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DEVELOPMENT OF MALARIA PARASITE DIAGNOSIS EXPERT SYSTEM (MPDEXS) USING FUZZY LOGIC

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ABSTRACT **RESEARCH ARTICLE**

This research work is focused on the implementation of a Malaria Parasite Diagnosis Expert System (MPDExS) using fuzzy logic approach. The research work was necessary because of the problems of the existing system such as Malaria diagnosis can only be performed by a medical professional, late identification of malaria may lead to death. The traditional method of medical diagnosis of malaria is characterized with the problem of precision and accuracy. In view of these problems, the objectives of the study are to implement a fuzzy logic based system that can be used to diagnose malaria in the absence of medical professional, to create a system that can be used on a personal computer to diagnose malaria, thereby reducing need to visit health centre and to develop an expert system that will be used to diagnose malaria using fuzzy logic parameters such as Body Mass Index (BMI), temperature and pulse rate. The significance of the research work are it will provide non-medical experts with a useful tool for malaria diagnosis, the system can be used for the diagnosis of malaria even in the absence of a medical expert, the system will help to reduce late diagnosis of malaria. The development methodology used is waterfall model. The design methodology used is Object Oriented Analysis and design. MATLAB programming language is chosen for the implementation.

KEYWORDS: Malaria Parasite Diagnosis, Expert System (MPDExS), Fuzzy Logic, Implementation & Development.

INTRODUCTION

This research work presents a novel method for development of Malaria Parasite Diagnosis Expert System (MPDExS) using Fuzzy Logic. In this method, based on the selection of the problem, the expert system gives some symptom from which the user needs to select from. Based on the selection of symptoms, the user is again asked some questions. According to the answer selected, the fuzzy expert system diagnoses the disease based on its knowledge, add catalyst factor (if any), do ranking and gives the result in fuzzy form. As fuzzy expert system deals with uncertainty and vague terms, it is generally accepted in different spheres of life. This research is motivated by the fact the use of the computer system for collecting and processing medical information is very vital. Detecting diseases at early stage can enable medical officers to overcome and treat them appropriately (Awotunde, Matiluko and Fatai, 2014). Identifying the treatment accurately depends on the method that is used in diagnosing the diseases. A Malaria Parasite Diagnosis expert system (MPDExS) can help a great deal in timely diagnosis of malaria. The proposed system will conclude the diagnosis based on Body Mass Index (BMI), Pulse Rate and Temperature.

An expert system is a branch of Artificial Intelligence (AI) that employs human knowledge captured in a computer to solve problems that ordinarily require human expertise. Also, Expert system refers to a type of computer application program that makes decisions or solves problems in a particular field, such as finance or medicine, by using knowledge and analytical rules defined by experts in the field. Human experts solve problems by using a combination of factual knowledge and reasoning ability. In an expert system, these two essentials are contained in two separate but related components, a knowledge base and an inference engine. The knowledge base provides specific facts and rules about the subject, and the inference engine provides the reasoning ability that enables the expert system to form conclusions. Expert systems also provide additional tools in the form of user interfaces and explanation facilities. User interfaces, as with any application, enable people to form queries, provide information, and otherwise interact with the system. Explanation facilities, an intriguing part of expert systems, enable the systems to explain or justify their conclusions, and they also enable developers to check on the operation of the systems themselves (Osubor and Chiemeke, 2015).

Fuzzy logic is an expert system algorithm used for solving problems. Fuzzy logic can be conceptualized as a generalization of classical logic. Modern fuzzy logic was developed by Lotfi Zadeh in the mid-1960s to model those problems in which imprecise data must be used or in which the rules of inference are formulated in a very general way making use of diffuse categories (Zadeh, 1965). In fuzzy logic, which is also sometimes called diffuse logic, there are not just two alternatives but a whole continuum of truth values for logical propositions. A proposition A can have the truth value 0.4 and its complement Ac the truth value 0.5. According to the type of negation operator that is used, the two truth values must not be necessarily add up to 1. Fuzzy logic algorithm can be applied in the diagnosis of ailments such as malaria by evaluating the symptom variables used by doctors to conclude if a patient is sick of malaria.

Background to the Study

Identification of malaria at early stage will be helpful as its effect is increasing drastically and causing harm to people’s life. Malaria is due to imbalance (increase) of amount of parasites in the patient's blood and an indicator for the degree of infection. Malaria is caused by a blood parasite named Plasmodium spp. It affects at least 300 to 600 million people every year and causes an estimated 3 million deaths. Early diagnosis and treatment of it is necessary (WHO, 2011). Expert system for disease diagnosis is becoming popular day by day. In today's world people are so busy, that they hardly have enough time to visit a doctor. So they can use the service of this expert diagnosis system residing home or office and have an idea about the disease. After that they can consult the specialist doctor if it is necessary or serious. Fuzzy logic algorithm can help in the early diagnosis of malaria when applied properly.

Statement of the Problem

The problems that necessitate this research work are:

a. Malaria diagnosis can only be performed by a medical professional.
b. Late identification of malaria may lead to death.

c. The traditional method of medical diagnosis of malaria is characterized with the problem of precision and accuracy. This negative impact this imprecision and inaccuracy have on the populace justifies this research work. The reason for choosing fuzzy logic is to address the uncertainty that characterize traditional medical diagnostic practice.

Aim and Objectives of the Research

The aim of this work is to develop Malaria Parasite Diagnosis Expert System (MPDExS) using Fuzzy Logic. The following are the specific objectives to realize the aim:

a. To implement a fuzzy logic based system that can be used to diagnose malaria in the absence of medical professional.
b. To create a system that can be used on a personal computer to diagnose malaria, thereby reducing need to visit health centre.
c. To develop an expert system that will be used to diagnose malaria using parameters such as Body Mass Index (BMI), temperature and pulse rate.
d. To implement a system that will present result of diagnosis instantly after necessary inputs are captured.
e. To design a system that will utilize Body mass index, pulse rate and temperature to diagnose malaria.

Significance of the Research Work

The significance of the research work are:

a. It will provide non-medical experts with a useful tool for malaria diagnosis
b. As an expert system, the system can be used for the diagnosis of malaria even in the absence of a medical expert.
c. The system will help to reduce late diagnosis of malaria.
d. The system will aid timely delivery of medical service to patients.
e. The system will contribute to the development of the medical sector.

Literature Review

Malaria is a mosquito-borne infectious disease affecting humans and other animals caused by parasitic protozoans (a group of single-celled microorganisms) belonging to the Plasmodium type. Malaria causes symptoms that typically include fever, tiredness, vomiting, and headaches. In severe cases it can cause yellow skin, seizures, coma, or death. Symptoms usually begin ten to fifteen days after being bitten. If not properly treated, people may have recurrences of the disease months later. In those who have recently survived an infection, re-infection usually causes milder symptoms. The disease is most commonly transmitted by an infected female Anopheles mosquito. The mosquito bite introduces the parasites from the mosquito's saliva into a person's blood. The parasites travel to the liver where they mature and reproduce. Malaria is a dangerous global health problem hence accurate diagnosis and suitable treatment is needed to curb it. Nearly 300–500 million malaria cases is recorded, resulting in 2 million deaths annually. Malaria is the number one cause of morbidity, accounting for about 38% of all outpatient illnesses, 36% of all admissions, and 33% of all deaths in children below five years. Malaria is the highest cause of death in health institutions with mortality rate of 17.1% (Duodu, Panford and Hafron-Acquah).

To help in timely diagnosis and treatment of malaria, an expert system is needed to aid medical professionals

Fuzzy Logic

Fuzzy logic is an extension of Boolean logic by Lotfi Zadeh in 1965 based on the mathematical theory of fuzzy sets, which is a generalization of the classical set theory. By introducing the notion of degree in the verification of a condition, thus enabling a condition to be in a state other than true or false, fuzzy logic provides a very valuable flexibility for reasoning, which makes it possible to take into account inaccuracies and uncertainties. One advantage of fuzzy logic in order to formalize human reasoning is that the rules are set in natural language. Automated systems based on fuzzy logic have been used widely in control systems, household appliances, decision making systems, the medical and automobile industries. Terminologies used in fuzzy logic include but not limited to fuzzification, defuzzification, membership function, rules, domains, linguistic variables and so on. While Boolean algebra set values only include {0, 1}or {False, True}, it is believed through fuzzy logic that there are other values between 0 and 1 or False and True, which are sometimes referred to as in-between values. In other words, Boolean logic engages the principles of totally inclusive and exclusive rules on its set of {0, 1} while the principles of totally inclusive, exclusive and 'in between values' rules is engaged in fuzzy logic (Dernocourt, 2013).

The idea of fuzzy logic was first advanced by Dr. Lotfi Zadeh of the University of California at Berkeley in the 1960s. Dr. Zadeh was working on the problem of computer understanding of natural language. Natural language (like most other activities in life and indeed the universe) is not easily translated into the absolute terms of 0 and 1. (Whether everything is ultimately describable in binary terms is a philosophical question worth pursuing, but in practice much data we might want to feed a computer is in some state in between and so, frequently, are the results of computing.) It may help to see fuzzy logic as the way reasoning really works and binary or Boolean logic is simply a special case of it.

Fuzzy logic includes 0 and 1 as extreme cases of truth (or "the state of matters" or "fact") but also includes the various states of truth in between so that, for example, the result of a comparison between two things could be not "tall" or "short" but ".38 of tallness." Fuzzy logic seems closer to the way our brains work. We aggregate data and form a number of partial truths which we aggregate further into higher truths which in turn, when certain thresholds are exceeded, cause certain further results such as motor reaction. A similar kind of process is used in neural networks, expert systems and other artificial intelligence applications. Fuzzy logic is essential to the development of human-like capabilities for AI, sometimes referred to as artificial general intelligence: the representation of generalized human cognitive abilities in software so that, faced with an unfamiliar task, the AI system could find a solution (Uzoka, Obat & Barker, 2009).

Fuzzy logic starts with and builds on a set of user-supplied human language rules. The fuzzy systems convert these rules to their mathematical equivalents. This simplifies the job of the system designer and the computer, and results in much more accurate representations of the way systems behave in the real world. Additional benefits of fuzzy logic include its simplicity and its flexibility. Fuzzy logic can handle problems with imprecise and incomplete data, and it can model nonlinear functions of arbitrary complexity. "If you don't have a good plant model, or if the system is changing, then fuzzy will produce a better solution than conventional control techniques," says Bob Varley, a Senior Systems Engineer at Harris Corp., an aerospace company in Palm Bay, Florida. You can create a fuzzy system to match any set of input-output data. The Fuzzy Logic Toolbox makes this particularly easy by supplying adaptive techniques such as adaptive neuro-fuzzy inference systems (ANFIS) and fuzzy subtractive clustering.

Fuzzy logic models, called fuzzy inference systems, consist of a number of conditional "if-then" rules. For the designer who understands the system, these rules are easy to write, and as many rules as necessary can be supplied to describe the system adequately (although typically only a moderate number of rules are needed). In fuzzy logic, unlike standard conditional logic, the truth of any statement is a matter of degree. (How cold is it? How high should we set the heat?) We are familiar with inference rules of the form p -> q (p implies q). With fuzzy logic, it's possible to say (.5* p) -> (.5 * q). For example, for the rule if (weather is cold) then (heat is on), both variables, cold and on, map to ranges of values. Fuzzy inference systems rely on membership functions to explain to the computer how to calculate the correct value between 0 and 1. The degree to which any fuzzy statement is true is denoted by a value between 0 and 1. Not only do the rule-based approach and flexible membership function scheme make fuzzy systems straightforward to create, but they also simplify the design of systems and ensure that you can easily update and maintain the system over time (Beth, Claudio & Burhan, 2012).

Fuzzy Set Theory and Fuzzy Memberships

Fuzzy set theory is known as the basis of all fuzzy logic methods. With using fuzzy sets, crisp values can be defined with degree of memberships to predefine sets, mathematically. The scores of 1 and 0 are assigned to true and false in a set, respectively. Any vague reality can be clarified by applying fuzzy sets, therefore the researchers can utilize it to determine any uncertain situation in medicine such as the severity of disease, the probability of disease, the degree of sign and symptoms and any vague or incomplete knowledge. In addition, with an effectiveness of this method to determine the nature of disease with fuzzy sets, decision making can be facilitated in diagnosis process. Hence, we can imply that fuzzy set theory might be a suitable tool to develop a computerized diagnosis system. Based on the fuzzy sets, health and disease have complementary relations, but they are not opposite. The algorithm is formulated as three fuzzy sets consisting of the symptoms as *S* sets, diagnosis as *D* sets, and patients as *P* sets to describe disease diagnosis process. Thus, physicians based on the clinical experience create a relationship with the patient to disease diagnosis according to the set of symptoms (Patel and Virparia, 2012).

Relevance of Fuzzy Logic in Medical Diagnosis

The diagnostic decisions taken by medical experts depend upon familiarity, experience, expertise, knowledge, capability and perception of the medical scientist. As the complexity of system increases, it is not easy to follow a particular path of diagnosis without any mistake. Fuzzy logic presents powerful reasoning methods that can handle uncertainties and imprecision. An aggregation of the knowledge, observation and experience of medical experts serves as the backbone of a fuzzy models based medical diagnostic system. The novel methodologies are presented for physician’s decisions in medical informatics, medical problems solving and for the assessment of treatment planning decision process in diseases and therapies. Problem solving algorithms are proposed for data handling, pattern recognition, fuzzy segmentation of data and diagnosis of diseases using genetic algorithm fuzzy approach (Awotunde, Matiluko & Fatai, 2014).

Expert system based on fuzzy logic employed in medical diagnosis has proved to be of great importance, providing a clear and impressive evaluation report of medical data. They have also provide a quick and easy means of medical condition diagnosis even at the absence of an expert or medical personnel based on the knowledge base built into it and acquire from experts in the field. The development of web based applications and interfaces enabled the medical practitioners to share their experiences and expertise across the world (Manish, & Sedamkar, 2013).

The capability of fuzzy logic to represent the knowledge and a quantitative result in form of linguistic expression can be useful, because most of the diagnoses, usually have been performed based on the probability of clinical findings. Coupled with the literary evidence, another advantage of using a fuzzy approach is about fuzzy theory with using simulating human thinking and decision making which can implement medical evidence-based theory to improve diagnosis. Due to the proven effectiveness of applying fuzzy methods in the world of medicine to model uncertainty, it has been utilized in diagnosis process with different applications according to the type of disease and objective of the researchers. Various studies have been performed in this context with different methods. Accordingly, the authors in this systematic review, survey the significant applications on the disease diagnosis. Generally, the process of applying fuzzy logic in disease diagnosis is described in Figure 2.2 with its different steps." rules for knowledge representation (Imavan, Anosike and Obi, 2020).

Fuzzy Logic in Medical Decision Support Systems

Medical diagnosis and treatment are usually accompanied by decision making process. Timely and accurate decision making based on clinical knowledge and patient information to diagnosing, treating and managing the diseases, is complex. In the most recent studies, Decision Support Systems (DSSs)are one of the early computerized systems that were developed in medicine with trying to suggest the best recommendation to assist the physicians in decision making. By applying fuzzy logic to model physician diagnosis decisions, the more accurate mathematical model can be developed in the context of DSS. One of the important parts of DSS is knowledge representation, where fuzzy logic can provide an effective way to dealing with the problem of knowledge representation with uncertainty and imprecision. Unlike classic methods, fuzzy logic can represent vague knowledge in a set of fuzzy based rules. In addition, with the similarity of fuzzy logic to natural language, it can stimulate how the medical expert makes a decision in the best way. Hence, DSSs are recognized as easy-to-use applications, because of their high accuracy and low complexity (Djam and Kimbi, 2020).

Fuzzy Inference System (FIS) is one of the main categories of fuzzy methods. FIS is the process of formulating the mapping from a given input to an output using fuzzy logic and it involves all of the membership functions, fuzzy logic operators and if-then rules. Therefore, FES as one of the most popular fuzzy methods can be included to fuzzy inference systems. As medical knowledge has benefited from the use of fuzzy logic, FES for disease diagnosis was developed to detect diseases more accurate and quicker. FES utilizes a collection of different fuzzy methods such as fuzzy membership sets and fuzzy rule-based reasoning to develop relations between input and output data. Generally, to date, various systems have been developed using FES methods which are applied for diagnosis of different diseases.

Fuzzy Logic in Malaria Diagnosis

There are a number of factors especially environmental that affects the spread of malaria; this includes but not limited to season, climate etc. The *Anopheles gambiae* complex which is a complex of about seven species of mosquitoes is the major and the most effective vector for the transmission of malaria. They are majorly in Africa and temperate regions because they cannot withstand frost. *Plasmodium falciparum*, a species of *Plasmodium* is a protozoan and a parasite that is carried by the female Anopheles mosquitoes and the major causative parasite of malaria. Temperature affects the transmission cycle of P. falciparum in many different ways, but the effects on the duration of the sporogonic cycle of the parasite and vector survival are particularly important. At temperatures below about 22oC the determining factor is the number of mosquitos surviving the parasite's incubation period, which takes 55 days at 18^{o}C and ceases at around 16oC. After 55 days the proportion of a cohort of mosquitos that survives is only 0.003. Epidemic malaria tends to occur along the geographical margins of the endemic regions, when the conditions supporting the equilibrium between the human, parasite and mosquito vector populations are disturbed. This leads to a sharp but temporary increase in disease incidence. Malaria is an ancient disease having a huge social, economic, and health burden. It is predominantly present in the tropical countries. Even though the disease has been investigated for hundreds of years, it still remains a major public health problem with 109 countries declared as endemic to the disease in 2008. Fuzzy logic can be applied in malaria diagnosis for early diagnosis and treatment (Djam, Wajiga, Kimbi and Blamah, 2020).

Over the past decade, most researches in disease diagnosis have emphasized on the use of computer aided diagnosis methods which can improve decision making by healthcare professionals. To date, various computational methods have been developed and introduced in this regard. These kinds of tools can simulate the thinking process of experts to solve the problem of the complicated process of diagnosis. It is obvious that we can map a quantitative medical result to linguistic expression with a fuzzy method for better comprehension. Furthermore, due to easy mapping, it has been used in diagnosis process to improve decision making over 20 years ago. Various systems, applications, and algorithms are being developed by utilizing fuzzy logic in the context of disease diagnosis, showing that it is advantageous in accurate diagnosis of malaria and other diseases. However, it has some advantages and disadvantages in comparison with other artificial intelligent methods. Due to the fact that inherent of medicine and diagnosis process are uncertain and ambiguous, fuzzy logic can describe disease definition and its severity, clearly. Using fuzzy logic, the symptoms of malaria experienced by the patient can be evaluated and a conclusion can be drawn to determine if patient is suffering from malaria or not. It is a least expensive and time saving technique for diagnosing the disease (Alaba and Isaac, 2016).

Model Development and Data Collection

Design Methodology:

This research work adopts Object Oriented Design (OOD) method because OODM commences with an abstract model of the application as input and supports the production of a design model as output. The design model comprises an information model and a behaviour model. The information model is a static representation of the software system using a set of diagrams which represents a global view of the software system classes and components. The behaviour model depicts the dynamic of the software system. The designer of a software system should start the design from an abstract model of the application, which is accomplished through a system analysis. That abstract model is the first representation of the software system.

Software Development Model

The Waterfall Model software development model will be adopted. The waterfall Model illustrates the software development process in a linear sequential flow; hence it is also referred to as a linear-sequential life cycle model. This means that any phase in the development process begins only if the previous phase is complete. In waterfall model phases do not overlap. In Waterfall model, typically, the outcome of one phase acts as the input for the next phase sequentially. Below is a diagrammatic representation of different phases of waterfall model.

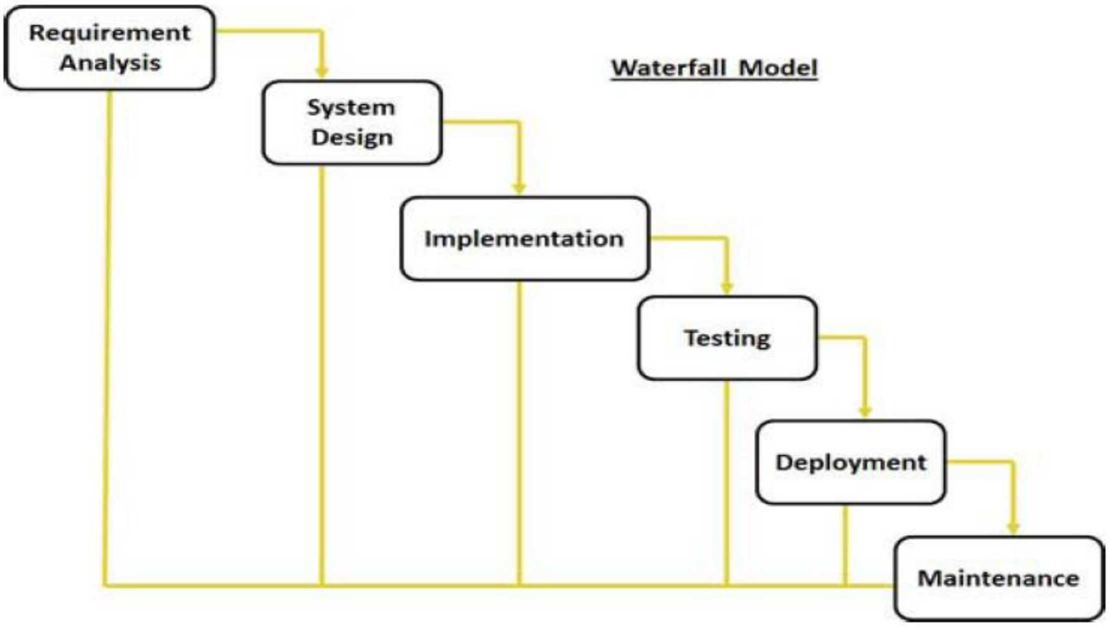

Figure 3.1: Waterfall Model

Design Methodology

Object Oriented Analysis and Design Model:

The design methodology used is Object Oriented Analysis and Design Methodology (OOADM). This methodology was used because it enables the design and development of a system from an object point of view.

Fuzzy Logic Model of Malaria Parasite Diagnosis Expert System (MPDExS)

Main goal is receiving data into the system using crisp inputs. The users reads the exact numbers taken from the instruments for measuring the patients' weight, height, temperature and pulse rate in Beats per minute (BPM) respectively, kilograms, Celsius and meters.

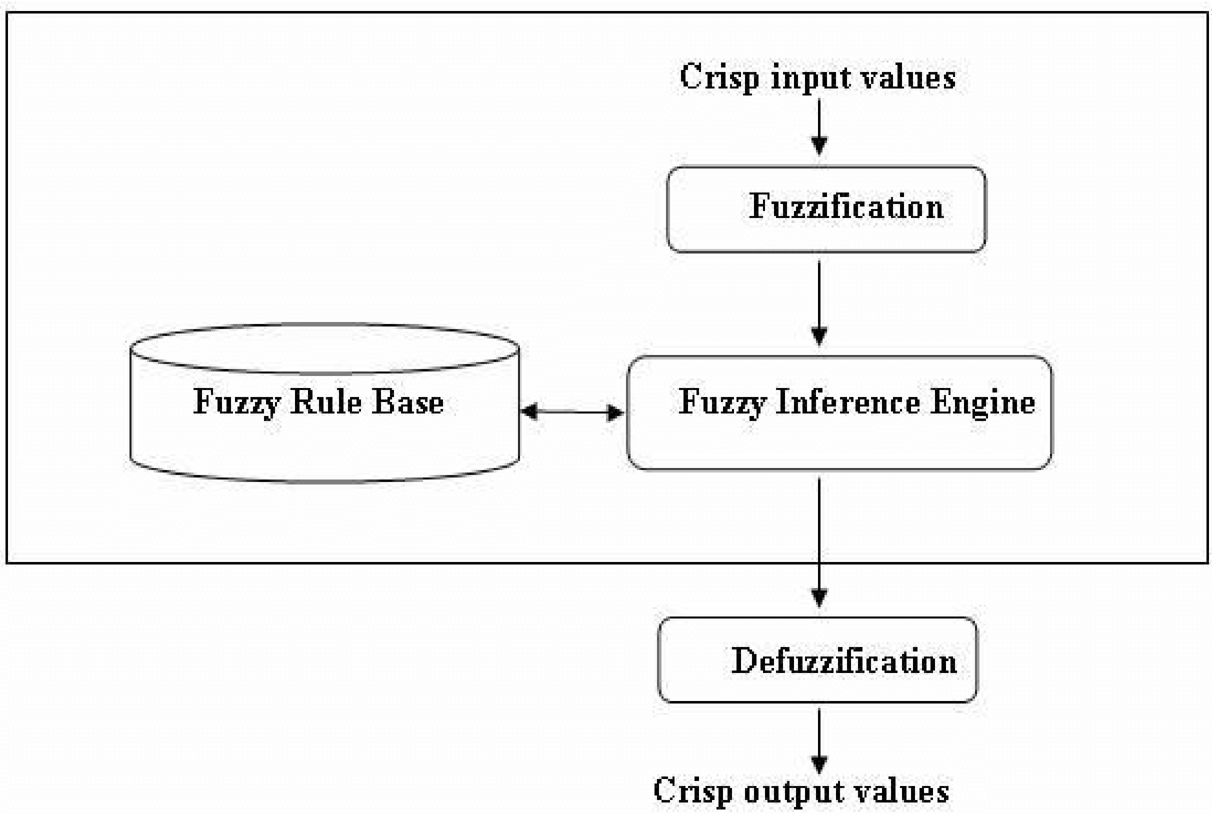

Figure 3.2: Fuzzy Logic Model

Knowledge Base

The Knowledge Base will be acquired from the medical experts and malaria references review. The Knowledge Base Contains of a set of condition (IF and THEN) in the decision matrices constructed using logical gate (AND) operator and forward chaining and storing in data-store for references by the inference engine.

Fuzzification

Fuzzification is a process that determines the degree of membership to the fuzzy set based on fuzzy membership function. This is done by selecting input parameters into the horizontal axis and projecting vertically to the upper boundary of membership function to determine the degree of membership. The first step in the development of fuzzy logic based expert system is to construct fuzzy sets for the parameters. On the basis of domain experts' knowledge, both input and output parameters selected for this research will described with four linguistic variables (minor, moderate, severe and very severe).

Inference Engine

Fuzzified input will be matched with the syntax and a set of fuzzy logic actions are generated. Sample of the rules is shown below:

a. If temperature, Body Mass Index (BMI) and pulse rate are (low). Then parasite diagnosis equal (malaria free) and the treatment equal (discharge patients without medication).

b. If temperature and BMI are (medium), pulse rate is (low) Then the parasite diagnosis equal (Moderate malaria) and treatment equal (Articulate tablet or Amodiaquine syrup).

The inference engine strategy that will be used to draw conclusion is forward chaining. Inference strategy that begins with a set of known facts, derives new facts using rules whose premises match the known facts, and continues this process until a goal state is reached or until no further rules have premises that match the known or derived facts.

Defuzzification

This is to generate the values that should be representative of the output from the inference engine. The defuzzifier translates the output from the inference engine into crisp output. The input to the defuzzification process is a fuzzy set while the output of the defuzzification process is a single number (crisp output). This is due to the fact that the output from the inference engine is usually a fuzzy set, while for most real life applications, crisp values are often required. The three common defuzzification techniques are: max criterion, center-of gravity and the mean of maxima. Center-of-gravity defuzzification technique will be adopted.

Applied Research Methodology:

The research methodology therefore adopted is applied research methodology. Applied research refers to scientific study and research that seeks to solve practical problems. Applied research is used to find solutions to everyday problems, cure illness, and develop innovative technologies, rather than to acquire knowledge for knowledge's sake.

Data Collection:
The study will adopt a survey research design. Purposive sampling method will be
used to select ten (10) patients that have been diagnosed with malaria. The information collected will be presented in the format of the table 3.1 below.

Table 3.1: Data Table

s/no	Gender	Temperature(°c)	Weight(kg)	Height (M)	Pulse Rate	Body Mass Index (Kg/M^2)	Diagnosis
1	Male	38.5	70	1.75	100	22.86	Uncomplicated Malaria
2	Female	39.0	55	1.60	110	21.48	Severe Malaria
3	Male	37.8	80	1.80	90	24.69	Uncomplicated Malaria
4	Female	40.2	65	1.55	120	27.05	Severe Malaria
5	Female	39.5	50	1.50	115	22.22	Uncomplicated Malaria

6	Male	38.0	75	1.70	95	25.95	Uncomplicated Malaria
7	Male	37.5	85	1.82	88	25.65	Severe Malaria
8	Female	40.3	63	1.53	120	26.92	Severe Malaria
9	Female	39.5	50	1.50	115	22.22	Uncomplicated Malaria
10	Male	40.1	54	1.74	100	17.88	Severe Malaria

A fuzzy rule will be constructed after analysis of available dataset to enable determination of diagnosis.

Fuzzy Inference System Model

Mamdani FIS model in MATLAB will be used in determining the diagnosis:

The inputs to the system are:

1. BMI
2. Temperature
3. Pulse Rate

The output of the system is:

1. Diagnosis

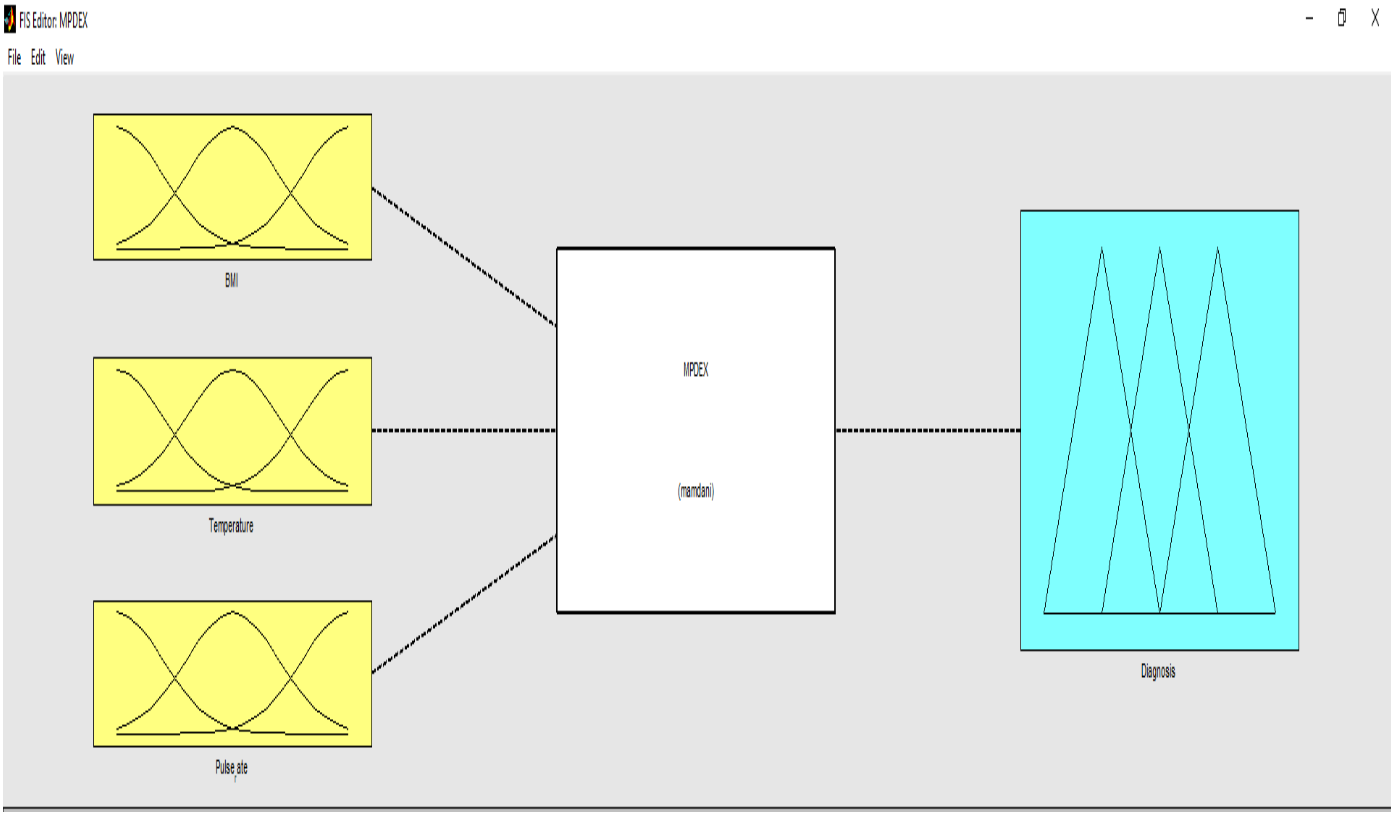

Figure 3.1: Mamdani FIS Model

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APPENDIX A

SOURCE CODES

```
function fis = createMalariaFIS_legacy()
    % Create a new FIS
    fis = newfis('MalariaDiagnosis');

    % === Add Inputs ===

    % BMI Input
    fis = addvar(fis, 'input', 'BMI', [10 40]);
    fis = addmf(fis, 'input', 1, 'Low', 'trapmf', [10 10 18 22]);
    fis = addmf(fis, 'input', 1, 'Normal', 'trapmf', [20 23 27 30]);
    fis = addmf(fis, 'input', 1, 'High', 'trapmf', [28 32 40 40]);

    % Pulse Rate Input
    fis = addvar(fis, 'input', 'Pulse', [40 130]);
    fis = addmf(fis, 'input', 2, 'Low', 'trapmf', [40 40 60 70]);
    fis = addmf(fis, 'input', 2, 'Normal', 'trapmf', [65 75 90 100]);
    fis = addmf(fis, 'input', 2, 'High', 'trapmf', [95 110 130 130]);

    % Temperature Input
    fis = addvar(fis, 'input', 'Temp', [35 42]);
    fis = addmf(fis, 'input', 3, 'Low', 'trapmf', [35 35 36.5 37]);
    fis = addmf(fis, 'input', 3, 'Normal', 'trapmf', [36.5 37.2 38 38.5]);
    fis = addmf(fis, 'input', 3, 'High', 'trapmf', [38 39 42 42]);

    % === Add Output ===

    fis = addvar(fis, 'output', 'MalariaRisk', [0 10]);
    fis = addmf(fis, 'output', 1, 'Low', 'trimf', [0 0 4]);
    fis = addmf(fis, 'output', 1, 'Medium', 'trimf', [3 5 7]);
    fis = addmf(fis, 'output', 1, 'High', 'trimf', [6 10 10]);

    % === Add Rules ===

    ruleList = [
        1 1 1 1 1 1;
        2 2 2 2 1 1;
        3 3 3 3 1 1;
```

```
        3 2 3 3 1 1;
        2 3 3 3 1 1;
        1 3 2 2 1 1;
        1 2 3 2 1 1;
        3 1 1 2 1 1;
        2 2 3 2 1 1
    ];
    fis = addrule(fis, ruleList);

    % === Display the FIS Editor ===
    fuzzy(fis);
end
```

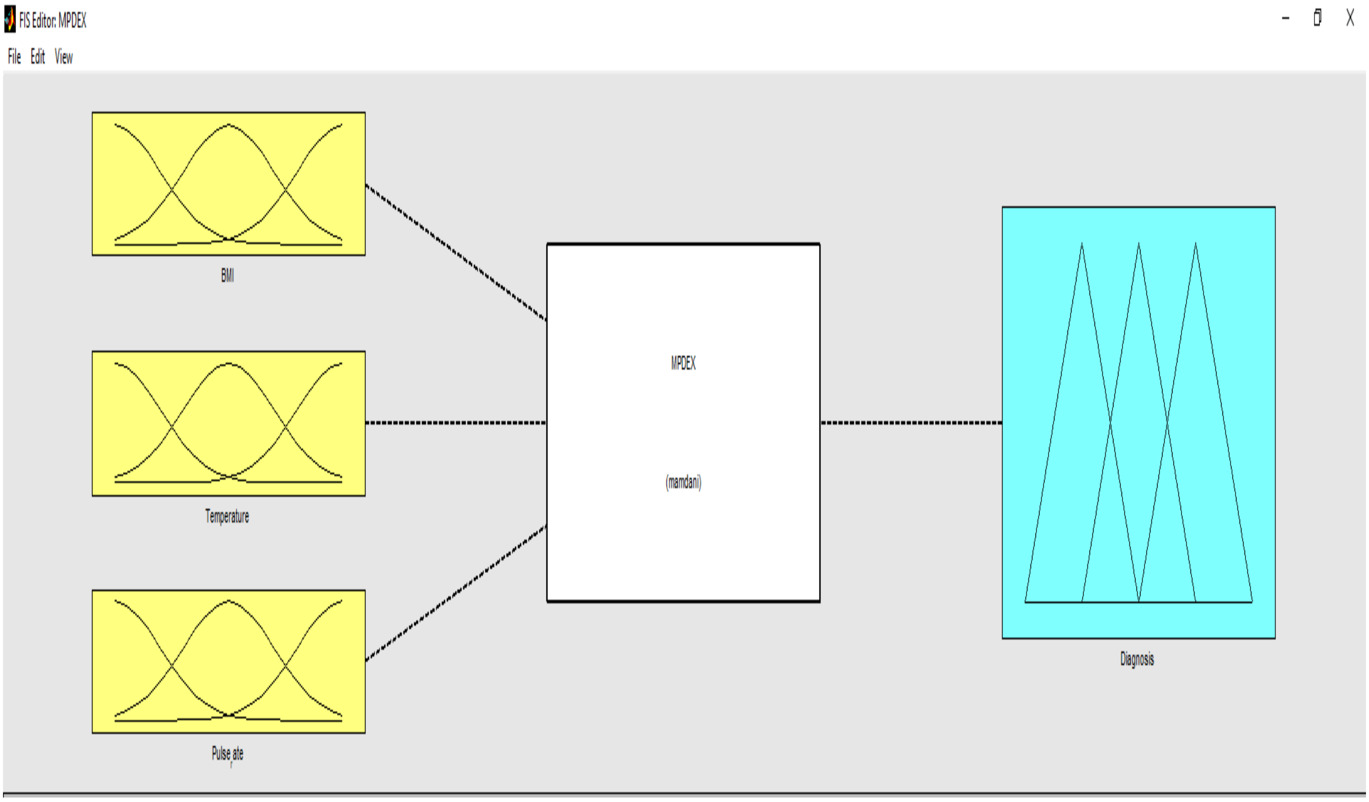
```matlab
% Create the GUI figure window
f = figure('Name', 'Malaria Diagnosis System', ...
           'NumberTitle', 'off', ...
           'Position', [100 100 500 400]);

% === Create FIS (Fuzzy Inference System) ===

% Create the FIS structure
fis = newfis('MalariaDiagnosis');

% Add input variables (BMI, Pulse, Temperature)
fis = addvar(fis, 'input', 'BMI', [10 40]);
fis = addmf(fis, 'input', 1, 'Low', 'trapmf', [10 10 18 22]);
fis = addmf(fis, 'input', 1, 'Normal', 'trapmf', [20 23 27 30]);
fis = addmf(fis, 'input', 1, 'High', 'trapmf', [28 32 40 40]);

fis = addvar(fis, 'input', 'Pulse', [40 130]);
fis = addmf(fis, 'input', 2, 'Low', 'trapmf', [40 40 60 70]);
fis = addmf(fis, 'input', 2, 'Normal', 'trapmf', [65 75 90 100]);
fis = addmf(fis, 'input', 2, 'High', 'trapmf', [95 110 130 130]);

fis = addvar(fis, 'input', 'Temp', [35 42]);
fis = addmf(fis, 'input', 3, 'Low', 'trapmf', [35 35 36.5 37]);
fis = addmf(fis, 'input', 3, 'Normal', 'trapmf', [36.5 37.2 38 38.5]);
fis = addmf(fis, 'input', 3, 'High', 'trapmf', [38 39 42 42]);

% Add output variable (Malaria Risk)
fis = addvar(fis, 'output', 'MalariaRisk', [0 10]);
fis = addmf(fis, 'output', 1, 'Low', 'trimf', [0 0 4]);
fis = addmf(fis, 'output', 1, 'Medium', 'trimf', [3 5 7]);
fis = addmf(fis, 'output', 1, 'High', 'trimf', [6 10 10]);

% Define rules for FIS
rules = [
    1 1 1 1 1 1;
    2 2 2 2 1 1;
    3 3 3 3 1 1;
```

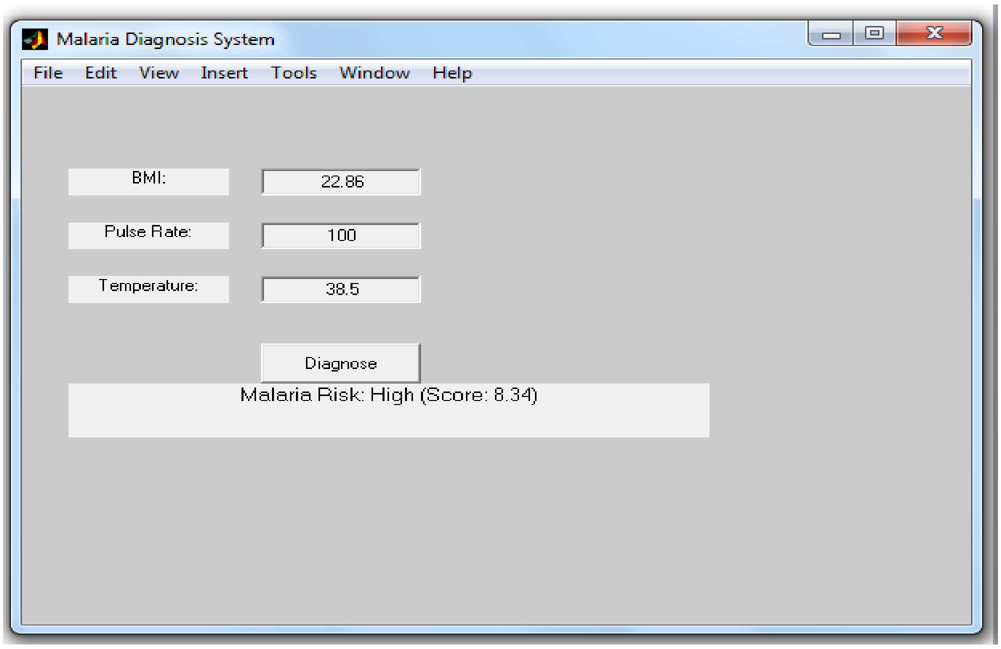
```matlab
    2 3 3 3 1 1;
    1 3 2 2 1 1;
    1 2 3 2 1 1;
    3 1 1 2 1 1;
    2 2 3 2 1 1
];
fis = addrule(fis, rules);

% === GUI Components ===

% BMI Input
uicontrol('Style', 'text', 'Position', [30 320 100 20], ...
          'String', 'BMI:');
bmiEdit = uicontrol('Style', 'edit', 'Position', [150 320 100 20], ...
                    'Tag', 'bmi');

% Pulse Input
uicontrol('Style', 'text', 'Position', [30 280 100 20], ...
          'String', 'Pulse Rate:');
pulseEdit = uicontrol('Style', 'edit', 'Position', [150 280 100 20], ...
                      'Tag', 'pulse');

% Temperature Input
uicontrol('Style', 'text', 'Position', [30 240 100 20], ...
          'String', 'Temperature:');
tempEdit = uicontrol('Style', 'edit', 'Position', [150 240 100 20], ...
                     'Tag', 'temp');

% Result Display
resultLabel = uicontrol('Style', 'text', 'Position', [30 140 400 40], ...
                        'Tag', 'result', 'FontSize', 12, ...
                        'String', 'Malaria Risk:');

% Diagnose Button
uicontrol('Style', 'pushbutton', 'Position', [150 180 100 30], ...
          'String', 'Diagnose', ...
          'Callback', 'diagnoseCallback');
```

APPENDIX B

OUTPUT

Mamdani FIS Model





Malaria Diagnosis Form