otherwise the system will subtly remind the user that the fellow eye is not yet tested (See Figures 4.20 - 4.21).

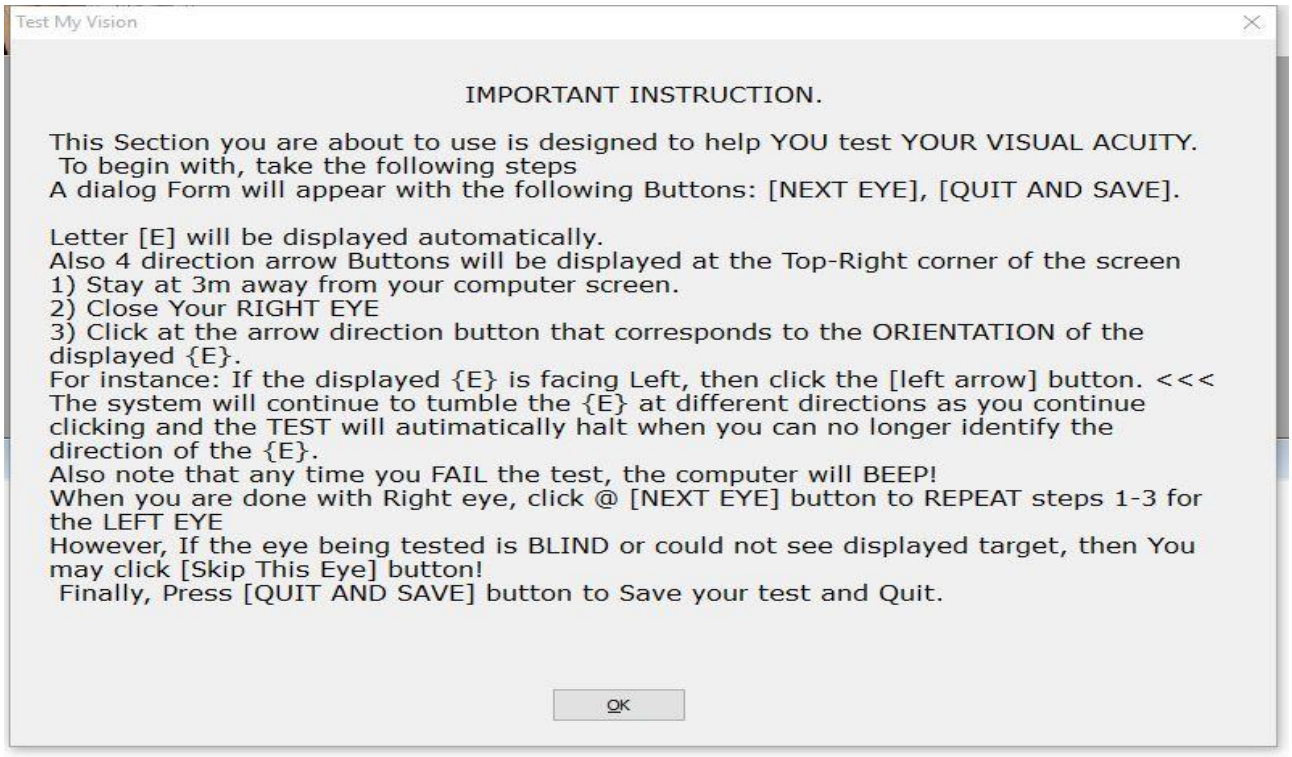


Figure 4.17: User Instruction prior to running visual acuity Test

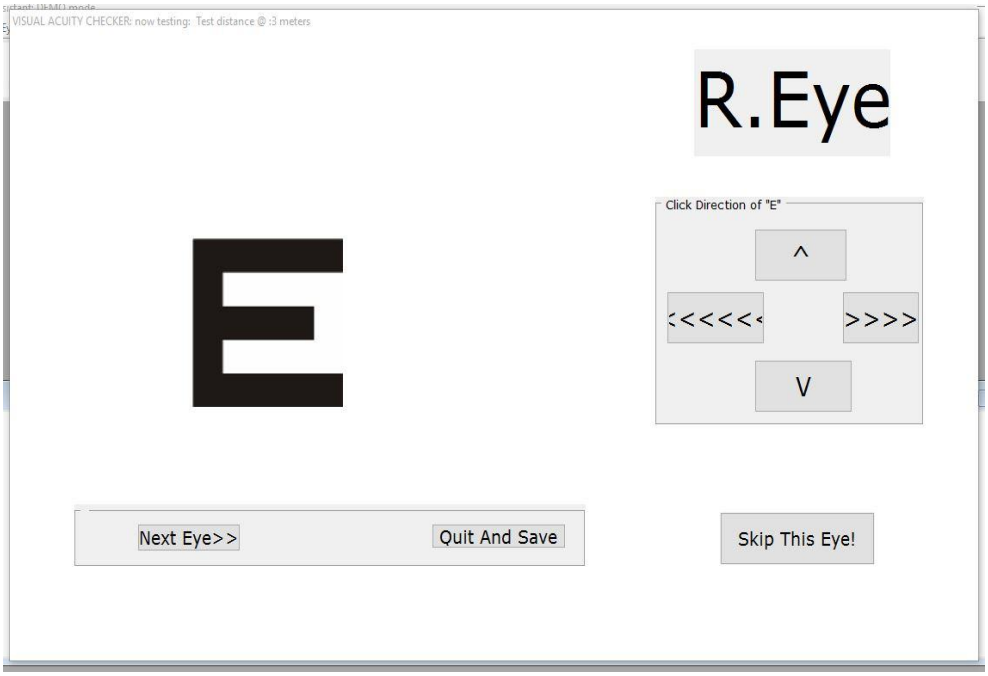


Figure 4.18: Running Visual acuity testing for Right eye

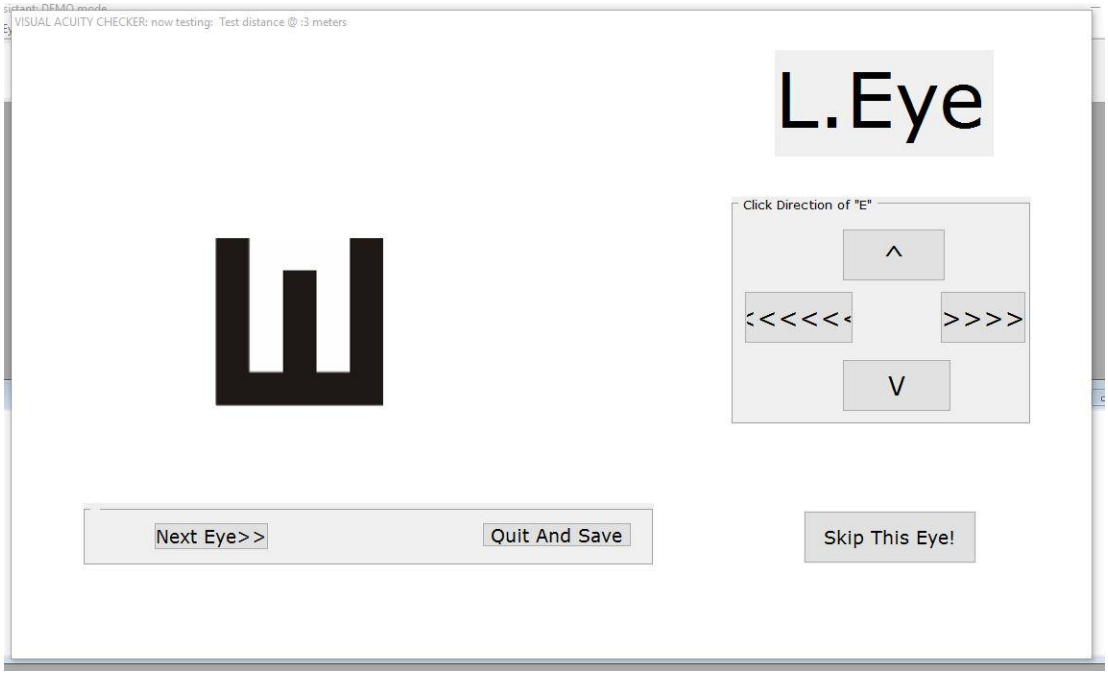


Figure 4.19: Running Visual acuity testing for left eye

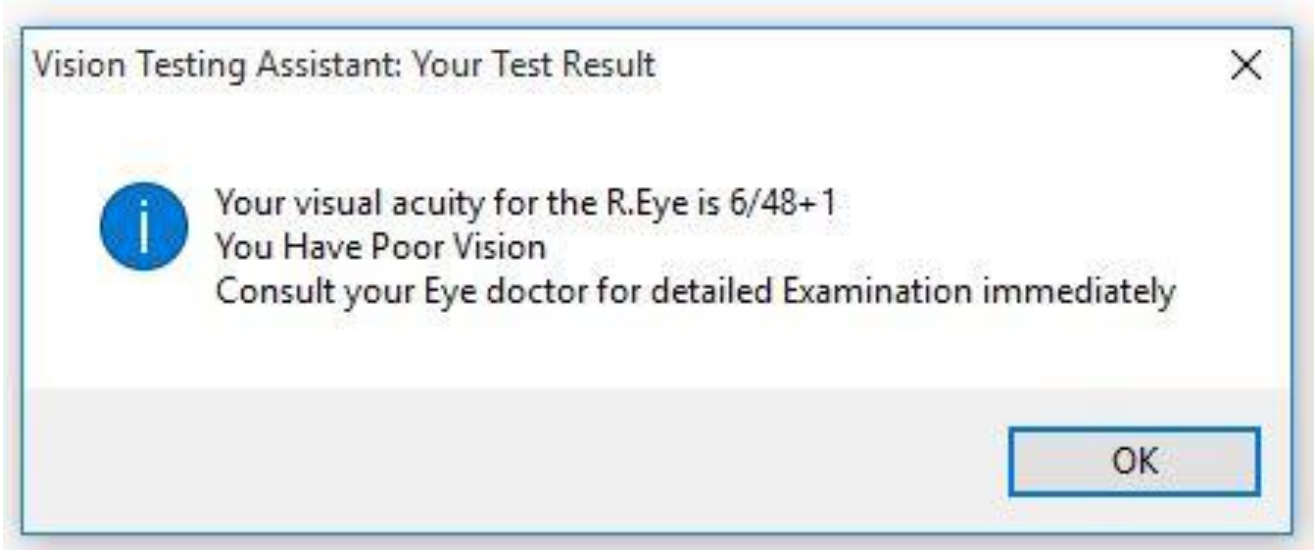


Figure 4.20: Instant display of Visual acuity test result

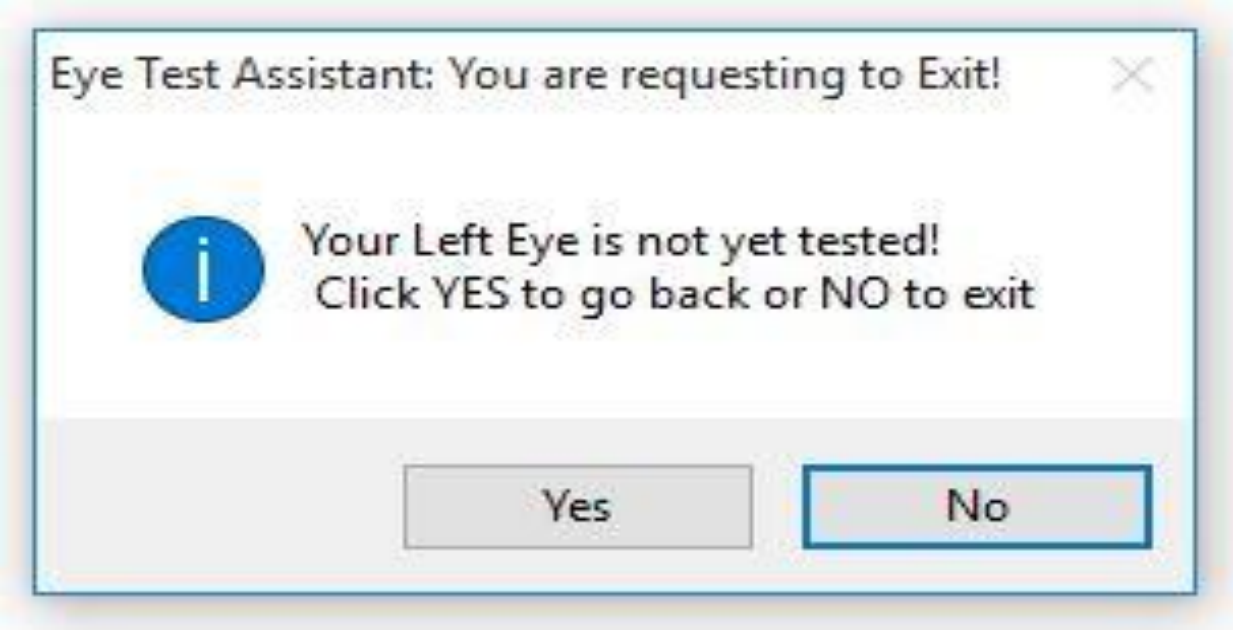


Figure 4.21: Visual acuity test Warning message

After measurement of the patient's visual acuity, the system must have gotten idea of how poor or good the patient's vision. It will then proceed to ask the patient some relevant diagnostic questions based on the vision recorded. This means that if visual acuity measured is totally skipped, the system will not continue with the diagnosis. This feature is what makes CFRMFEDD very unique from other existing systems as it serves as a way of cross checking the patient's claims (symptoms) with actual status of the patient's vision. This rules out malingering, clamming and pretense. Without this facility in place as found in existing systems, the patient can claim any symptom and hence deceive the system to make faulty diagnosis based on faulty data.

In Figure 4.22, the necessary instructions on how to run symptom checking was displayed using on-the-fly message-box control. Afterwards, the patient was asked to select which eye(s) he had the complaints (See Figure 4.23). Later, the first diagnostic question was asked and the patient was expected to click <YES> or <NO> button. If Yes is selected, an input box will pop up and the patient is expected to score

his/her conviction on the symptom provided in form of Certainty factor (CF). In Figure 4.24, the patient answered YES to the question: Do you have sunlight disturbance? Patient was consequently prompted to score his degree of certainty in which he selected "Probably" which corresponds to certainty factor of 0.6. Further questions were asked until all the questions were either exhausted or the answers did not correspond to any eye disease known to the system (See Figures 4.24 & 4.25), thereafter the result is saved (See Figure 4.28) and control transferred to diagnostic manager (See Figure 4.29) for final diagnosis.

It is also interesting to observe that at the first question, there were 132 questions remaining to be asked a (See Figure 4.23) but after the second question, there were only 65 questions to ask (See Figure 4.24) and after the seventh question, there was no question remaining to be asked (See Figure 4.25). This implies that a procedure that could have taken 132 questions only took 7 questions to arrive at diagnosis. This again is one of the features of CFRMFEDD that makes it unique from others as it employs efficient pre-processing algorithm to shorten the number of questions and time it would have taken to make a diagnosis.

Furthermore, partial diagnosis could be observed in between while the consultation session is not yet concluded (See Figure 4.26). This feature again is unique as it makes it an excellent tool for learning purposes especially for medical students and resident doctors (See Figure 4.27).

Ability to always communicate to the user the progress of task performed at end of each program stage is helpful in keeping the user's attention as well as notifying the user when things go wrong. For instance, Figures 4.28 shows when the diagnostic manager has finished gathering all the symptom information from the patient and Figure 4.29 shows when it was forwarding its finding to the diagnostic manager.

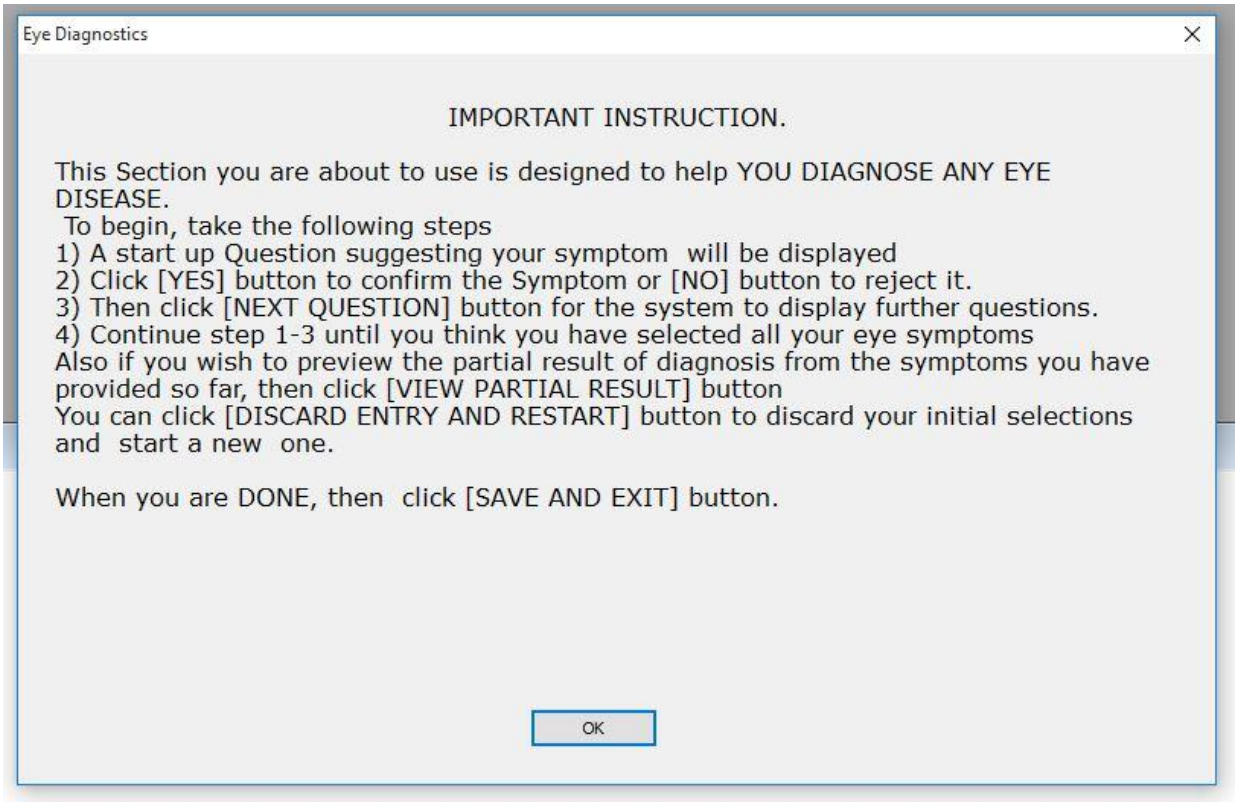


Figure 4.22: User instruction prior to using symptom checker

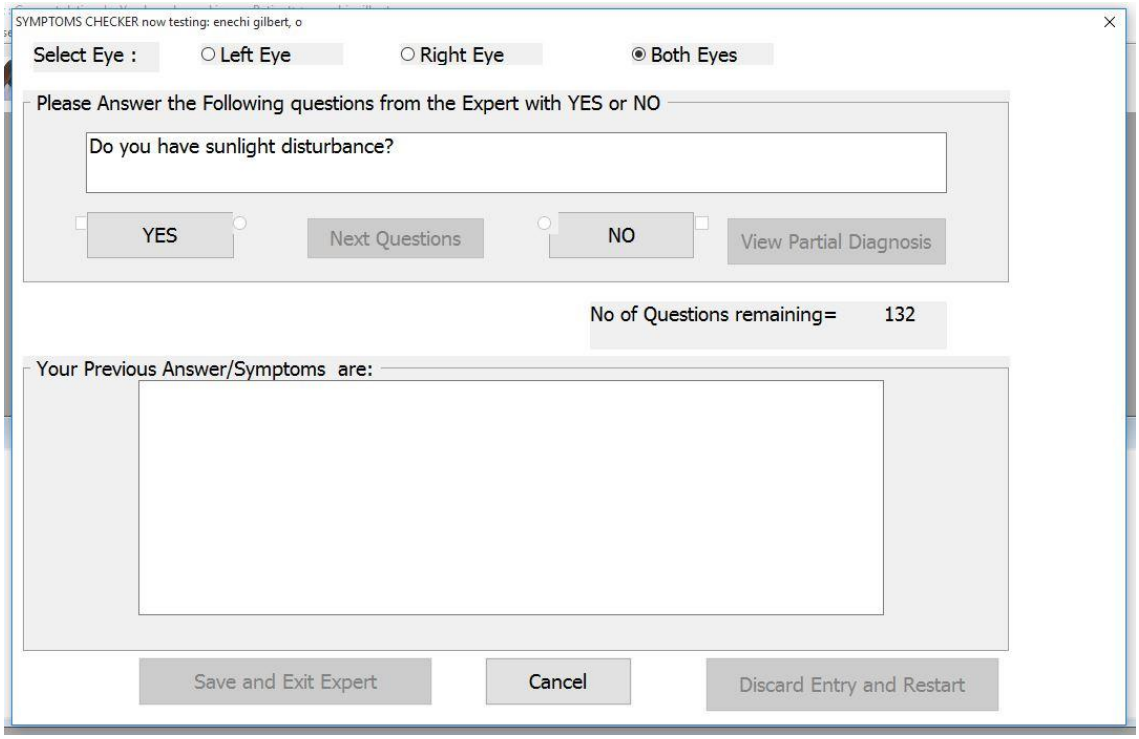


Figure 4.23: Symptom checker startup/Main Page

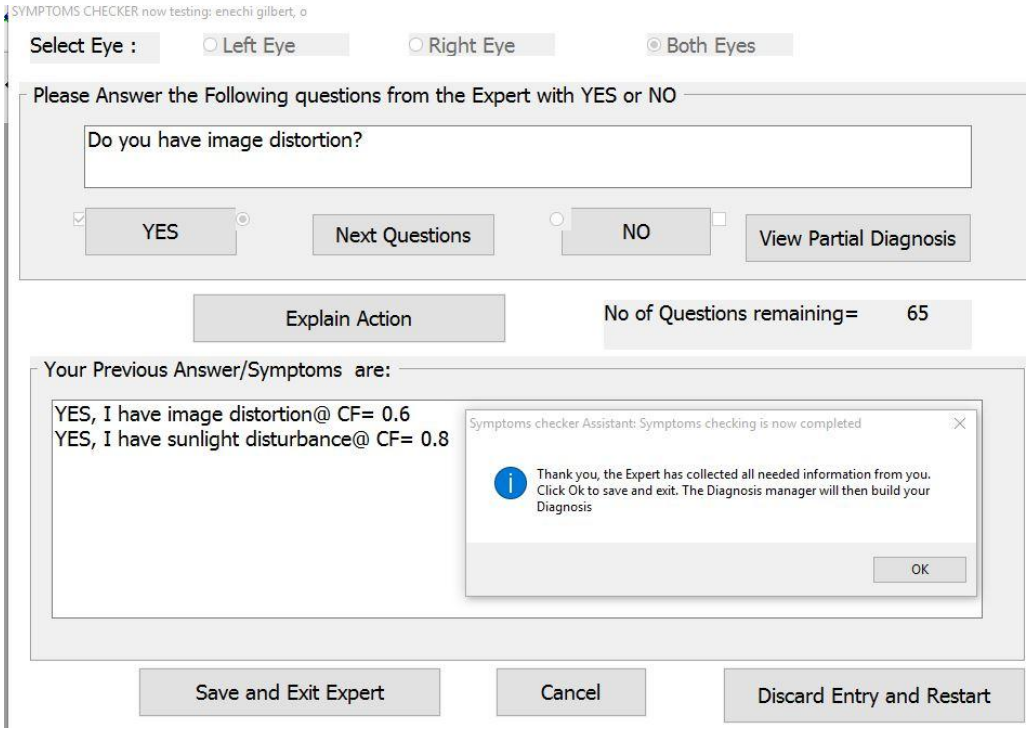


Figure 4.24: Symptom checker at intermediate stage

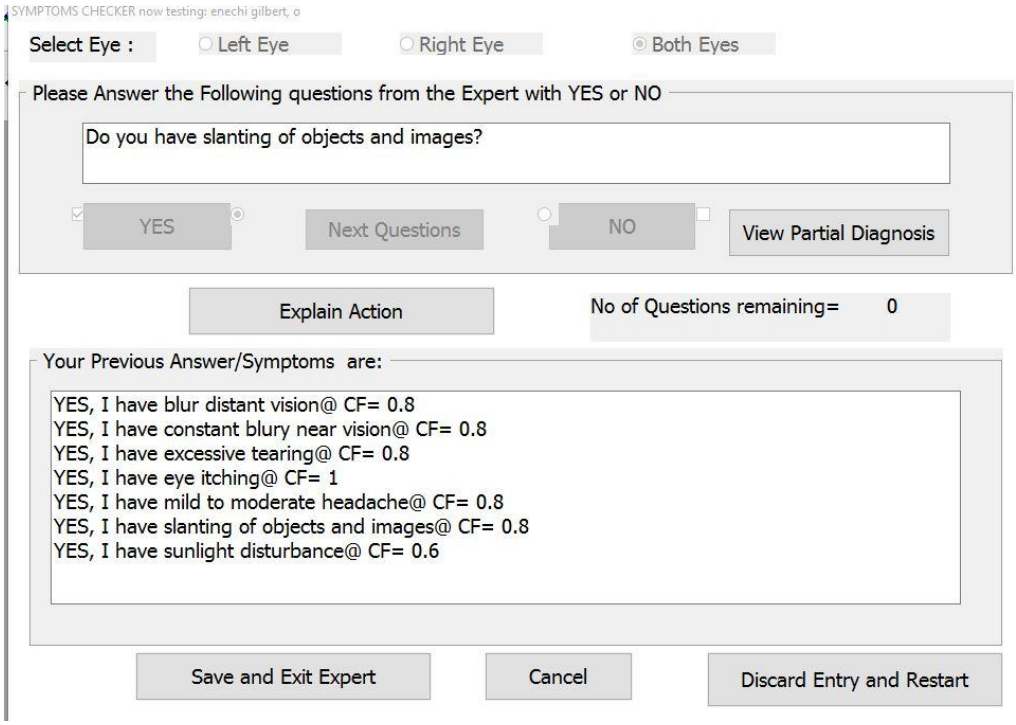


Figure 4.25: Symptom checking at final stage

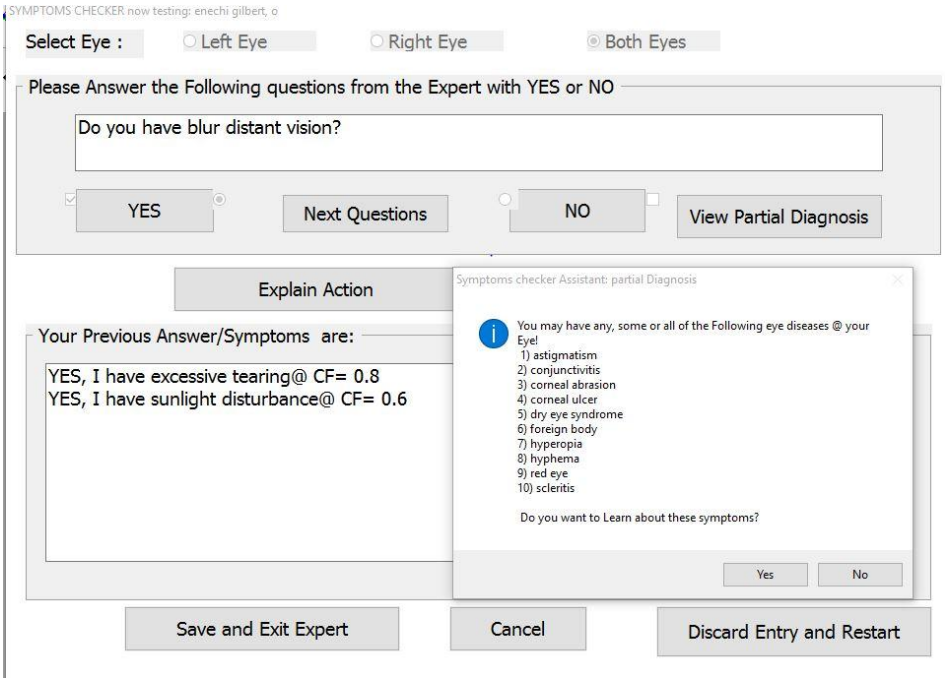


Figure 4.26: Partial diagnosis Request-Confirmation

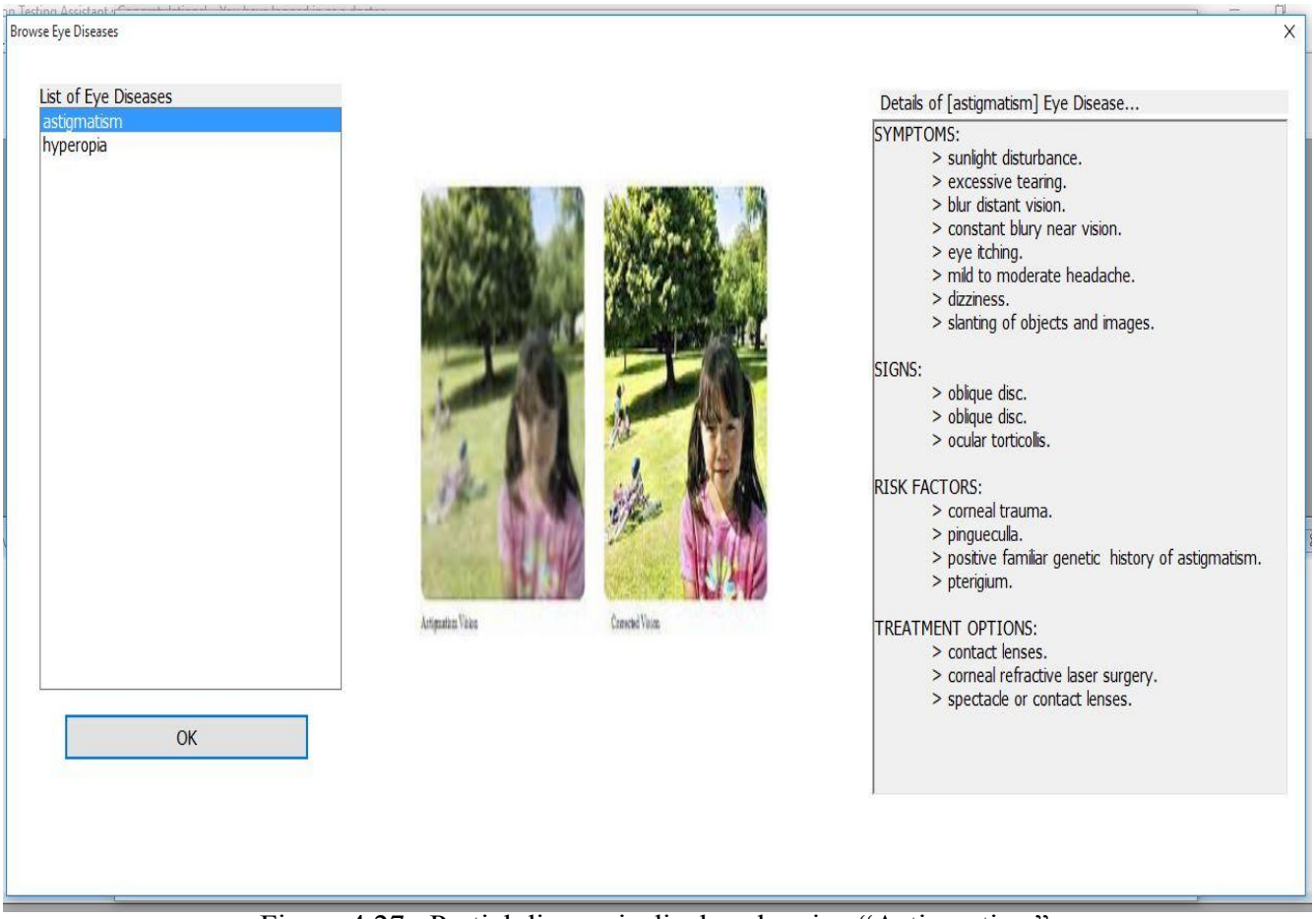


Figure 4.27: Partial diagnosis display showing “Astigmatism”

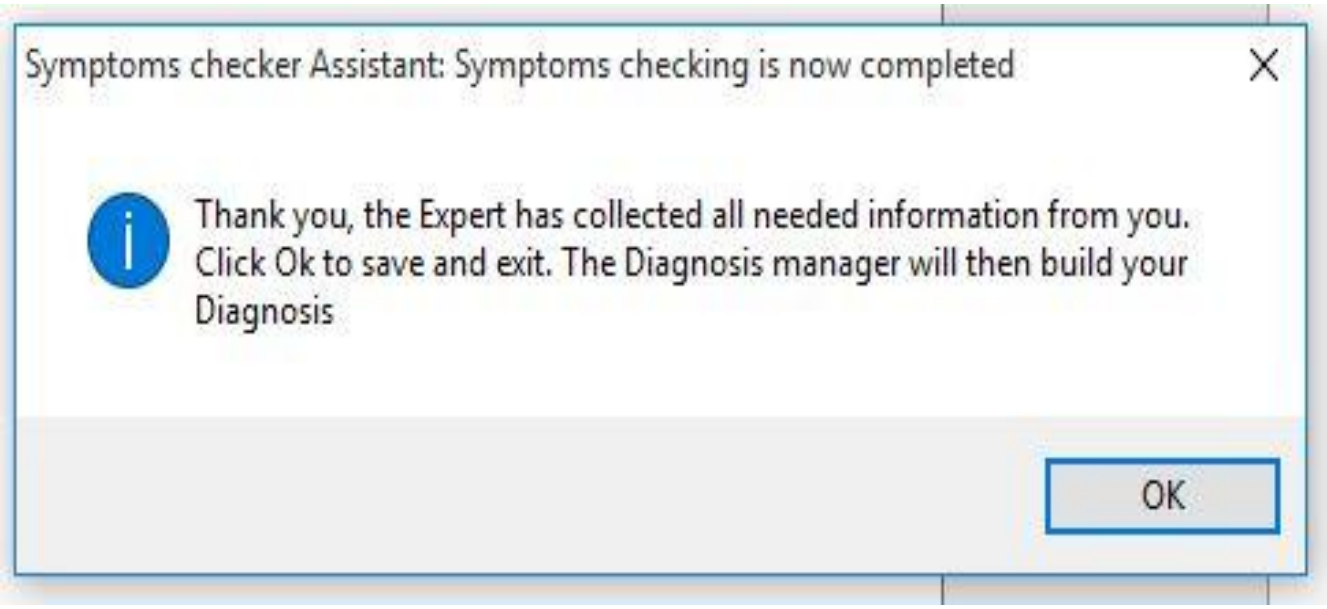


Figure 4.28: Saving symptoms checker result after successful symptoms collection

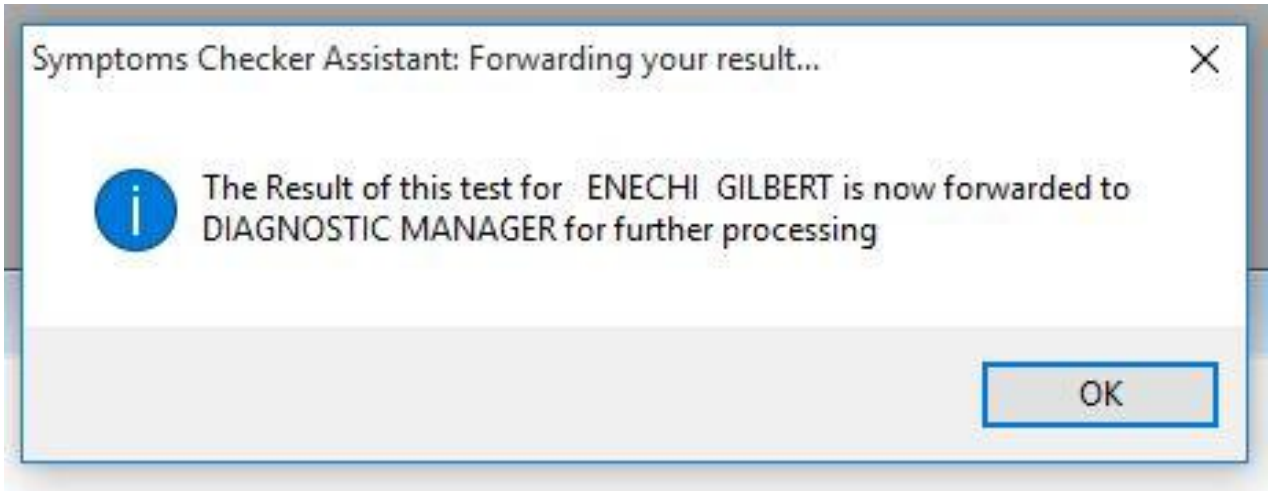


Figure 4.29: Forwarding symptoms checker Result to Diagnostic manager

Figures 4.30 & 4.31 demonstrated the power of certainty factor in which the patient was able to declare the degree of certainty associated with the symptoms he provided. Conversely, the system was able to declare the degree of certainty associated with the diagnosis made. For instance in Figure 4.32, the system made a single disease diagnosis of astigmatism with a CF of 0.36 which translates to "**May be Astigmatism**".

It is also interesting to note that the patient can learn more about the diagnosed disease by clicking the <View PROOF of Diagnosis/Lean About Disease> button as shown in Figure 4.32 and also the fact that the page has the image of a doctor leaves the patient with the impression that he has just consulted a doctor!

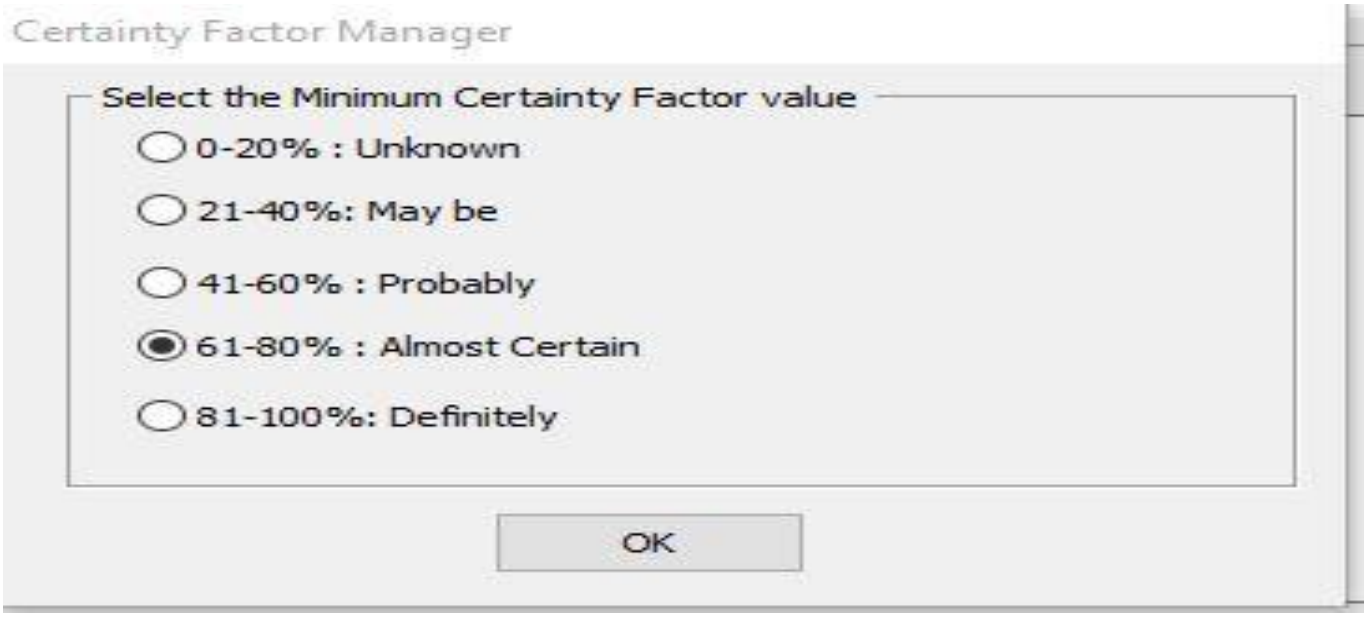


Figure 4.30: Certainty factor manager

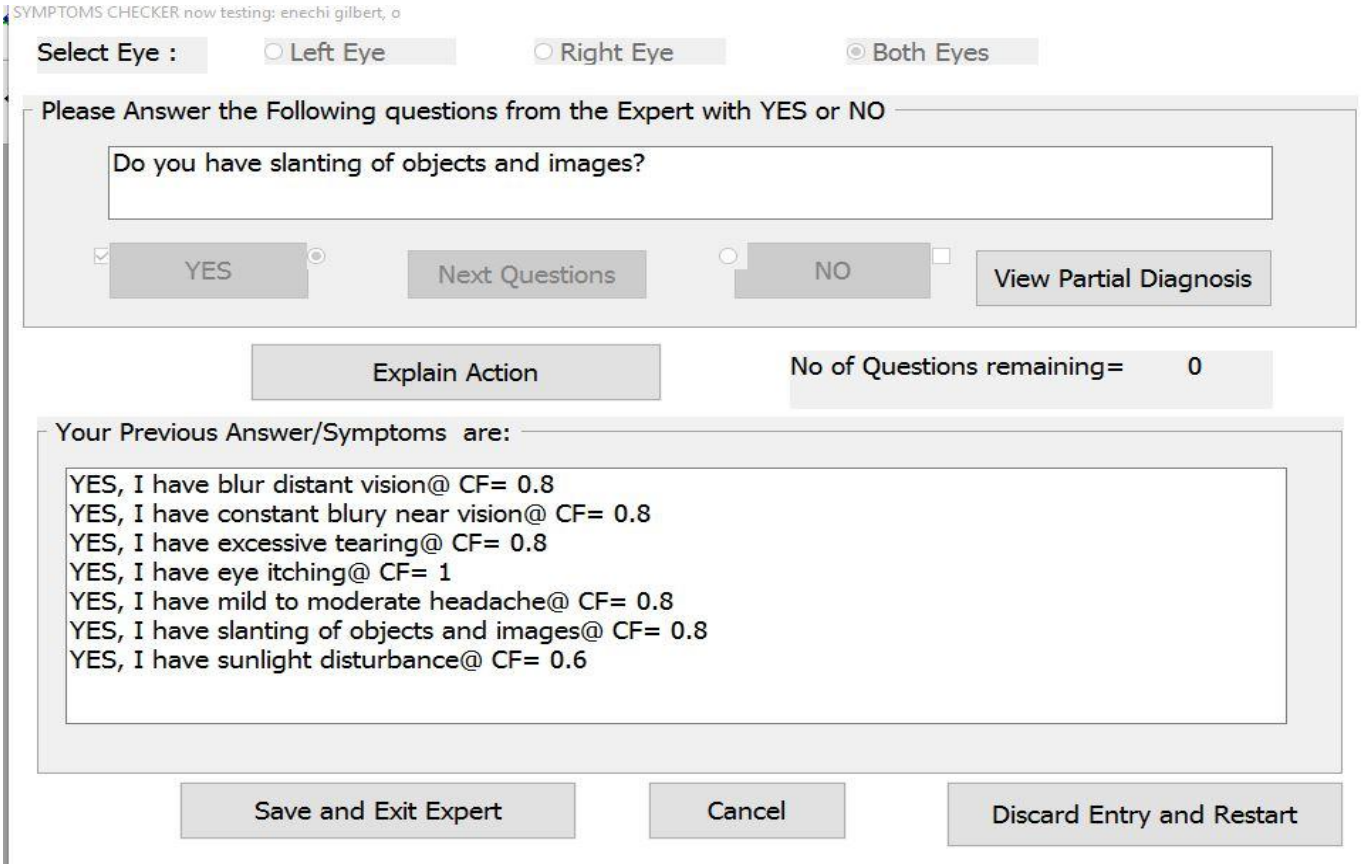


Figure 4.31: Presented symptoms with their associated Certainty factors

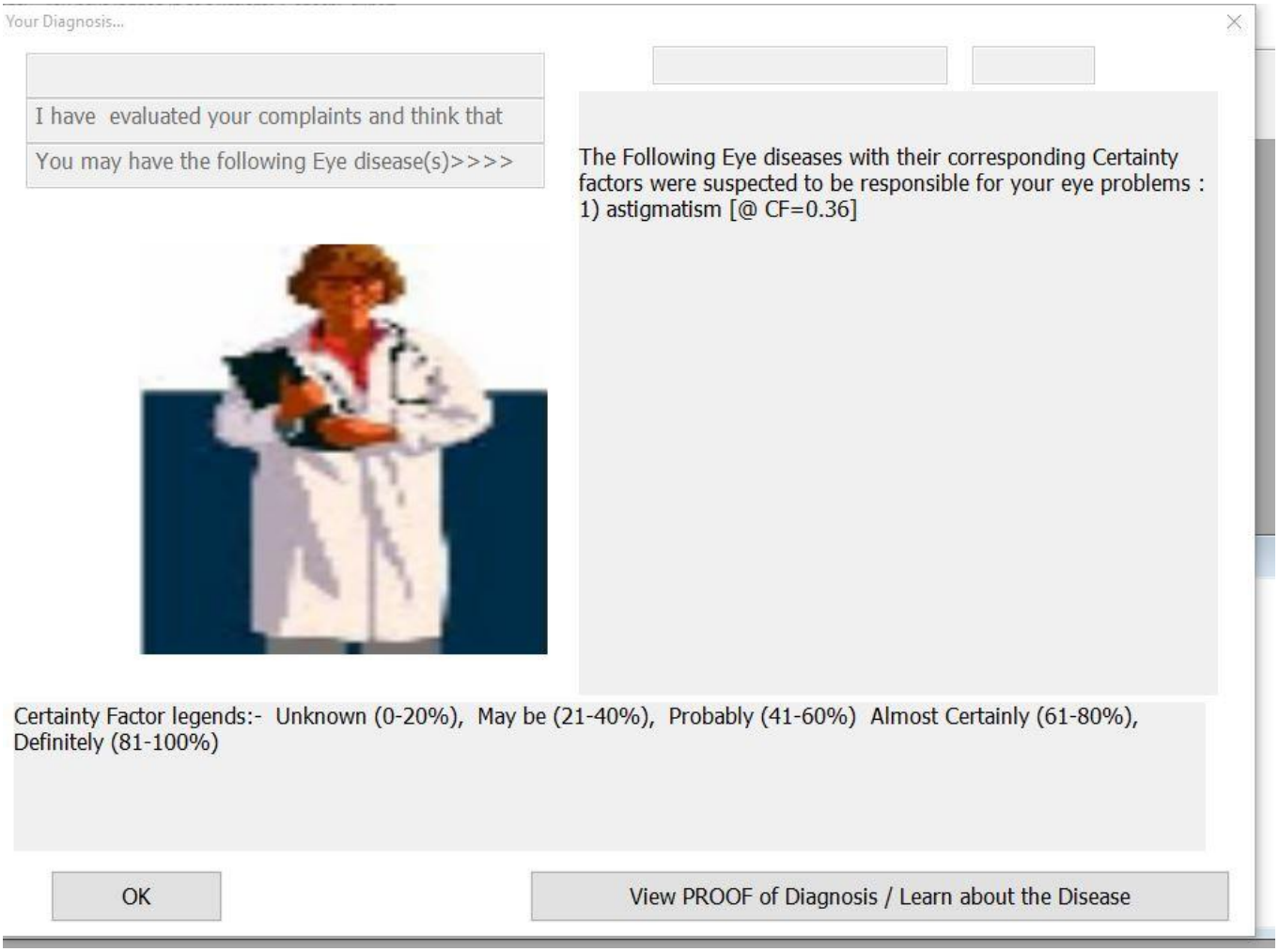


Figure 4.32: Diagnosis of Astigmatism @ 36% certainty factor

The ability to update the knowledge base when there is change of medical information often entails deletion of old facts and replacement with new facts. As earlier stated only the doctor or system admin has the privilege to modify the database. Since facts deleted could not be recovered, the two levels of confirmation were provided. This is to rule out inadvertent action. Figures 4.33 – 4.35 demonstrated an attempt by the user to delete "**black eye**" disease from the database. After a last warning, the user still insisted in deleting the disease by clicking <Ok> button as a confirmation to delete.

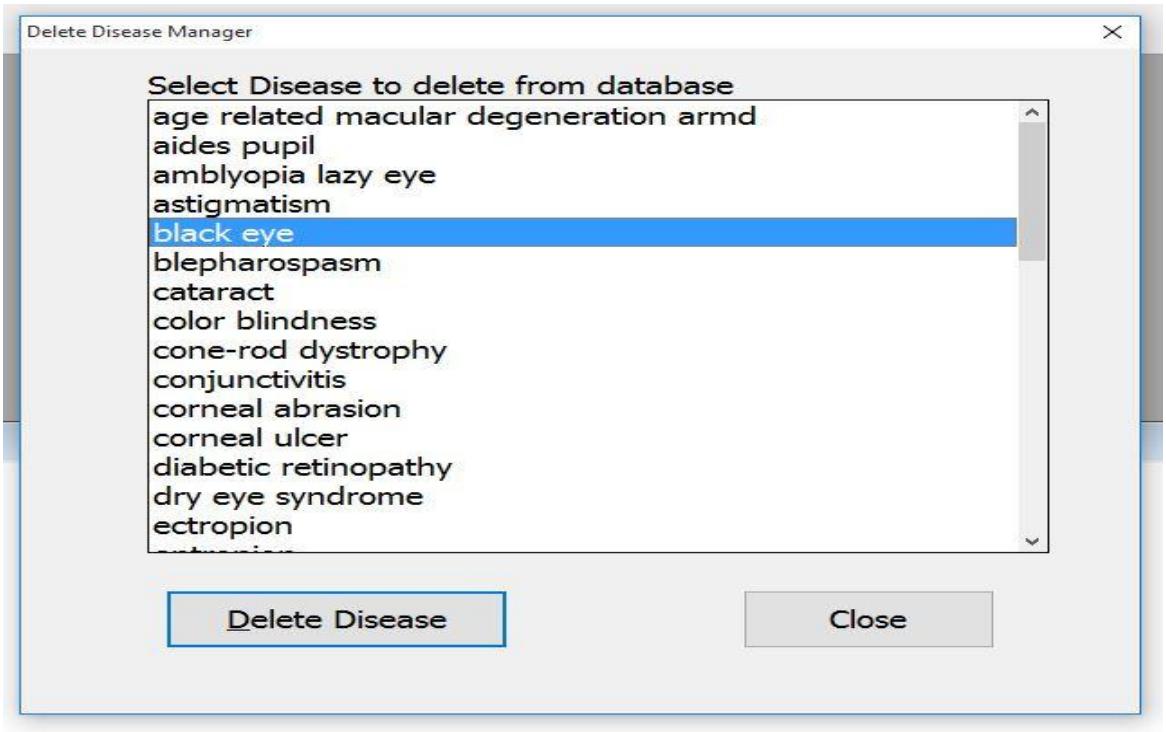


Figure 4.33: Selecting existing disease to delete from database

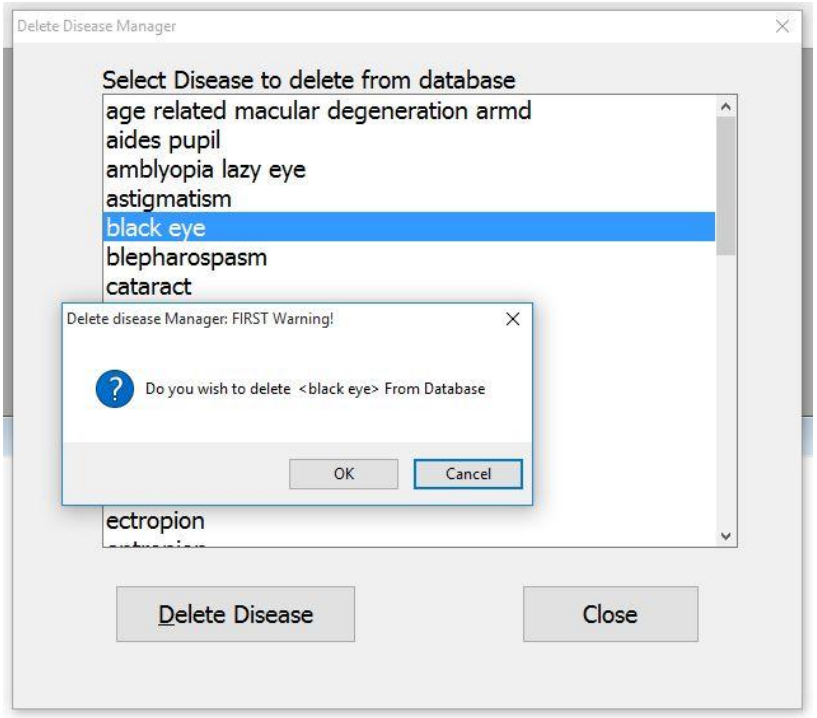


Figure 4.34: Confirmation to delete (First warning)

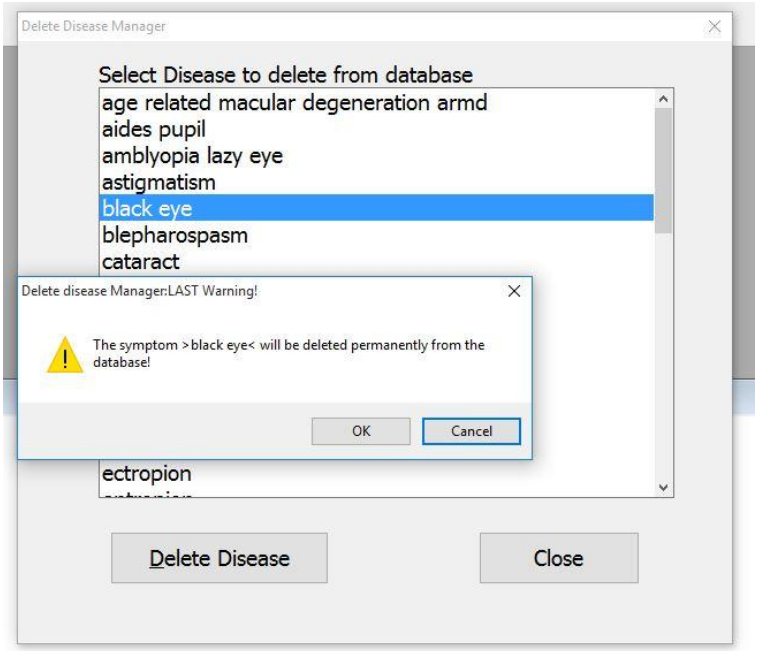


Figure 4.35: Confirmation to delete (last warning)

Another important feature of CFRMFEDD is its application as a learning tool. Both patients, medical students, doctors and researchers can learn about the various eye diseases by clicking <browse> eye disease button. The patients can browse the disease list and learn the attributes of those diseases while medical personnel can in addition to above, peruse the attribute lists that contain all the symptoms, signs, risk factors, treatment plan and disease images as shown in Figures 4.36- 4.42.

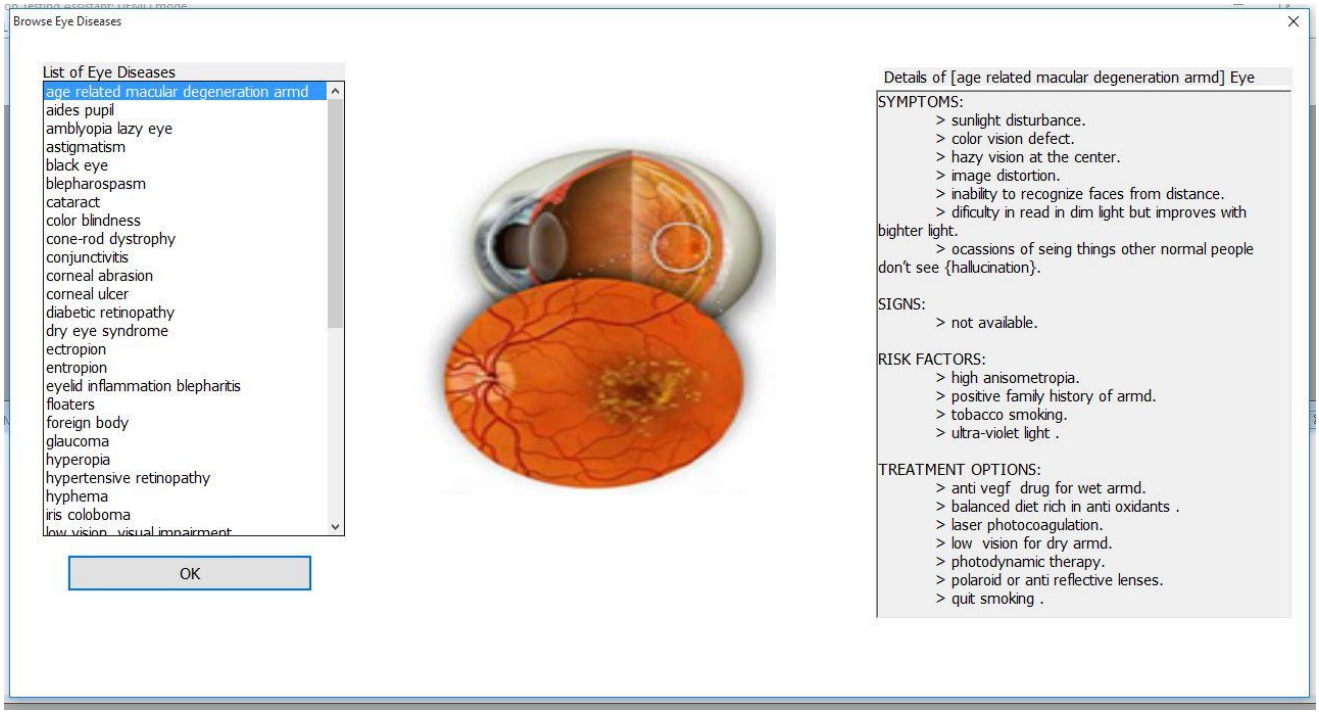


Figure 4.36: Browsing eye disease from menu system

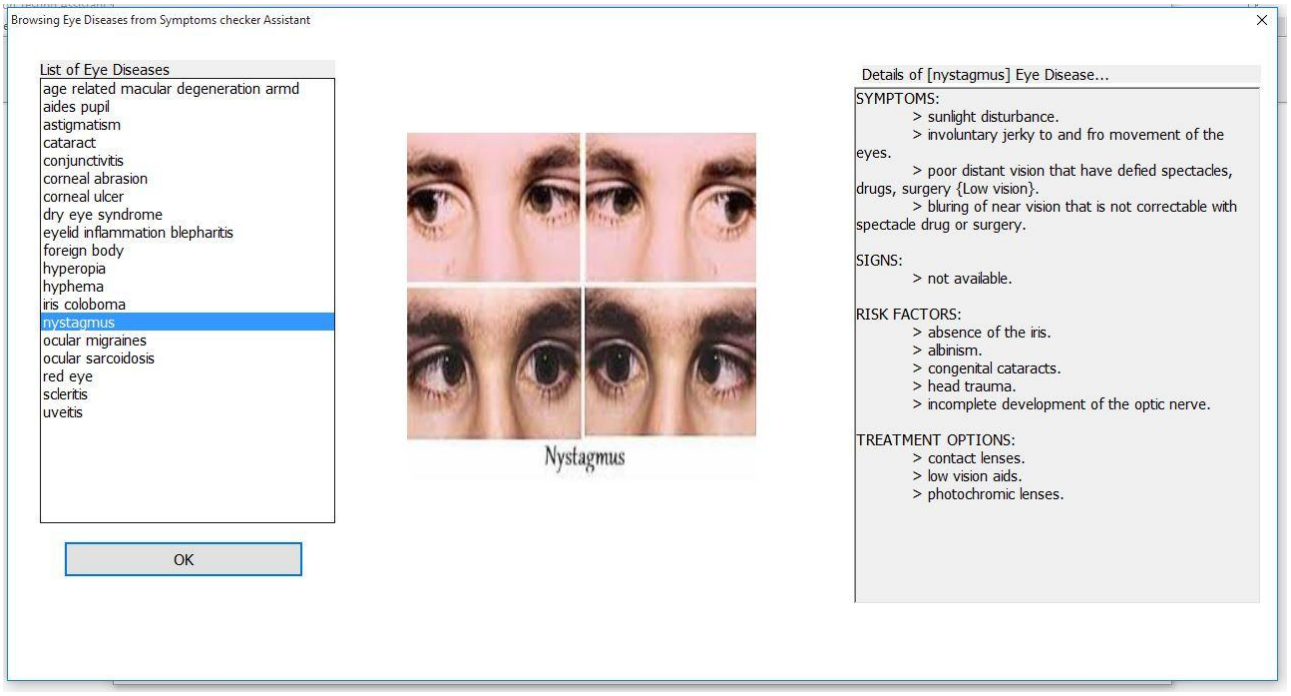


Figure 4.37: Browsing eye disease from symptoms checker

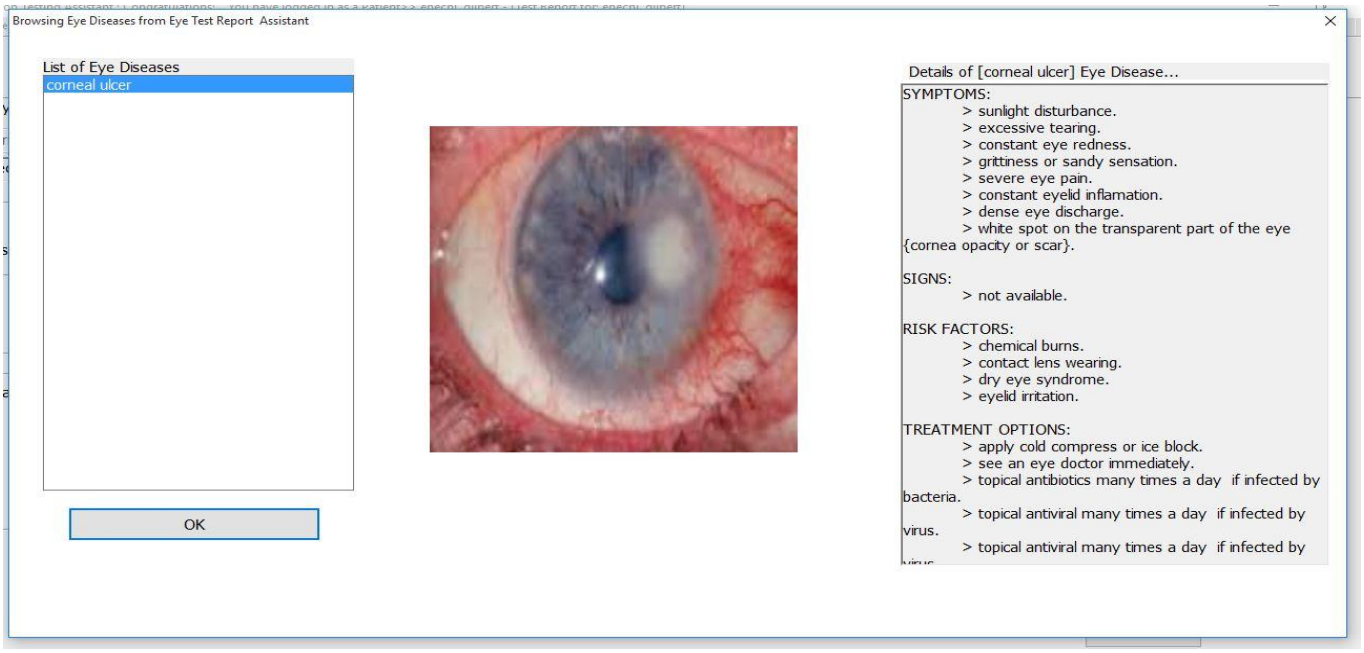


Figure 4.38: Browsing eye disease from report page

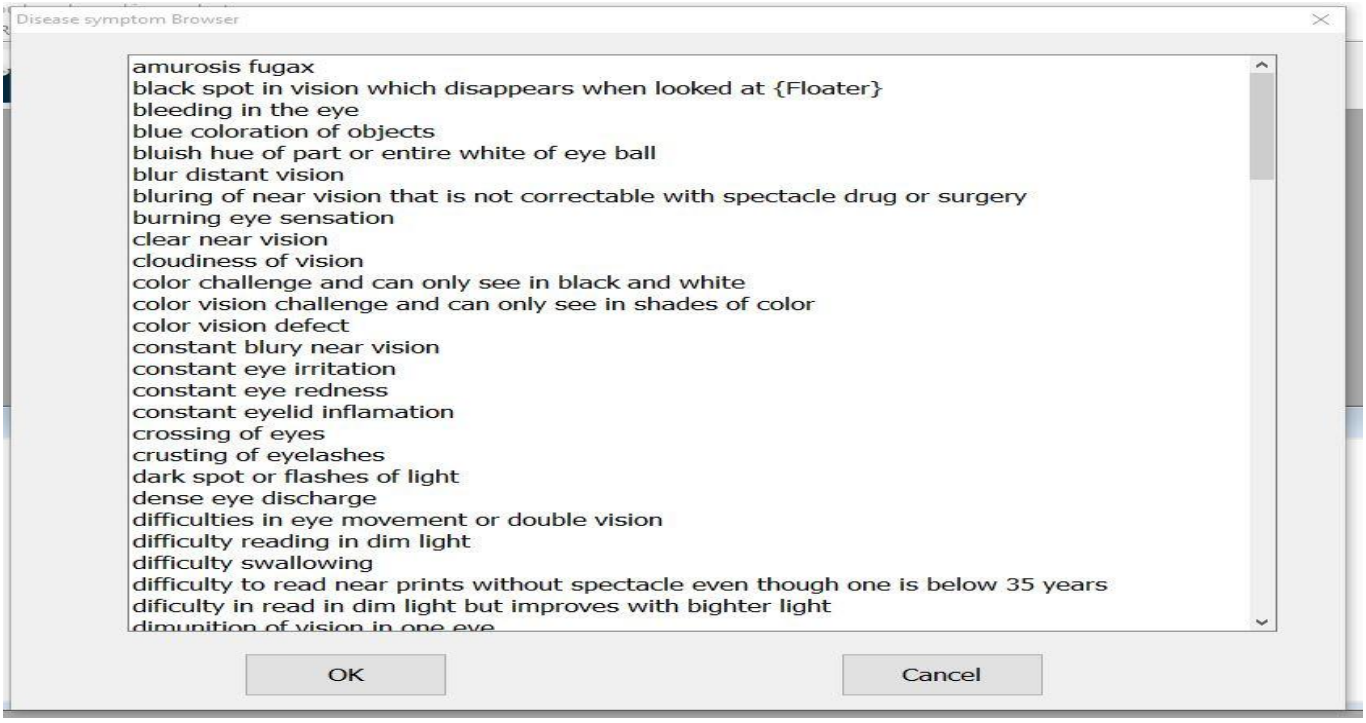


Figure 4.39: Browsing Symptoms list

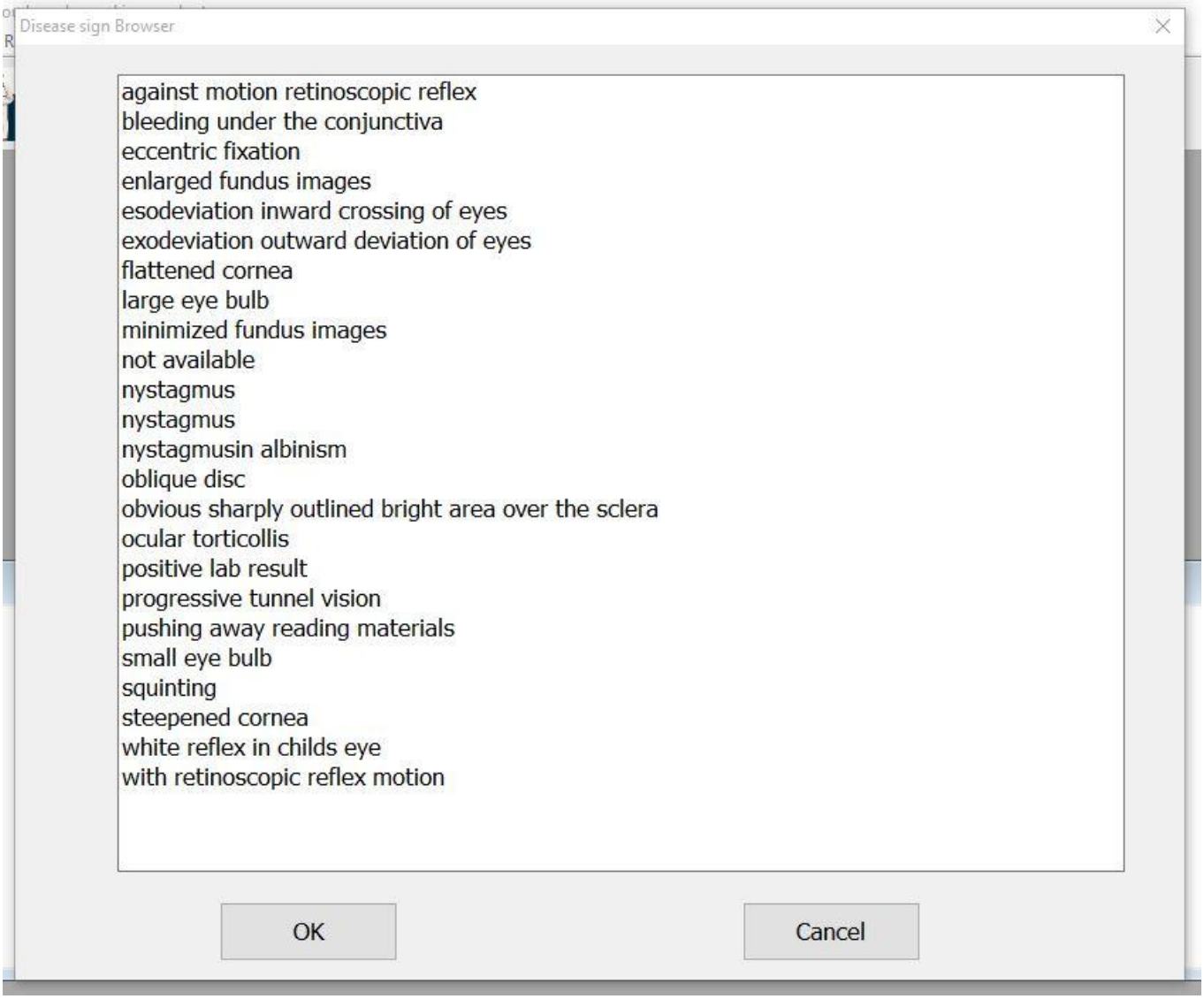


Figure 4.40: Browsing Signs list

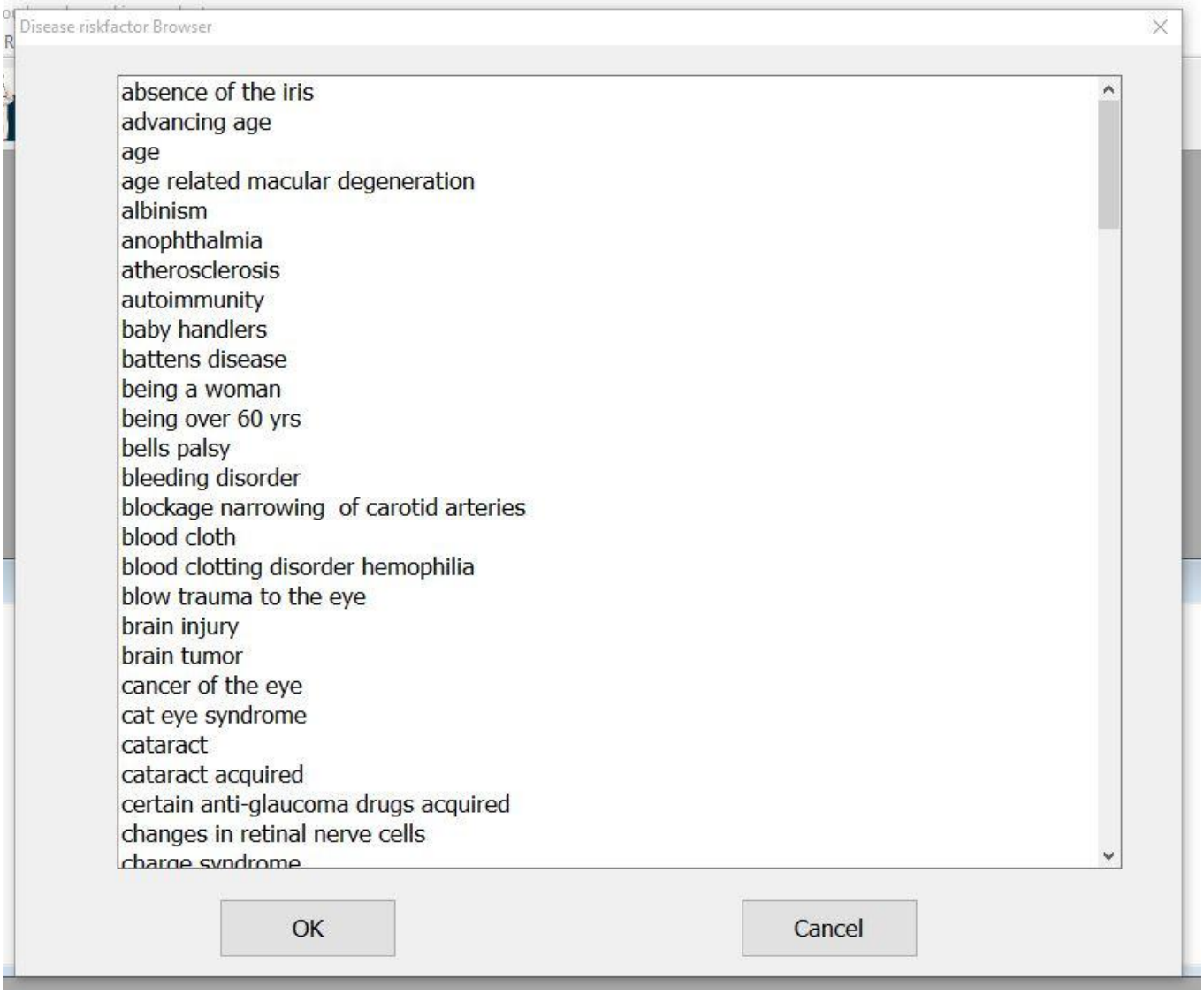


Figure 4.41: Browsing Risk Factors list

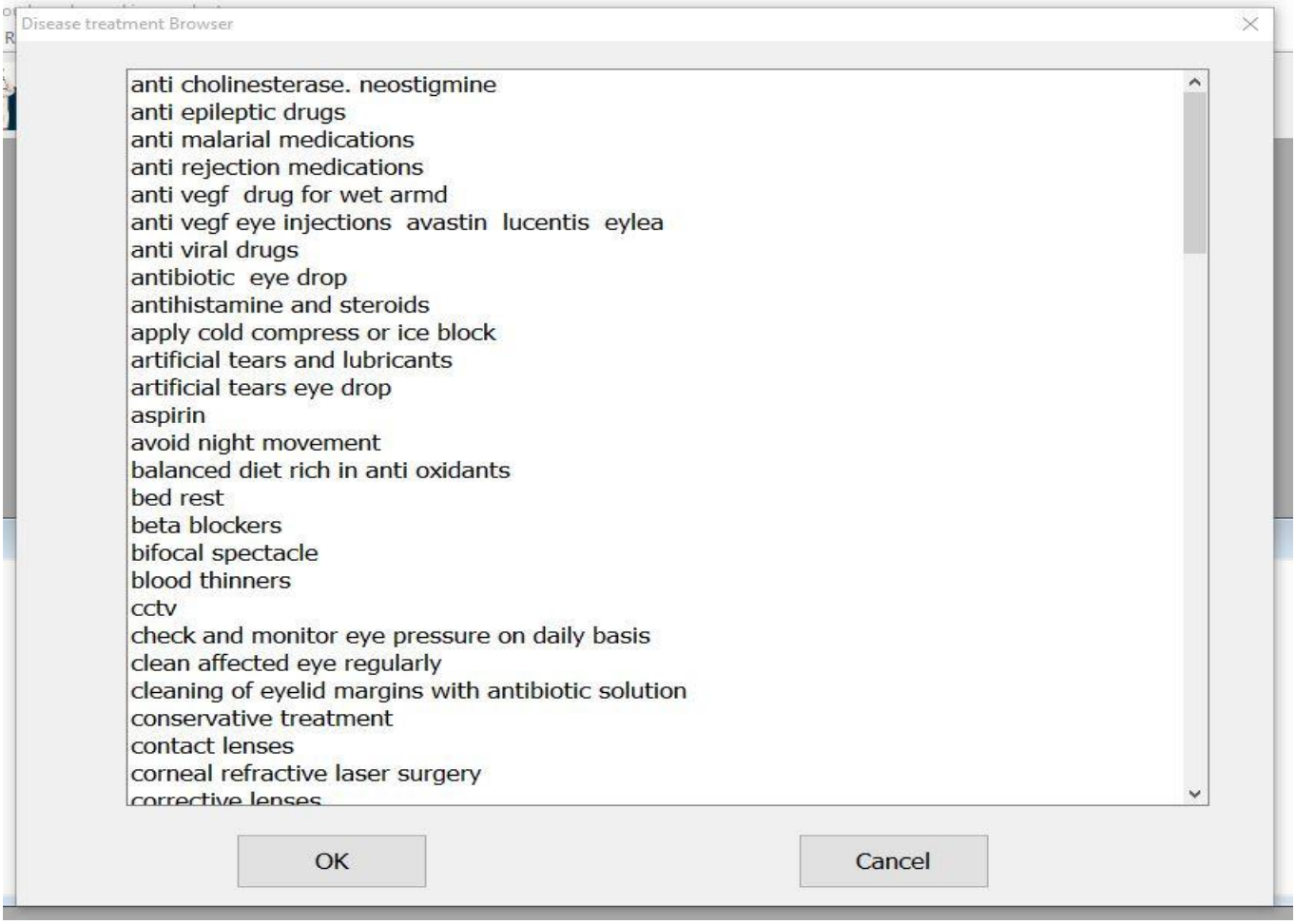


Figure 4.42: Browsing Treatment list

CFRMFEDD could be used as monitoring medical tool as each time a patient performs eye test, the result is stored in his/her medical file. It is therefore possible for a patient to monitor the status of his/her vision by doing regular eye check. At any point in time, each patient can view and print out all the eye tests associated with him/her but cannot view another patient's result due to ethical reasons. This privacy protection was enforced through use of log-in facility. However, the system admin or the doctor has a global privilege rite and can therefore view any patient's past records. In Figure 4.43, a patient was able to view all his past records and could even learn more about each diagnosis by clicking <view disease> button.

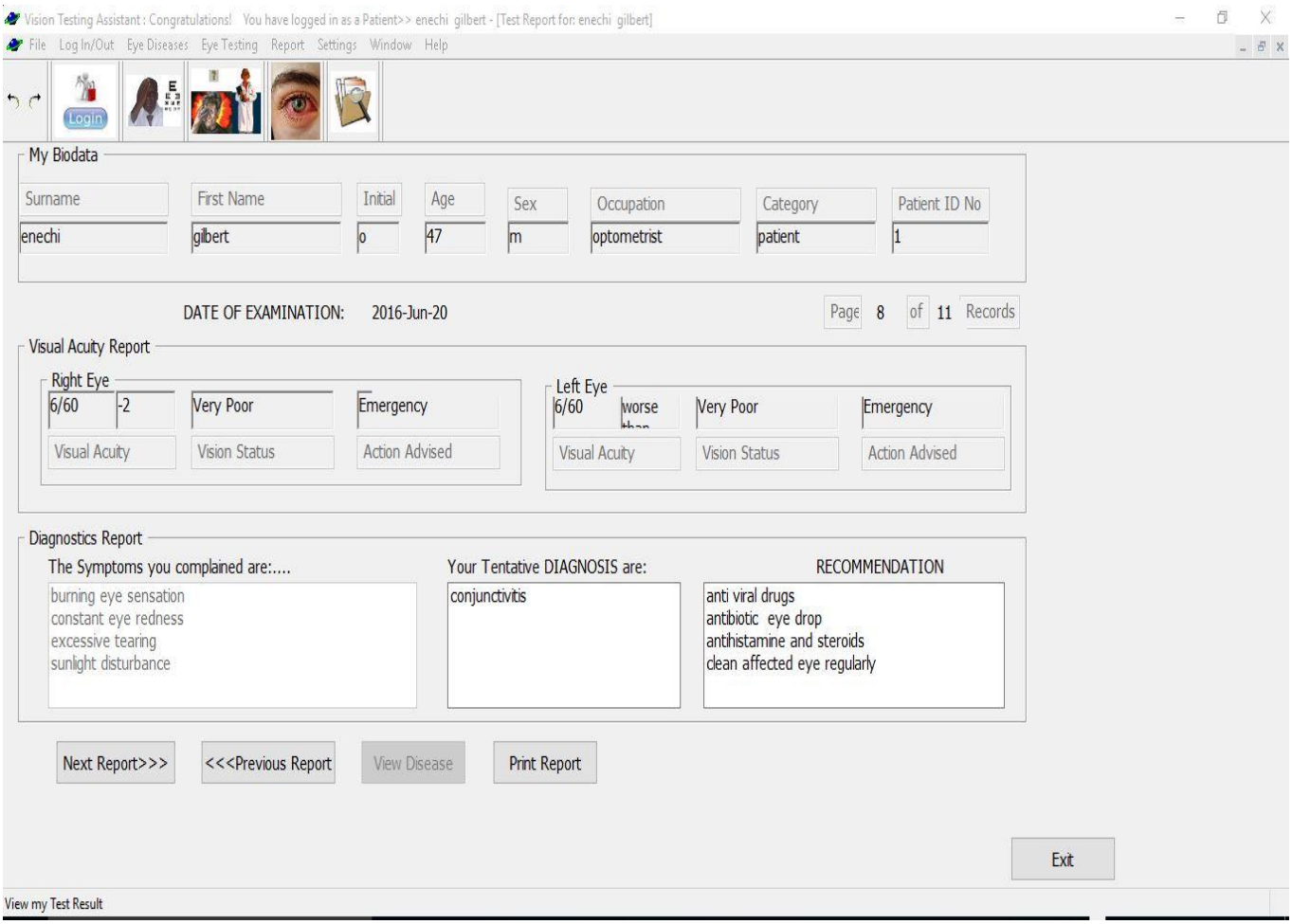
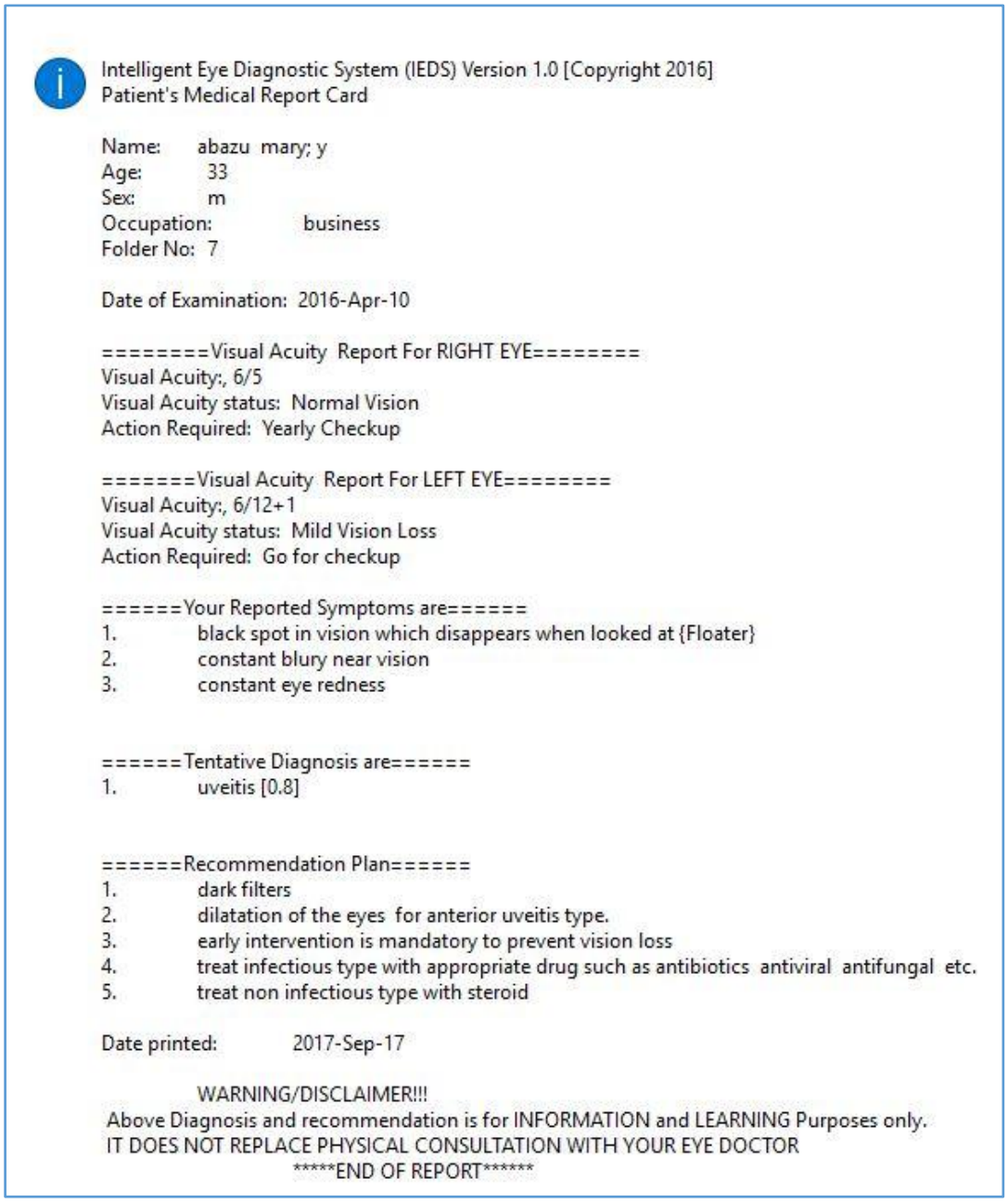


Figure 4.43: Viewing Report/Print Page

It is possible to get a hard copy of the test report by printing it out. In Figure 4.44, a medical assistant was able to print out test report of a patient "**Abazu Mercy, age 33 with diagnosis of uveitis**". The print out contains a comprehensive summary of patient's eye condition to the extent of facts available in the knowledge base. However, the report also bears a warning/disclaimer informing the patient that the report does not replace physical consultation with eye doctor and thereby satisfying the necessary ethical issues.



Intelligent Eye Diagnostic System (IEDS) Version 1.0 [Copyright 2016]
Patient's Medical Report Card

Name: abazu mary; y
Age: 33
Sex: m
Occupation: business
Folder No: 7

Date of Examination: 2016-Apr-10

========Visual Acuity Report For RIGHT EYE========
Visual Acuity:, 6/5
Visual Acuity status: Normal Vision
Action Required: Yearly Checkup

========Visual Acuity Report For LEFT EYE========
Visual Acuity:, 6/12+1
Visual Acuity status: Mild Vision Loss
Action Required: Go for checkup

======Your Reported Symptoms are======
1. black spot in vision which disappears when looked at {Floater}
2. constant blury near vision
3. constant eye redness

======Tentative Diagnosis are======
1. uveitis [0.8]

======Recommendation Plan======
1. dark filters
2. dilatation of the eyes for anterior uveitis type.
3. early intervention is mandatory to prevent vision loss
4. treat infectious type with appropriate drug such as antibiotics antiviral antifungal etc.
5. treat non infectious type with steroid

Date printed: 2017-Sep-17

WARNING/DISCLAIMER!!!
Above Diagnosis and recommendation is for INFORMATION and LEARNING Purposes only.
IT DOES NOT REPLACE PHYSICAL CONSULTATION WITH YOUR EYE DOCTOR
******END OF REPORT******

Figure 4.44: Eye test and Diagnosis result display and print out

Figures 4.45 – 4.47 provide help facility to the user. It also gives the user opportunity to participate in the future improvement of the program by reporting any bug encountered during the program run. Also the contact information about the author was made available to the user for easy communication with the system developer.

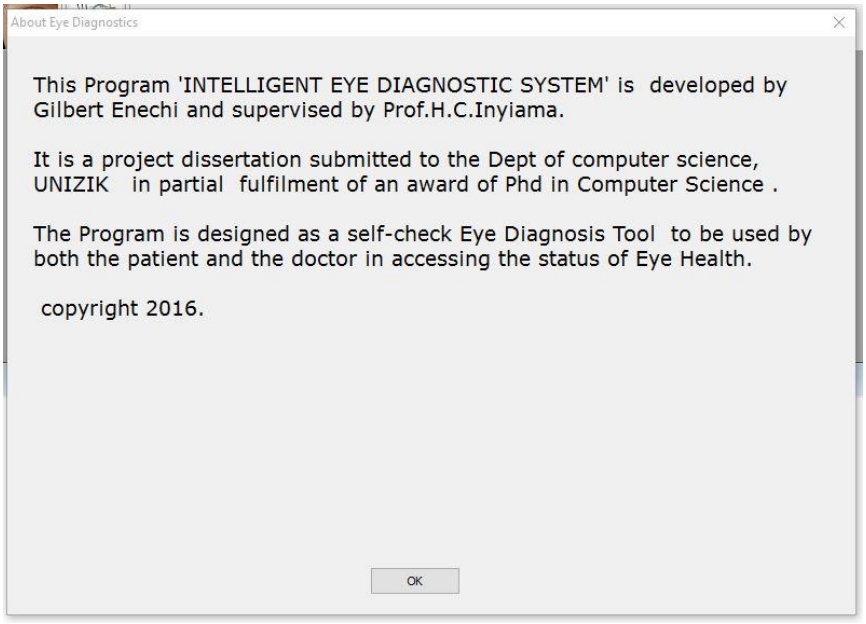


Figure 4.45: Help about Eye diagnostics system

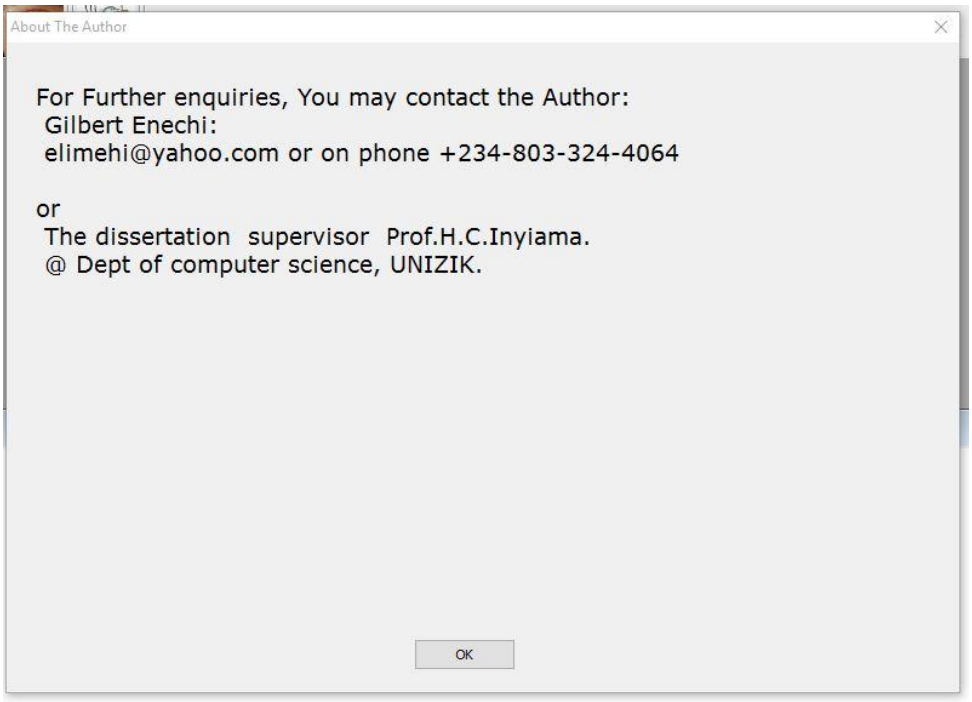


Figure 4.46: Help_About Author

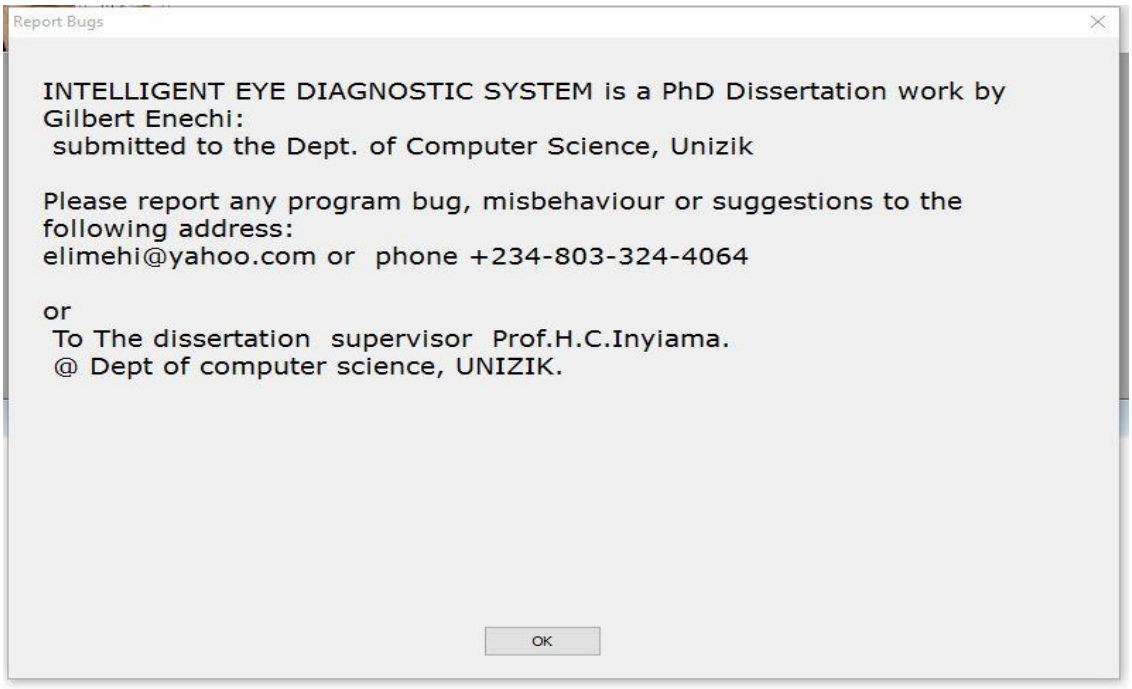


Figure 4.47: Help_Report Bugs

Password facility helps in the protection of vital system resources from malicious access or unintended database update. Only the system Admin or the doctor can update the database and therefore must provide a secured password at system log-in. The password can be changed at will by the appropriate user when necessary. In Figure 4.48 – 4.49, a user attempted to change his password and was asked to enter his old password first. Having provided the correct password known to the system, he was then permitted to provide a new password and after a follow up confirmation, the old password was overwritten with the new password.

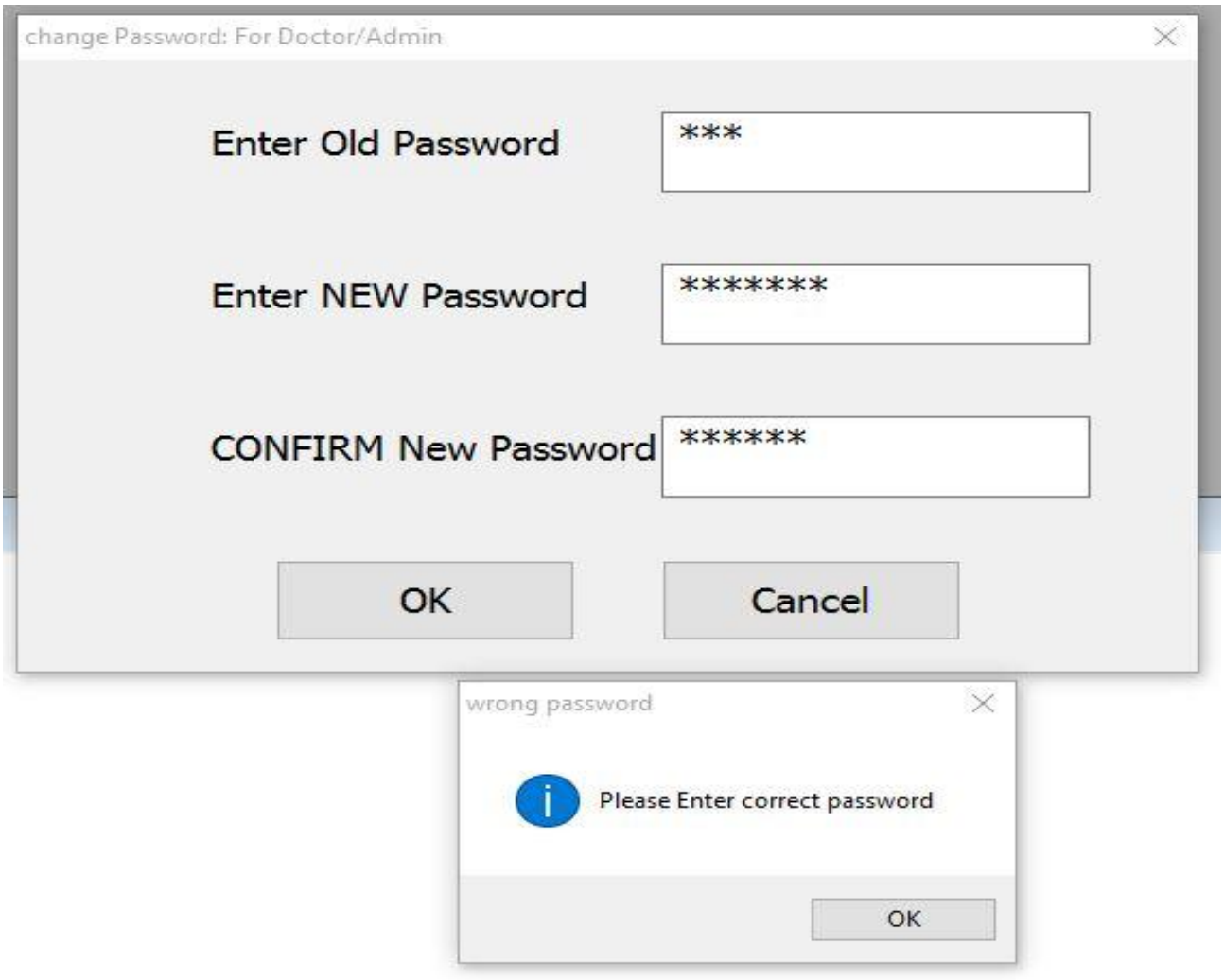


Figure 4.48: Wrong password change notified

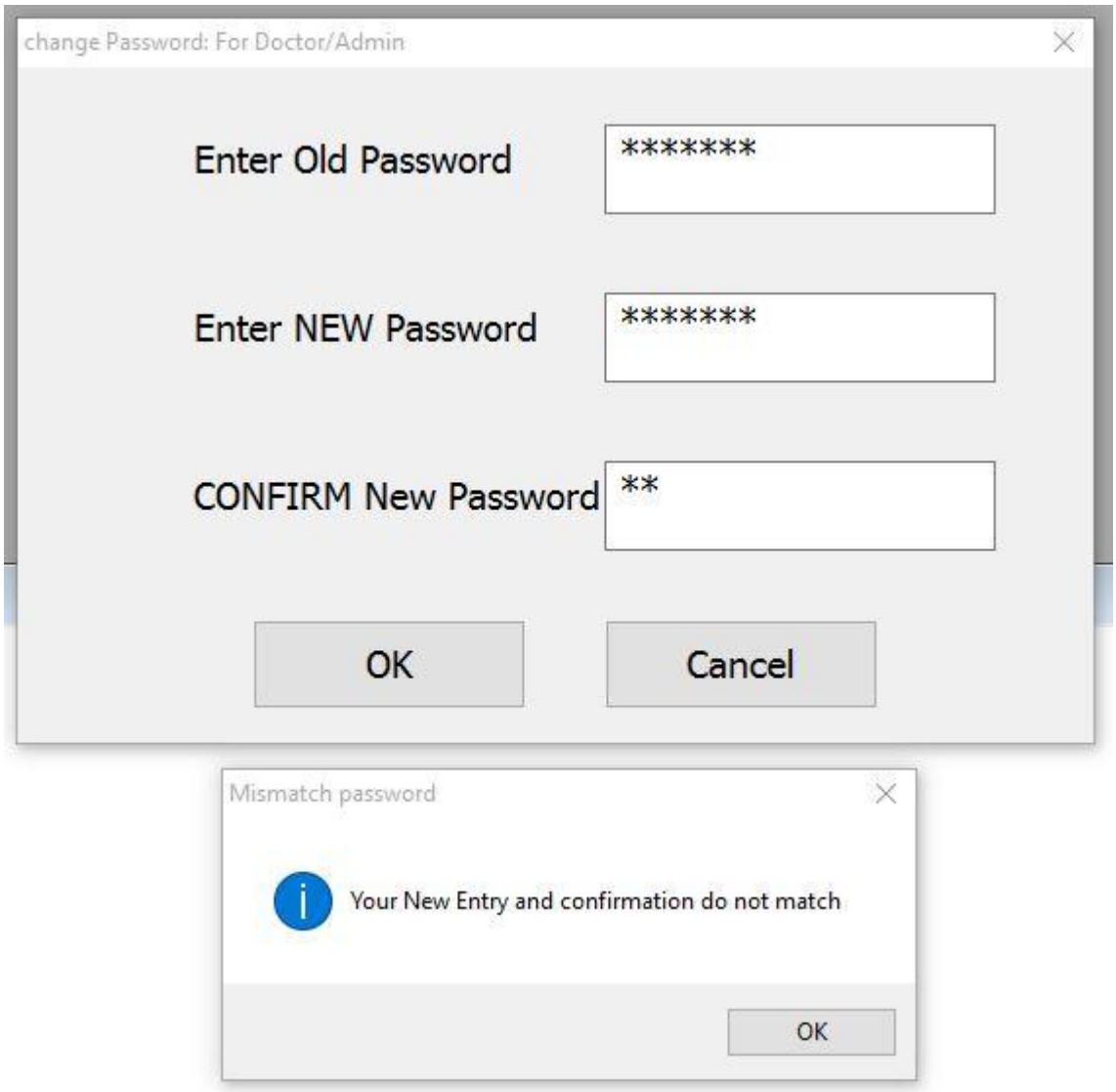


Figure 4.49: Mismatch password change notified

As earlier noted by Feigenbaum et al.(1992), the ability of an expert system to explain actions or reasoning behind its diagnosis and recommendations can increase the confidence the user will have on that system especially in matters concerning human health. During a consultation with a human doctor, the doctor will pose a question to the patient and expects to receive an answer. In some situations, the patient has ethical rite to demand from the doctor why such a question was asked. Similarly, during eye test with CFRMFEDD, the patient can demand from the system to explain the rationale behind the questions asked or the diagnosis made. Figure 4.50 – 4.51 showed a situation where a patient who was diagnosed of "**aides pupil and Cataract**" demanded for explanation. The system replied accordingly by itemizing its reasoning.

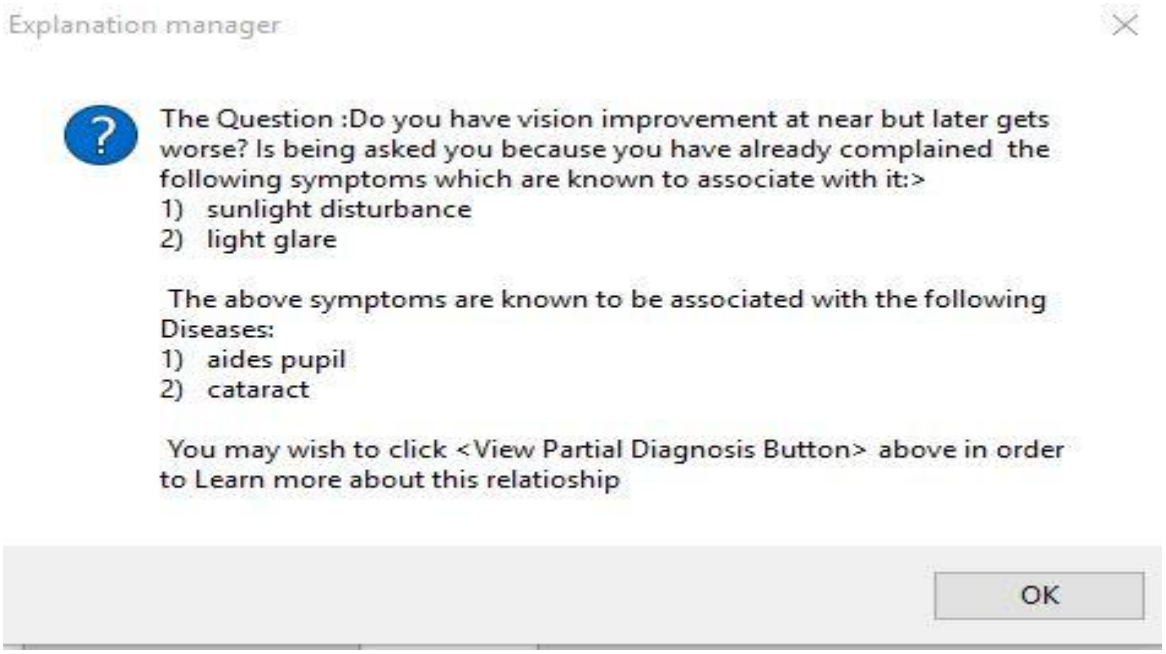


Figure 4.50: System action explained to user

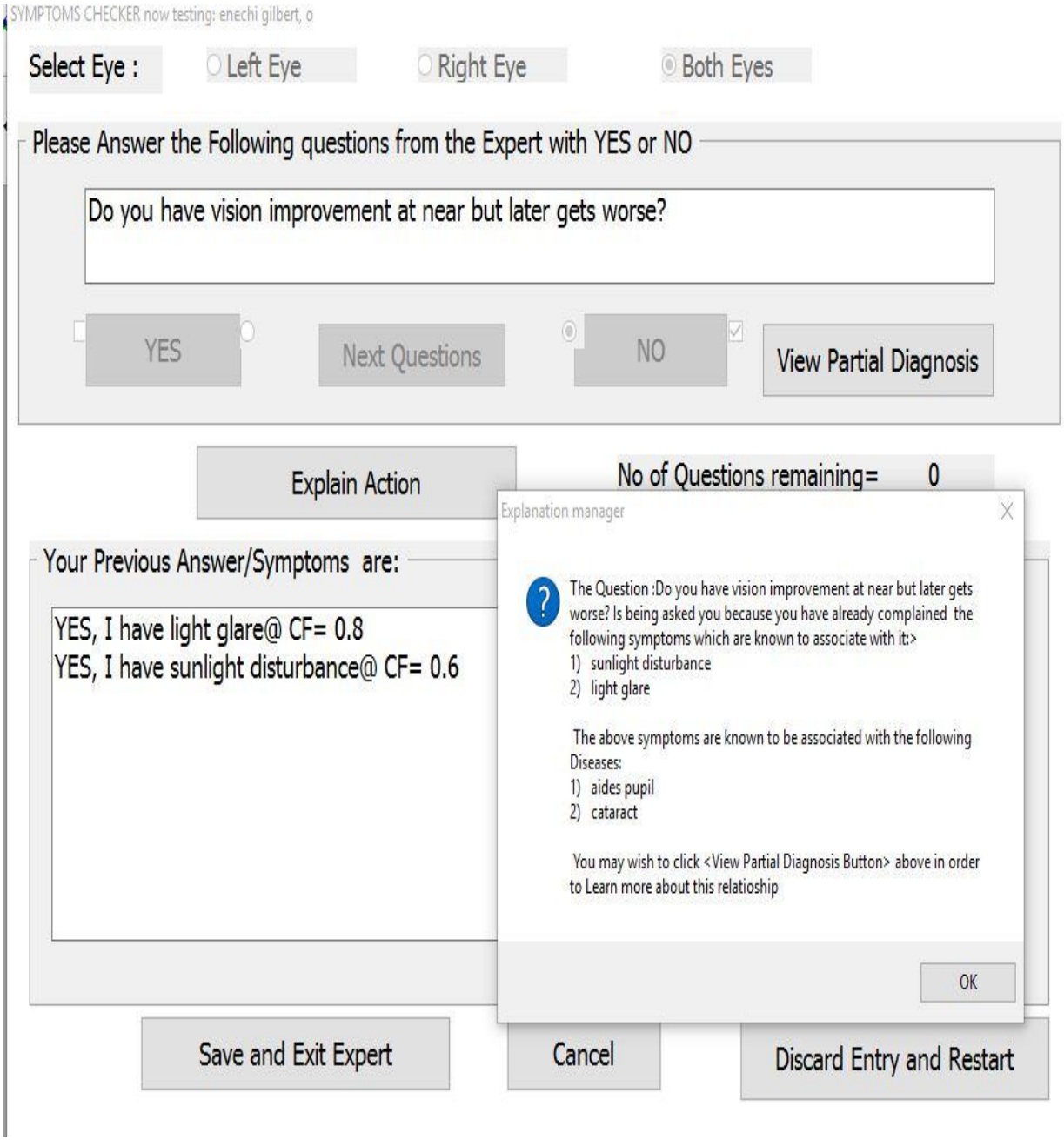


Figure 4.51: User demanding Explanation

CHAPTER FIVE

SUMMARY, CONCLUSIONAND RECOMMENDATION

5.1 Summary

Recent advances in medical sciences and in computer technology have sparked a paradigm shift from therapeutic medicine to preventive medicine. The power to control the personal health of an individual is now placed at the hands of the individual himself. The ability to detect deviations from normal health by self is the beginning of eradication of avoidable ailments such as blindness. Prevention of avoidable blindness by all by the year 2020 is a noble and ambitious goal set by the world health organization's vision 2020 team. One of the ways in achieving this goal is what CFRMFEDD was designed to handle. CFRMFEDD is designed to enable an individual test his/her vision through the help of non-expert/medical assistant and then take appropriate action(s). Development of CFRMFEDD does not succeed on platter of gold. Numerous challenges faced the infant stages of this dissertation. One of the earlier challenges encountered by the researcher was the hording of information by the domain experts who initially had misconstrued fear of job competition and thought that the system when fully implemented could take over their jobs. It took the assurances of the researcher to convince the experts otherwise, yet some still lived with that impression and hence could not open up completely as expected.

Since this dissertation is innovative and rare as it combined two important eye examination and diagnostic protocols into one platform, getting relevant resource materials during project development was challenging. As stated by WHO(2012), about 80% of global blindness are due to causes that are preventable, therefore, CFRMFEDD will prove to be one of the rare expert systems needed urgently especially in developing countries for elimination of preventable blindness.

When CFRMFEDD is installed in computers that are accessible and within reach of the patients, the patient can check the status of his/her vision regularly. This fact alone has a multiplier beneficial effect. For instance, the frequent visits to eye doctors will reduce as patients only have to consult their doctors for real cases. Indirectly, the patient will save money on transport fare, the doctor's consultation fees and also save the risks of road traffic mishaps often associated with such frequent visits. On the other hand, the eye doctors are saved the time for unnecessary consultations and may harvest and invest this time on research and literary publications. But, the afore-mentioned shall not leave one with the impression that doctor's job will be affected but rather it will boost patronage as some patients could still be treated (even in the eye clinic) by an assistant in the absence of eye doctor. Moreover, patients will become more alert and aware of their visual status and hence make adequate consultations as necessary.

CFRMFEDD again shall be an inevitable tool at the hands of medical students, ophthalmology residents, consultant ophthalmologists, optometric interns, practicing optometrists, general medical practitioners, etc, especially in the area of learning and research. When CFRMFEDD is run at demo-mode, students can learn various relationships between symptoms, signs, risk factors and treatment plans for most common eye conditions and could develop their training and diagnostic skills with this facility. Also learning and mastering the process of recording and scoring visual acuities for a patient shall be an added advantage of using CFRMFEDD especially for the ophthalmic nursing students.

Although CFRMFEDD, like any other invention of man is not without shortfalls, it is hoped that these shortfalls and other services it has left undone will be a point of stimulus and anchor for future researchers on this dissertation.

Once again this dissertation has once more reinforced the conviction and proved that computer technology can intelligently be applied to help solve the problems of modern man.

5.2 Conclusion

An intelligent eye diagnostic model was developed and implemented. The model enabled the user to test his visual acuity through the help of a medical (non-expert) assistant. It allows the patient to present his symptoms and the degrees of certainty associated with the symptoms. It also allows the doctor to document eye diseases with their associated degrees of certainty. CFRMFEDD could performeye disease diagnosis and output a valid prescription and advisory note to the patient. The test results were analyzed and a comparable results were gotten with that of domain (human) expert. The knowledge base was dynamic and updatablеduring testing to include new diseases and disease attributes.Furthermore, a friendly user interface enabled the user to navigate the system with ease. With the training and educational tools provided by this model, resident doctors, medical students, other clinicians and even patients will be able to learn more about eye diseases, signs, symptoms, risk-factors and treatment options. Test results weresaved in computer hard drive and hard copies are printed which a patient could present to eye doctor at a convenient time when necessary.With this print out, the doctor could at least have a snapshot of patient's eye condition as it happened at the beginning of the condition.

CFRMFEDD will no doubt increase the consciousness of the patients about their eye health, save the patients expenses on health, save the eye doctors more time to invest into research, enrich the quality of medical training in schools and provide opportunities for exchange of ideas, skills and research findings. The overall impact of this dissertation is to help reduce preventable blindness globally and indirectly increase the per capita income of individuals and the gross domestic products of nations. Persons who would have been unnecessarily incapacitated due to blindness could then positively contribute their own quota in the development of the economy of their state. However, other aspects of eye diagnosis which were not covered by this model could provoke the need for future research.

5.3 Recommendations

The following recommendations are proposed:

a) That certainty factor model be applied as a method of reasoning and rule base model applied as a method of knowledge representation in designing expert systems for small knowledge base /database set.
b) That CFRMFEDD be deployed in medical schools and schools of optometry in developing countries for the training, learning and research activities for both the clinical students and teaching staff.
c) That CFRMFEDD be deployed in primary healthcare centers in the developing countries where non-medical staff, nurses and other para-medical staff could use it to evaluate eye patients in remote and inaccessible communities.
d) That a further research be conducted to see how this model could be applied in other areas of medicine and human endeavor.

5.3.1 Application Areas

CFRMFEDD may be applied in the following areas of human endeavor

a) Community Health centers
b) Ophthalmology clinics
c) Optometry clinics
d) General medicine
e) Ophthalmic laboratories
f) Home use
g) Academic institutions

h) Teaching hospitals

i) Research institutes

j) Schools

5.3.2 Suggestions for further Research

It is noted earlier that providing CFRMFEDD services on the internet could help extend the accessibility of this system to a larger community and network. The researcher therefore suggests that further work on this dissertation may focus on the design, implementation and hosting of web based platform for the system.

Since the standard distance for using CFRMFEDD for measuring visual acuity is 3m and the current system uses the standard extended-cable or wireless keyboard/mouse for getting patient's response, further research is needed in developing a wireless large size 6-keypad device for getting input from patients some of who could not see the standard small-size input device due to their vision status.

5.3.3 Review of Achievements

The researcher has developed an Intelligent Eye Diagnostic Model that could measure the visual acuity of patients and provide diagnosis. By so doing the following achievements could be noted.

a) The actual results produced by CFRMFEDD is similar with the expected results. CFRMFEDD also proved that expert systems can be reliable, consistent, and repeatable and can therefore withstand stress and overload.

b) CFRMFEDD has revealed a model of diagnosis which can universally be applied in other areas ofhuman endeavor (engineering, agriculture, social sciences, banking, economy, etc) where troubleshooting and problem diagnosis are task focus.

c) CFRMFEDD has proven that expert system can be a universal platform for convergence of ideas and knowledge of various experts.

d) The knowledge of experts can be stored and used intelligently even beyond the lifespan of the domain expert.

e) It is possible to apply artificial intelligence technology through an expert system by integrating the interface, the inference engine and the knowledge base.

f) That expert system can help in check-mating or eliminating incidences and prevalence of medical conditions such as blindness.

g) Expert system can be inevitable for learning, research and tutelage

h) The researcher has developed a user-friendly interface which can be used by various classes of people irrespective of gender, literacy level and social status; and also has developed an inference engine that uses the knowledge base extracted from domain experts to measure the visual acuity of patients and diagnose various eye conditions.

5.4 Contribution to knowledge

Development of CFRMFEDD has contributed to the body of knowledge as follow:

a) This work is rare, unique and adventurous as presently there is no known system in developing countries which has combined the ability of measuring visual acuity with the power of eye disease diagnosis in a single platform. The ones available could either measure visual acuity or diagnose eye conditions but not both.

b) It has provided a universal model for the design and implementation of diagnostic and troubleshooting protocols in most human related activities.

c) It has empowered the individuals and the patients to take their health destiny at their own hand and enables them to check their ocular health status at convenience and then take necessary action.

d) It has contributed to the pool of research database and knowledge in medical diagnosis technology as several researchers, students and clinicians may refer to this work now and in future.

References

Abdull, M., Sivasubramaniam, S., Murthy, G., Gilbert, C., Abubakar, T., Ezelum, C., & Rabiu, M. (2009). Causes of Blindness and Visual Impairment in Nigeria: The Nigeria National Blindness and Visual Impairment Survey. *Investigative Ophthalmology & Visual Science, 50*(9), 4114-4120. Retrieved December 2, 2016

Agrawal, R., & Singh, S. (2014). Rule Based Expert System with an Object-Oriented Database for an Educational Institute. *Int. Jr. of Computing and Technology, 1*(1), 166-168. Retrieved from www.IJCAT.org

Ambinder, E. P. (2000). Oncology and the Information Revolution. In R. Bast, D. W. Kufe, & R. Pollock (Eds.), *Holland-Frei Cancer Medicine* (5th ed.). B.C. Decker. Retrieved January 5, 2013, from http://www.ncbi.nlm.nih.gov/books/NBK20949/

American_Optometric_Association. (2016). *Comprehensive Eye and Vision Examination*. Retrieved December 2, 2016, from http://www.aoa.org: http://www.aoa.org/patients-and-public/caring-for-your-vision/comprehensive-eye-and-vision-examination?sso=y

Aniba , M. R., Siguenza, S., Friedrich, A., Plewnia, F., Poch, O., Marchler-Bauer, A., & Thompson, J. (2009). Knowledge-based expert systems and a proof-of-concept case study for multiple sequence alignment construction and analysis. *Briefings in Bioinformatics, 10*(1), 11-23.

Anjaneyulu, K. S. (1998). *Expert Systems: An Introduction.* Retrieved January 12, 2013, from http://www.ias.ac.in/resonance/Mar1998/pdf/Mar1998p46-58.pdf

August, C. (1988). Visual Acuity Measurement. *Italian Journal of Ophthalmology*, 1-15.

August, C. (2001). The Historical Evolution of Visual Acuity Measurement. *Proceeding of 2001 Annual Meeting of the Cogan Society for Ophthalmic History.* Retrieved november 7, 2012, from http://www.ski.org/Colenbrander/Images/History_VA_Measuremnt.pdf

Bach, M. (1996). The "Freiburg Visual Acuity Test"- Automatic measurement of visual acuity. *Optometry and Vision Science, 73*, 49-53.

Bach, M. (2007). The Freiburg Visual Acuity Test - Variability unchanged by post-hoc re-analysis. *Graefe's Arch Clini. Exp. Ophthalmol, 245*, 965-71.

Bach, M. (2011). *Freiburg Vision Test ('FrACT').* Retrieved 2012, from http://michaelbach.de/fract/index.html

Bailey, I. (1976). New Design Principles for Visual Acuity Letter Charts. *Am.Optom & Physiol Opt, 53*, 740.

Bank, G. (1986). Artificial intelligence in medical diagnosis: The INTERNIST/CADUCEUS approach. *Crit Rev Med Inform, 1*(1), 23-54.

Barnett, G. O., Famiglietti, K. T., Kim, R. J., Hoffer, E. P., & Feldman, M. J. (1998). DXplain on the Internet. *Proceedings of AMIA Annual Symposium, Fall 1998*, (pp. 607-11).

Bauer, B. A., Lee, M., Bergstrom, L., Wahner-Roedler, D. L., Bundrick, J., Litin, S., & Hoffer, E. (2002). Internal medicine resident satisfaction with a diagnostic decision support system (DXplain) introduced on a teaching hospital service. *Proceedings of AMIA Annual Symposium, 2002*, pp. 31-5.

Bhupendra, K. (2016). *Representing uncertainty in expert system.* Retrieved December 9, 2016, from http://www.slideshare.net: http://www.slideshare.net/magician008/representing-uncertainty-in-expert-systems

Bogdan , L. (2006). *Uncertainty Management.* Retrieved January 6, 2017, from www.computing.surrey.ac.uk: www.computing.surrey.ac.uk/teaching/2006-07/.../week4_Intro_Uncertainty_2.ppt

Bond, W., Schwartz, L. M., Weaver, K. R., Levick, M., & Graber, M. L. (2012). Differential diagnosis generators: An evaluation of currently available computer programs. *J Gen Intern Med, 27*(2), 213-9. doi:10.1007/s11606-011-1804-8.

Buchanan, B. G., & Shortliffe, E. H. (1984). Rule based expert systems: The MYCIN_experiments of the Stanford Heuristic Programming Project. *ISBN 978-0-201-10172-0*.

Cara, S. (2013). *OTM Test1*. (C. H. Graham, Editor) Retrieved from https://www.studyblue.com: https://www.studyblue.com/notes/note/n/otm-test-1/deck/7472092

Catford, G. V. (1973). Development of visual acuity. *Archives of Disease in Childhood, 48*(1), 47-50.

Chakraborty, R. C. (2010). *Artificial Intelligence: Introduction.* Retrieved December 12, 2013, from http://www.myreaders.info/01-Introduction_to_Artificial_Intelligence.pdf

Chandrasekaran, B., & Johnson, T. (1993). *Generic Tasks and Task Structures: History, Critique and New Directions.* Retrieved January 5, 2013, from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.21.1227

Cimino, C., Barnett, G. O., Hassan, L., Blewett, D. R., & Piggins, J. L. (1991). Interactive Query Workstation: Standardizing access to computer-based medical resources. *Comput Methods Programs Biomed, 35*(4), 293-9.

Claffie, S. (2006). *). iChartPlus: Visual Acuity Digital Eye Chart Testing Software for Eye Care professionals by Eye Care Professionals.* Retrieved May 20, 2012, from http ://www. icharplus.com/.

Coiera, E. (2003). Clinical Decision support system. In *Guide to Health Informatics* (2nd ed.). London: Arnold.

Craig, B. (2011). *Systems Analysis: Document Existing System(s)_ Gather data.* Retrieved June 15, 2012, from http://it.toolbox.com/blogs/enterprisesolutions/systems-analysis-document-existing-systems-gather-data-43880.html

Daly, J. (1989). *efficient method and apparatus for creating and storing characters for display on a video screen.* USA, Washington: patent No 4907282.

Dave, J. (2010). *Eyesite: Self-service vision test.* Retrieved June 4, 2012, from http://www.solohealth.com/eyesite/

Davidzon, G., Pankey, E., Loudon, T., Schmid, P., Berger, B., & Berkowicz, D. (2008). SemanticDx: A prototype to facilitate use of biostatistics at the point-of-care. *Proceeding of AMIA Annual Symposium, 2008 Nov 6*, (p. 921).

Diez, F. J., & Druzdel, M. J. (2006). Reasoning under Uncertainty. In *Encyclopedia of Cognitive Science.*

Elhanan, G., Socratous, S. A., & Cimino, J. J. (1996). Integrating DXplain into a clinical information system using the World Wide Web. *Proceeding of AMIA Annual Fall Symposium*, (pp. 348-52).

Elkin, P. L., Liebow, M., Bauer, B. A., Chaliki, S., Wahner-Roedler, D., Bundrick, J., . . . Lee, M. (2010). The introduction of a diagnostic decision support system (DXplain) into the workflow of a teaching hospital service can decrease the cost of service for diagnostically challenging Diagnostic Related Groups (DRGs). *Int J Med Inform, 79*(11), 772-7.

Engelmore, R. S., & Feigenbaum, E. (1993). *EXPERT SYSTEMS AND ARTIFICIAL INTELLIGENCE.* Retrieved January 2013, 4, from http://www.wtec.org/loyola/kb/c1_s1.htm

Fatimah, I., Juliana, B., & Fathilah, J. (2001). *Expert System for Early Diagnosis of Eye Diseases Infecting the Malaysian Population.* Retrieved from http://eprints.um.edu.my: http://eprints.um.edu.my/9296/1/Expert_system_for_early_diagnosis_of_eye_diseases_infecting_the_Malaysian_population.pdf

Feigenbaum, E. A., Friedland, P. E., Johnson, B. B., Nii, P. H., Schorr, H., Shrobe, H. B., & Engelmore, R. S. (1992). Knowledge-Based Systems Research and Applications in Japan. *AI magazine, 15*(2), 29-43.

Fisher, J. (1990). *MYCIN Clinical Decision Support System.* Retrieved september 27, 2012, from http://neamh.cns.uni.edu/MedInfo/MYCIN.html

Fjed, H. (2003). Towards guidelines for touch screen design: Perception of Button form and extension. In M. Rauterherg (Ed.), *LNTERACT-03* (p. 76). IOS Press.

Freeman, W. T., Pastor, E. C., & Carmichael, O. T. (2000). Learning low-level vision. *Int. J. Comp. Vision, 40*, 25-47.

Friendly, D. (1984). An automated visual acuity testing computer program in Apple II system. *Am J Ophthalmol, 99*, 188-92.

Gary, H., & Jeniffer, P. (2016). *What To Expect During A Comprehensive Eye Exam.* Retrieved January 4, 2017, from http://www.allaboutvision.com: http://www.allaboutvision.com/eye-exam/expect.htm

Gerven, M. A., & Van, J. (1970). *Bayesian networks for clinical decision support : A rational approach to dynamic decision-making under uncertainty.* Retrieved September 10, 2012, from http://hdl.handle.net/2066/30201

Goiti, L. (2015). Fuzzy logic in wind energy. In M. Socoro, M. Juan, D. Antonio, & C. Carlos, *Soft computing applications for renewable energy and energy efficiency.* Hershey, PA, USA: Information science reference.

Gregory, F. (1979). The Seeds of Artificial Intelligence: SUMEX-AIM. *NIH Publication 80-2071, National Institutes of Health, Division of Research Resources, Washington, D.C.*

Harry, E. P. (1976). Presentation of the INTERNIST System. In N. J. Brunswick (Ed.), *Proceedings of the AIM Workshop, Rutgers University.*

Heckerman, D. E. (1989). A tractable algorithm for diagnosing multiple diseases. *Fifth Workshop on Uncertainty in Artificial Intelligence of Association for Uncertainty in Artificial Intelligence, Mountain View,* (pp. 174-81). California.

Heckerman, D., & Shortliffe, E. (1992). From certainty factors to belief networks. *Artificial Intelligence in Medicine, 4*(1), pp. 35-52. doi:10.1016/0933-3657(92)90036-0

Heckerman, D., Horvitz, E., & Nathwani, B. (1990). Toward Normative Expert Systems: The PATHFINDER Project. *A Conference Proceeding of the Stanford for biomedical informatics research.*

Heskes, T., Albers, K., & Kappen, H. J. (2003). Approximate inference and constraint optimisation. *Proceedings UAI,* pp. 313-320.

Hoffer, E. P., Feldman, M. J., Kim, R. J., Famiglietti, K. T., & Barnett, G. O. (2005). DXplain: Patterns of Use of a Mature Expert System. *Proceedings of AMIA Annual Symposium, 2005,* (pp. 321-5).

Hoffman , J., & Murph, R. (1993). *Comparison of Bayesian and Dempster-Shafer Theory for Sensing: A Practitioner's Approach.* Retrieved June 26, 2015, from http://citeseerx.ist.psu.edu: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.52.1457&rep=rep1&type=pdf

Hubley, J., & Gilbert, C. (2006). Eye health promotion and the prevention of blindness in developing countries: critical issues. *Br J Ophthalmol, 90*(3), 279–284.

Hvam, L. (2008). Knowledge Representation and Forms of Reasoning for Expert Systems. In *Product Customization.* Berlin, Heidelberg: Springer.

Illinois, U. (2006). *https://www.cs.uic.edu.* (C. University of Illinios, Ed.) Retrieved December 8, 2016, from Reasoning Under Uncertainty: https://www.cs.uic.edu/~liub/teach/cs511-spring-06/cs511-uncertainty.doc

Imre, J. R., & Janos, F. (2008). Intelligent Systems. *Int. J. of Computers, Communications & Control, 3*, pp. 132-38.

Jack, D. M. (1982). INTERNIST: Can Artificial Intelligence Help? In P. Donald, & C. Connelly (Eds.), *Clinical Decisions and Laboratory Use* (3rd ed., pp. 251-69). Minneapolis: University of Minnesota Press.

Jack, D. M. (1990). The Background of INTERNIST-I and QMR. In I. Bruce, A. Blum, & K. Karen (Eds.), *History of Medical Informatics* (pp. 427-33). New York, USA: ACM Press.

Jackson, P. (1998). *Introduction to Expert Systems (3rd Ed.).* Addison Wesley.

Jacob, B., Ole, J., & Erik , F. (2014). Barriers to medical device innovation. *Med Devices (Auckl), 2014*(7), 205-209. doi: 10.2147/MDER.S43369

Jags, E. (2012). *What are the component parts of an expert system?* Retrieved september 16, 2012, from http://www.jagsict.co.uk/Expert_systems/expert_05.html

Jesse, R., Luciano, L., & Dara, L. (2010). Physical Diagnosis. *Arch Ophthalmol, 128*(12), 1576-1582. doi:10.1001/archophthalmol.2010.275

Jimison, H. B. (1990). Generating explanations of decision models based on an augmented representation of uncertainty. In R. D. Shachter, L. Kanal, T. Levitt, & J. Lemmer (Eds.), *Uncertainty in Artificial Intelligence.* North Holland: New York, In press. .

Jorgo, C. (2010). Why Patients Should Be More Empowered: A European Perspective on Lessons Learned in the Management of Diabetes. *J Diabetes Sci Techno*, 1570-1573.

Kabari, L. G., & Nwachukwu, E. O. (2013). Neural Networks and Decision Trees For Eye Diseases Diagnosis, Advances in Expert Systems, Prof.V, Petrica (Ed),. InTech, Do:10.5772/51380, Available from http://www.intechopen.com/books/advances-in-expert-systems/neural-networks-and-decision-trees-for-eye-diseases-diagnosis. doi:10.5772/51380

Karunagapally, K. (2013). *Test types used in optometry*. Retrieved January 6, 2018, from https://www.slideshare.net/pravi_dear/types-of-test-charts

Kelly, R. (2017). *How to make an inference in 5 easy steps*. Retrieved January 15, 2017, from http://www.thoughtco.com

Kendal, K. (1988). *Systems Analysis & Design.* Prentice Hall.

Klein, J. G. (2005). Five pitfalls in decisions about diagnosis and prescribing. *British Medical Journal, 330*(7494), 781-783.

Kragt, M. (2009). *A beginners guide to Bayesian network modelling for integrated catchment management.* Australian Government, Environment, Water heritage and Arts. Landsacpe Logic. Retrieved November 6, 2016, from http://www.utas.edu.au: http://www.utas.edu.au/__data/assets/pdf_file/0011/588467/TR_9_BNs_for_Integrated_Catchment_Management.pdf

krithica, S. (2012). Efficacy of a remote based computerized visual acuity measurement. *Br J. Ophthalmol, 96*(7), 987-90.

Kuchenbecker, J. (2002). Options and limits of visual function tests available on the internet. *Ophthalmologe, 99*(11), 866-72.

Kulikowski, C. A., & Weiss, S. M. (1982). Representation of Expert Knowledge for Consultation: The CASNET and EXPERT Projects. In P. Szolovits (Ed.), *Artificial Intelligence in Medicine.* BouldeR, Colorado: Westview Press.

Kumar, S. (2008). Automated determination of distance visual acuity: Towards. *Clinical and Experimental Optometry, 9*(1), 545-550.

Kurniawan, R., Yanti, N., Nazri, M., & Zulvandri, K. (2014). 2014 International Conference of Advanced Informatics: Concept, Theory and Application (ICAICTA). IEEE. doi:10.1109/ICAICTA.2014.7005925

Landis, J., & Kosch, G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics, 33*(1), 159-174. Retrieved February 2, 2017, from http://www.jstor.org/stable/2529310

Lars, F. (1986). Vanishing Optotypes: New type of acuity test letters. *Arch.Ophthalmol, 104*(8), 1194-98.

Lauritzen, S. L., & Spiegelhalter, D. J. (1988). Local computations with probabilties on graphical structures and their application to expert systems. *Royal Statistical society, B*(50), 154–227.

Lemaire, J. B., Schaefer, J. P., Martin, L. A., Faris, P., Ainslie, M. D., & Hull, R. D. (1999). Effectiveness of the Quick Medical Reference as a diagnostic tool. *CMJ, 161*(6), 725-8.

lemay, s. (2008). *Aspect Ratio Adaptable Data Set.* USA: Patent 20080111841.

London, S. (1998). DXplain: A Web-based diagnostic decision support system for medical students. *Med Ref Serv Q, 17*(2), 17-28.

Mark, L. (2001). *A Tutorial on Bayesian Belief Networks.* Retrieved April 7, 2015, from https://pdfs.semanticscholar.org: https://pdfs.semanticscholar.org/ed54/3eedde24edd50e39f5567f036b632499240a.pdf

Mark, W. (2006). *Essential Optics Review for the Boards: Types of Visual Acuity Testing*. Retrieved January 4, 2017, from http://www.medrounds.org: http://www.medrounds.org/optics-review/2006/05/31.html

Masić, I., Ridanović, Z., & Pandza, H. (1999). Expert systems in pulmonology. *Med. Arh, 53*(3 Suppl 1), 39-42.

McCorduck, C., & Pamela, U. (1979). *Machines who think.* San Francisco: W H. Freeman.

McTear, M. F. (2002). Spoken dialogue technology: Enabling the conversational user interface. *ACM Computing Surveys, 34*, p. 90.

Merck, D. (2006). *Disadvantages Of Self-help.* Retrieved January 2, 2017, from https://www.mentalhelp.net: https://www.mentalhelp.net/articles/disadvantages-of-self-help/

Michael, P. (2014). *Windows 10 new fwindows-10-new-features-a-summary.* Retrieved march 10, 2016, from https://4sysops.com: (Michael Pietroforte (2014), Windows 10https://4sysops.com/archives/windows-10-new-features-a-summary/#two-update-modes

Milanich, A. (2008). New Optotypes for checking visual acuity. *Measurement techniques, 51*(8), 865-67.

Miller, R. A., & Masarie, F. E. (1989). Use of the Quick Medical Reference (QMR) program as a tool for medical education. *Methods Inf Med, 28*(4), pp. 340-5.

Miller, R. A., McNeil, M. A., Challinor, S. M., Masarie, F. E., & Myers, J. D. (1986). The INTERNIST-1/Quick Medical Reference project-status report. *West J Med, 145*(6), 816-22.

Miller, R. A., Pople, H. E., & Myers, J. D. (1982). INTERNIST-1: An experimental computer-based diagnostic consultant for general internal medicine. *N Engl J Med, 307*(8), 468-76.

Mooij, J. M., Wemmenhove, B., Kappen, , H. J., & Rizzo, T. (2007). Loop corrected belief propagation. *Proceedings of AISTATS*.

Murphy, A. H. (1966). A note on the utility of probabilistic predictions and the probability score in the cost-loss ratio decision situation. *Journal of Applications in Meteorology, 5*, 534-37.

Murphy, B. P., Weiss, Y., & Jordan, M. I. (1999). Loopy belief propagation for approximate inference: An empirical study. *Proceedings of Uncertainty in AI*, pp. 467–475.

Naser, A., & Zaiter, A. (2008). *Expert System for Diagnosing Eye Diseases Using Clips.* Retrieved from http://www.jatit.org: http://www.jatit.org/volumes/research-papers/Vol4No10/5Vol4No10.pdf

Nathwani, B. N., Clarke, K., & Clarke, T. (1997). Evaluation of an expert system on Lymph node pathology. *PubMed, 9*, pp. 1097-110. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/930873628(9), 1097-110.

Ntsoane, M., & Oduntan, O. (2010). A review of factors influencing the utilization of eye care services. *S Afr Optom, 69*(4), 182-192.

ODORBN. (2012). *2012 Registered Optometry/Eye Clinics.* Retrieved January 5, 2013, from http://www.odorbn.gov.ng/LIST%20OF%20CLINICS.htm

Ophthalmology, I. C. (1984). *Visual Acuity Measurement standards.* Retrieved January 5, 2017, from http://www.icoph.org: http://www.icoph.org/dynamic/attachments/resources/icovisualacuity1984.pdf

Pearl, J. (1988). Probabilistic reasoning in intelligent systems. In K. Morgan (Ed.), *Networks of Plausible Inference.* San Francisco, California.

Perry, C. A. (1990). Knowledge bases in medicine: A review Bull. *Journal of Medical Library Association, 78*(3), 271-82.

Pople, H. (1976). Presentation of the INTERNIST System. *AIM Workshop of Rutgers University.* New Brunswick, New York.

Randolph, A., & Miller, A. (1982). INTERNIST-1: An Experimental Computer-Based Diagnostic Consultant for General Internal Medicine. *New England Journal of Medicine, 307*, 468-76.

Regina, B., & Daryl, M. (2012). *A new approach to expert system explanations.* Retrieved October 29, 2012, from http://www.cogentex.com/papers/explanation-iwnlg98.pdf

Reich, L. N., & Ekabutr, N. (2002). The Effects of Optical Defocus on the Legibility of The Tumbling-E and Landolt-C. *Optom Vis Sci, 79*(6), 389.

Reus, N. (1994). *Assessment of benefits and drawbacks of using fuzzy logic. N WO especially in fire control systems.* TNO defence reserach: Netherland organization for applied scientific research.

Roger, T. (1985). Expert systems methodology: A conceptual analysis. *International Journal of Systems Research and Information Science, 1*, 11-22.

Rotheram-Borus, M. J., Ingram, B. L., Swendeman, D., & Lee, A. (2012). Adoption of self-management interventions for prevention and care. *J Prim Care, 39*(4), 649-60.

Scott, O. (2006). *Design and Implementation of interactive Visual Acuity chart.* Retrieved June 11, 2012, from http://www.smbs.buffalo.edu/oph/ped/IVAC.html.

Serge, R., & Tricia, U. (2012). Future trends in Global Blindness. *Indan J Ophthalmol, 60*(5), 387-395. doi:10.4103/0301-4738.100532

Shah, N. (2011). Vanishing optotype acuity: Repeatability and effect of the number of alternatives. *Ophthalmic Physiol Opt, 31*, 17-22.

Shankar, P., Walji, M., Ali, A., & Johnson-Throop, K. A. (2003). Decision support systems to identify different species of malarial parasites. *AMIA Annual Symposium Proceedings*, (p. 1006).

Shaun, S. (2017). *Medical device integration strategies explained.* Retrieved from http://searchhealthit.techtarget.com: http://searchhealthit.techtarget.com/feature/Medical-device-integration-strategies-explained

Sherman, A., & Howard, B. (2012). *A Comparative Study of Computer-Aided Clinical Diagnosis of Birth Defects.* Retrieved october 28, 2012, from http://bitsavers.trailing-edge.com/pdf/mit/lcs/tr/MIT-LCS-TR-283.pdf

Shiva, V., & Ahmad, A. (2011). Characteristics of Computational Intelligence (Quantitative Approach). *Proceedings of The 22nd Midwest Artificial Intelligence and Cognitive Science Conference* (p. 195). Ohio, USA: Midwest Artificial Intelligence and Cognitive Science. Retrieved January 20, 2017, from http://ceur-ws.org: http://ceur-ws.org/Vol-710/paper8.pdf

Shortliffe, E. H. (1976). *Computer-Based Medical Consultation: MYCIN.* New York: American Elsevier Press.

Shortliffe, E. H., & Buchanan, B. G. (1975). A model of inexact reasoning in medicine. *Mathematical Biosciences , 23*(3-4), 351-379. doi:10.1016/0025-5564(75)90047-4.

Shu-Hsien, L. (2005). Expert system methodologies and applications—a decade review from 1995 to 2004. *Expert Systems with Applications, 28*, 93-103. Retrieved March 5, 2017, from http://www.sci.brooklyn.cuny.edu/~kopec/cis718/fall_2005/sdarticle5.pdf

Shwe, M. A., Middleton , B., Heckerman, D.E, D. E., Henrion, M., Horvitz, J., Lehman, H. P., & Coooper, G. F. (1991). Probabilistic Diagnosis Using a Reformulation of the Internist-1/ QMR Knowledge Base. *Methods of Information in Medicine, 30*, 241-255.

Sotos, J. G. (1990). MYCIN and NEOMYCIN: two approaches to generating explanations in rule-based expert system. *Aviat Space Environ Med, 61*(10), 950-4. Retrieved from MYCIN and NEOMYCIN: two approaches to generating explanations in rule-based expert .

Szolovits, P. (1982). Artificial Intelligence and Medicine. In P. Szolovits (Ed.), *Artificial Intelligence In Medicine* (pp. 10-50). Boulder, Colorado: Westview Press.

Taylor, H. R. (1978). Applying new design principles to the construction of an illiterate-E. *Am J Optom & Physiol OpticS, 55*, 348.

Transportation, U. S. (2010). *System engineering guidebook for ITS: Design speciation templates.* Retrieved April 12, 2013, from http://www.fhwa.dot.gov/cadiv/segb/views/document/sections/section8/8_4_7.cfm

Vangie, B. (2017). *Fuzzy Logic.* Retrieved January 15, 2017, from http://www.webopedia.com: http://www.webopedia.com/TERM/F/fuzzy_logic.html

Vinod, K. (2014). *Technology will replace 80% of what doctors do.* Retrieved from http://fortune.com: http://fortune.com/2012/12/04/technology-will-replace-80-of-what-doctors-do/

Wendy, S. W. (2003). *How Visual Acuity Is Measured.* Retrieved December 10, 2012, from http://www.mdsupport.org/library/acuity.html

WHO. (2006). *International Statistical Classification of Diseases and Related Health Problems 10th Revision (ICD-10) Version for 2010: Diseases of the eye and adnexa (H00-H59).* Retrieved December 16, 2016, from http://apps.who.int: Retrieved march 2, 2012, from http://apps.who.int/classifications/icd10/browse/2010/en#/H54.4

WHO. (2012). *Visual Impairment and Blindness: Key Facts.* Retrieved February 2, 2016, from http://www.who.int/mediacentre/factsheets/fs282/en/

Wiederhold, G., Shortliffe, E. H., Fagan, L. M., & Perreault, L. E. (2001). Medical Informatics: Computer Applications in Health Care and Biomedicine. New York: Springer Press.

Winston, P. H. (1977). *What is Artificial Intelligence?* Retrieved september 2012, from http://assets.cs.ncl.ac.uk/seminars/175.pdf

Wise, B. (1986). *An Experimental Comparison of Uncertain Inference Systems.* PhD Thesis, Carnegie-Mellon University, The Robotics Institute and Department of Engineering and Public Policy, Pittsburgh, PA.

Young, J. H. (2009). *Frame-based expert systems. In Notes for Langston University CS 4173, Artificial Intelligence, chap.5.* Retrieved November 2012, from http://comsci.us/ai/notes/chap05.html

Zhang , Y. (2006). *Learning with Bayesian Networks by Heckerman.* Retrieved December 15, 2016, from research.microsoft.com: research.microsoft.com/en-us/um/people/heckerman/tutorial.pdf