

Fuzzy Models Applied to Medical Diagnosis: A Systematic Review

Labiga Laban Thomas¹, Ibrahim Goni², Gideon Daniel Emeje¹

¹Department of Computer Science, Faculty of Physical Science, Modibbo Adama University of Technology, Yola, Nigeria

²Department of Computer Science, Faculty of Science, Adamawa State University, Mubi, Nigeria

Email address:

labiga65@gmail.com (L. L. Thomas)

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Abstract: Fuzzy logic lies in the ability to process nonlinear relationships. Because of the clinical complexity and pathologic heterogeneity of various diseases, correct identification of patients with active disease likely depends on the presence of a single defining feature. Hence, it is not surprising that standard linear statistical methodologies are relatively inadequate for medical diagnosis. In the medical field, dealing with diagnosis error and several levels of uncertainties and imprecision in the diagnoses of diseases had been a great challenge. To solve such problems, artificial intelligence gives a solution through expert system. Fuzzy Logic handles uncertainties, imprecisions and obscurity in decision making. Fuzzy logic is been preferred by Researchers because of its flexible structure and use of intuitive methods instead of specific algorithm. It deals with the degree of membership as it refers to the extent to which an event occurred or can occur. Fuzzy set uses the continuum of logical values between 0 and 1. Different Fuzzy models were reviewed. These systems diagnose many diseases such as: Malaria born infectious disease, Heart related diseases or cardiovascular diseases (like Atherosclerosis), cancer, Asthma, Lungs cancer, Cold and Flu, Hepatitis, Osteomyelitis and Meningitis. In the near future, medical service delivery will be more accessible and more efficient due to availability of Medical Diagnostic Systems.

Keywords: Artificial Intelligence, Fuzzy Logic, Medical Diagnosis

1. Introduction

Due to insufficient medical specialist in most developing countries, the mortality of patients suffering from various diseases is on the increase. There is need for more specialists. However, while awaiting a number of specialists to consult, high risk diseases may spread out, the patients may sustain life-time damage or even die [1]. The number of mortality and time waiting to see a specialist could be reduced using computer technology. Special software's were developed to support the doctors in decision making without consulting the specialist directly [2]. With the emergence of Information Technology (IT), the health care delivery has witness an unprecedented opportunities, as modern practices became more knowledge –intensive, demand for intelligent and knowledge based systems are on the increase. Uncertainties and imprecision in the diagnoses of different diseases appears at several levels. Numerous variables involved in the

diagnosis and management of diseases which makes it complex because of the imprecision. Doctors' assessment of the patient might be insufficient and laboratory results may have errors [3]. Numerous sectors of the medical field have been automated in order to improve its precision and efficacy using fuzzy logic and other methods [4]. Fuzzy logic has been certified as one of the effective methods used to bring clarity in the field of medicine [5]. Mamdani and Takagi-Sugeno-Kang method of fuzzy inference are the two common inference methods used [6]. An expert system is a computer program that represents and reasons with knowledge of some specialist subject with a view to solving problems or giving advice [7].

2. Fuzzy Logic

Fuzzy logic is been preferred by Researchers because of its ability in handling obscurity in the related problems, flexible

structure and use of intuitive methods instead of specific algorithm [8]. This logic has been widely used to interpret uncertain knowledge present in a system which may include vague human assessment in problems [9]. Numerous researchers have used fuzzy logic to develop complex control systems and designed expert systems for diagnosis of different diseases but not much has been done on Bacterial Meningitis [10, 11].

2.1. Fuzzy Set Theory

The description of the concept of fuzziness includes imprecision, uncertainty and degree of truthfulness of values [12]. A fuzzy set is created to describe linguistic variables in more detail. The linguistic variable “temperature”, for instance, may have categories (members) of “very cold”, “cold”, “moderate”, “warm”, and “very hot”. Membership function is then developed for each member in the set. Fuzzy sets were derived by generalizing the concept of set theory. In a classical set (or crisp set), the objects in the set are called elements. An element x belonging to a set A is defined as $x \in A$. An element that is not a member in A is noted as $x \notin A$. The Membership function $\mu_A(x)$ is defined as an element in the universe U having a crisp value of 1 or 0. For every $x \in U$,

$$\mu_A(x) = \begin{cases} 1 & \text{if } x \in A \\ 0 & \text{if } x \notin A \end{cases} \quad (1)$$

This can also be expressed as $\mu_A(x) \in \{0,1\}$.

2.2. Membership Function

In fuzzy sets, the membership function assumes values in the interval $[0, 1]$. The range between 0 and 1 is referred to as the degree of membership while in crisps set Membership function takes a value of 1 or 0.

A fuzzy set A is defined as:

$$A = \{(x, \mu_A(x)) | x \in A, \mu_A(x) \in [0,1]\} \quad (2)$$

Where $\mu_A(x)$ is a membership function that belongs to the interval $[0, 1]$.

A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value between 0 and 1. The rules use the input membership values as weighting factors to determine their influence on the fuzzy output sets of the final output conclusion. Once the functions are inferred, scaled, and combined, they are defuzzified into a crisp output which drives the system. Semantically, probability theory and fuzzy logic use different notions: probability and degree of membership. Probabilities are the likelihoods that an event does or does not occur. Fuzzy Logic model refers to the extent to which an event occurred or can occur. Graphical representation of a conventional set (Boolean) and a fuzzy set which uses the continuum of logical values between 0 (completely false) and 1 (completely true). It employs the spectrum of colors instead of just white and black, assuming that at the same

time things can be partly false and partly true [13].

2.3. Types of Membership Function

- i. Triangular M F: Defined by its lower limit a , its upper limit b and the modal value m , so that $a < m < b$. We call the value $b-m$ margin when it is equal to the value $m-a$. mathematically express as;

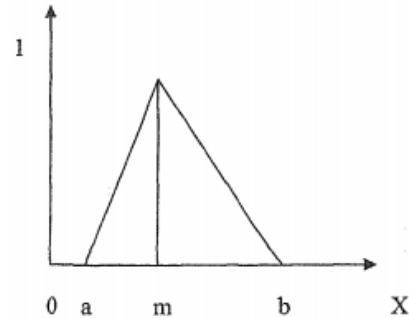


Figure 1. Triangular Fuzzy Set.

$$A(x) = \begin{cases} 0 & \text{if } x \leq a \\ (x-a)/(m-a) & \text{if } x \in (a, m) \\ (b-x)/(b-m) & \text{if } x \in (m, b) \\ 1 & \text{if } x \geq b \end{cases} \quad (3)$$

- ii. Gaussian membership function is another method often used to represent vague linguistic terms, mathematically is given by;

$$y = \text{Guassian}(x; \sigma, c) = e^{\frac{1}{2\sigma^2}(x-c)^2} \quad (4)$$

Where c_i and σ_i are the centre and width of the i th fuzzy set A_i respectively.

- iii. Singleton: It takes value 0 in all the universe of discourse except in the point m , where it takes the value 1. It is the representation of a crisp value. Mathematically is given by;

$$SG(X) = \begin{cases} 0, & \text{if } x \text{ not equal to } m \\ 1, & \text{if } x = m \end{cases} \quad (5)$$

- iv. L function: This function is define by two parameters a and b which can be express mathematically as;

$$L(X) = \begin{cases} 1 & \text{if } x \leq a \\ \frac{a-x}{b-a} & \text{if } a < x \leq b \\ 0 & \text{if } x > b \end{cases} \quad (6)$$

- v. Trapezoid function

Defined by its lower limit a , it's upper limit d and the upper and lower limit of its nucleus, b and c respectively. Mathematically express as follow;

$$A(X) = \begin{cases} 0 & \text{if } (x \leq a), (x \geq d) \\ (x-a)/(b-a) & \text{if } x \in (a, b) \\ 1 & \text{if } x \in (b, c) \\ (d-x)/(d-c) & \text{if } x \in (c, d) \end{cases} \quad (7)$$

2.4. Versatility of Fuzzy Models

Fuzzy logic is a concept that is widely used in the medicine field for risk analysis, prediction, diagnosis of many diseases such as Cancer, Asthma, Malaria, heart diseases, diabetes, meningitis etc. In general, fuzzy Logic has been observed to offer the following advantages: flexible structure, tolerance of imprecise, it can use intuitive methods instead of a specific algorithm and it is based on natural language [8]. Fuzzy logic can be applied in the following fields: engineering, mathematics, computer software developers and researchers. It has produced numerous real life applications such as washing machines, facial pattern recognition, air conditioners, transmission systems and control of subway systems, knowledge-based systems for multi-objective optimization of power systems, medical diagnosis and treatment plans, and stock trading [14]. In the last seven years, papers on Fuzzy systems has a linear variation with large slope ($y=546.6x - 1E + 06$, $R^2=0.964$) while papers on fuzzy deep learning increased exponentially ($y=0.69e0.533x$, $R^2=0.89$), [15]. A number of human diseases are diagnosed electronically by one expert system. Automated diagnosis provides conclusion and explanation [16]. Fuzzy expert system handles details of numerous patients and identifies challenges the patient is likely to encounter [17].

3. Fuzzy Logic Applied to Malaria Diagnosis

Humans get infected by a mosquito-borne disease called Malaria. African communities are greatly affected by Malaria. Divers methods of solving problems can be derived from the concept of Fuzzy Logic. Fuzzy expert system for the management of malaria (FESSMM) was designed to offer a decision support platform to health practitioners and physicians using Root Sum Square (RSS) [3]. Some researchers developed a medical diagnosis system for malaria using fuzzy logic in Visual Prolog Programming language while others designed a Decision Support System for Malaria and Dengue Disease Diagnosis [5],[18]. Diverse techniques, tools and approaches were analyzed for vector borne disease malaria [19]. A mathematical model for Malaria transmission using SIR-SI model was developed and illustrated in equation 8 [20].

$$\begin{cases} \frac{dS_h}{dt} = \mu N_h - \frac{a\gamma_h S_h I_m}{N_h} - \mu S_h + \rho R_h, \\ \frac{dI_h}{dt} = \frac{a\gamma_h S_h I_m}{N_h} - (\mu + \alpha) I_h + \frac{a\delta\gamma_h R_h I_m}{N_h}, \\ \frac{dR_h}{dt} = \alpha I_h - \frac{a\delta\gamma_h R_h I_m}{N_h} - (\mu + \rho) R_h, \\ \frac{dS_m}{dt} = \psi N_m - \frac{a\gamma_m I_h S_m}{N_h} - \psi S_m, \\ \frac{dI_m}{dt} = \frac{a\gamma_m I_h S_m}{N_h} - \psi I_m(t), \end{cases} \quad (8)$$

$$\text{With: } S_h(0) > 0, I_h(0) \geq 0, R_h(0) \geq 0, S_m(0) > 0, I_m(0) \geq 0.$$

Where μ , $\frac{1}{\mu}$, $\frac{1}{\psi}$, ψ , α , ρ , γ_h , and γ_m , are natural death rate of human, average life span of humans, average life span of mosquitos, natural death rate of mosquitos, mosquitos biting rate, rate of immunity loss, human and mosquitos transmission rate respectively.

3.1. Fuzzy Models Applied to Heart Related Diseases

Heart diseases also known as cardiovascular diseases refer to a variety of sicknesses (like Atherosclerosis) that affect the heart as well as all of the blood vessels in the body [21]. Handling uncertainty in diagnosing heart diseases can be done using Fuzzy Petri Nets fuzzy rule and modeling reasoning operation [22]. Heart disease is the number one killer of human. Sugeno fuzzy model was used by some researchers and a mathematical model for predicting the risk of heart diseases was developed [23, 24]. In every 34 seconds, one person dies due to cardiovascular diseases in United States [25]. Some heart disease risk factors may include smoke, cholesterol, blood pressure, sex and age. The strict boundary between what is Healthy and what is not does not exist [26]. Communities need to be aware of their respective Coronary artery disease risk in advance [27]. A real-time monitoring wrist-worn device was developed by [28].

3.2. Fuzzy Models Applied to Hepatitis

A system that diagnosis Cold and Flu was developed by using Type-2 Fuzzy Set [29]. Inputs to the system are: sneezing, sore throat, runny nose, temperature, body pain, cough, headache, vomiting, weakness, loss of appetite, conjunctivitis, swollen lymph nodes in the back. A design was made for an automated system to diagnose Hepatitis B using a multilayered Mamdani fuzzy inference system [30]. The input variables at layer I are ALT and AST while layer II has HBsAg, anti-HBsAg, anti-HBcAg, anti-HBcAg-IgM, HBeAg, anti-HBeAg, and HBV-DNA as its input variables to determine the output at different stages as no- hepatitis, acute hepatitis and chronic hepatitis.

3.3. Fuzzy Models in Diagnosing Meningitis

Supporting meningitis diagnosis amongst infants and children through the use of Fuzzy Cognitive Mapping (FCM) was proposed to explore the potential of fuzzy cognitive map in modeling of meningitis, to support physicians in obtaining accurate diagnosis and treatment. The results produced by the system are: specificity 80% and sensitivity 83.3% [31]. Other researchers proposed a Fuzzy Expert System for distinguishing between Bacterial and Aseptic Meningitis in order to avoid unnecessary antibiotic treatments, patient hospitalization, and misdiagnosis of bacterial meningitis. Weka 3.6.7. was for proper selection. The system accuracy, specificity, and sensitivity were 89%, 92 %, and 97%, respectively [32]. Differentials and fuzzy mathematics were used to diagnose Bacterial Meningitis, Influenza and Crimean Congo hemorrhagic fever [33].

3.4. Fuzzy Models Applied to Lungs Cancer

Lung cancer is described as uncontrolled growth of abnormal cells that start off in one or both lungs; usually in the cells that line the air passages. The abnormal cells do not develop into healthy lung tissue; they divide rapidly and form tumors. Detecting lung cancer at premature stage is instrumental to its cure [34]. Among other types of cancer, the most frequent one is Lung cancer [35]. A neuro fuzzy system was developed to handle it [36]. Fuzzy Rule Based Inference System for Detection and Diagnosis of Lung Cancer was proposed using fuzzy tool box. The system accepts input, confirmed disease and stage as the output using fuzzy logic toolbox [37].

3.5. Fuzzy Logic Applied to Osteomyelitis

Osteomyelitis is a disease that affects bone and bone marrow with imprecise symptoms. Mostly it starts as an acute infection which can become chronic if not diagnosed and treated on time [38]. It also occurs when newly formed bone matrix failed to undergo mineralization [39]. It is derived from Greek words osteon, meaning bone, myelo- meaning marrow, and -itis meaning inflammation: that is infection and inflammation of the bone marrow [40]. Osteomyelitis leads to softening and necrosis of bones. It is caused by deficiency of Vitamin D among adults [41]. A system for determining the severity level of knee osteoarthritis was designed by [42] where four input variables (knee pain, stiffness, crepitus and age) were used to determine the severity level of patient knee osteoarthritis. However, other important symptoms like swelling are not considered.

4. Conclusion

Fuzzy logic is a concept that is widely used in the medicine field for risk analysis, prediction, diagnosis of many diseases such as Cancer, Asthma, Malaria, heart diseases, diabetes, meningitis etc. In general, fuzzy Logic has been observed to offer the following advantages: flexible structure, tolerance of imprecise, it can use intuitive methods instead of a specific algorithm and it is based on natural language. The demand for intelligent and knowledge based systems is rapidly increasing as current medical practice is becoming more knowledge intensive in order to render more efficient services. This paper reviewed different Models and methods of diagnosing and treating Malaria born infectious disease, Heart related diseases, cancer, Asthma, Lungs cancer, Osteomyelitis and Meningitis. These methods of treating diseases could be used in both rural and urban areas in order to save lives.

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