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USING FUZZY LOGIC TO ENHANCE THE CLASSIFICATION AND DIAGNOSING OF HYPERTENSION

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ABSTRACT

High blood pressure, which has a widespread in today's world, is a disease that can cause serious damage to the cardiovascular system. To illustrate, in 1975, 594 million people were diagnosed with hypertension. However, the number has doubled over the last 40 years to become over 1.1 billion in 2015. Moreover, a significant number of patients do not even know they have hypertension due to the inadequate awareness of hypertension symptoms. Because of the difficulty with distinguishing the symptoms of hypertension, fuzzy logic can be utilized as an efficient diagnostic tool. Several research papers have suggested various diagnostic algorithms based on fuzzy logic. Hence, the contribution of this research is to investigate the most recent researches conducted on fuzzy logic for diagnosing hypertension. This will help to enhance the classification, diagnosing method and to overcome the limitations of existing approaches.

Keywords: *Fuzzy logic, classification method, diagnosing method, Hypertension, Blood Pressure.*

1. INTRODUCTION

Blood pressure (BP) is the force of the blood pushing against walls of the blood vessels (1, 2). Blood pressure is measured in units of millimeters of mercury (mmHg) and characterized always by pair systolic and diastolic readings. The former is the top number of blood pressure reading which is the blood pressure when the heart pumps it around the body (i.e. 128 mmHg) and the latter is the bottom number which is pressure when the heart relaxes and refills with blood (i.e. 83 mmHg). Genetic and environmental factors affect the blood pressure status such as family history, age, gender and race (3, 4). High blood pressure or hypertension is higher pressure puts extra strain on heart and blood vessels. This happens when the systolic reading is greater than 140 mmHg and the diastolic reading is greater than 90 mmHg. Moreover, hypertension will be classified for three important causes (5):

a. Special Causes happen for special patients such as race, ethnicity and pregnancy.

b. Primary Causes of Hypertension: environmental risk factors, drugs and other substances that impair BP control and genetic and childhood risk factors.

c. Secondary Causes of Hypertension is a cause of other diseases such as kidney disease, tumors or others.

Hypertension poses a serious threat to the human life, with 9.4 million person in the world dying every year as result of the high blood pressure implications (6, 7).

This paper addresses the existing work in the direction of enhancing the hypertension classification and diagnosing methods based on the Fuzzy logic.

The concept of fuzzy logic emerged in 1965 when Lotfi A. Zadeh published his theory of fuzzy sets and system as the generalization of classical and Boolean logic. Unfortunately, his theory was strongly rejected by many conservative members of the scientific community. However, with time, many proponents for his theory have appeared, and fuzzy logic concepts have been utilized in various fields and integrated with several applications (8-10).

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Fuzzy logic is based on simulating human thinking and natural activities. It uses all the possible values in the period [0,1] to describe human logic, and it can be used as an effective tool for many control system applications such as transportation, crime investigation, clinical decision support system, improving TV clarity, washing machine among other engineering applications (11, 12).

The contribution of this article is an abbreviated review of fuzzy logic and its application on classification and diagnosis hypertension and to highlight the newest publication on this area.

2. FUZZY LOGIC AND SIMILAR CONCEPTS

This part of this paper highlights some differences between fuzzy logic and similar concepts.

2.1 Fuzzy Logic versus Binary Logic

Binary logic is based on two values, 1 (i.e. true) and 0 (i.e. false). Obviously, these two values do not cover all the possible values in this interval [0, 1]. However, fuzzy logic can encompass all the possible values in the period [0, 1].

Hence, this property better describes all the potential possibilities. For example, when using the binary system to represent the height of people, a specific point is selected as a threshold. Consequently, every person with a height less than this value is considered as short, and any person with a height greater than or equal the agreed upon score is considered tall. The binary system can be written as follows:

$$Is\ Sam\ Tall\ ?\ \left\{\begin{matrix}\text{Yes}\\ \\ \text{No}\end{matrix}\right\}\ Binary\ (Boolean)\ logic$$

This assumption includes the threshold value in one of these two groups. However, in real life applications, problems are not that simple. For instance, there are some people with moderate height. Therefore, to describe the height of these people we need another characteristic other than tall or short, such as very tall, tall, average tall, short and very short. So the fuzzy description can be written as follows:

$$Is\ Sam\ Tall\ ?\ \left\{\begin{matrix}\text{Very tall}\\ Tall\\ Average\\ \text{Short}\\ \text{Very Short}\end{matrix}\right\}\ Fuzzy\ Logic$$

To summarize, the main difference between Binary Logic and fuzzy logic is the definition of their sets. To explain that let X be the universe of discussion and x be an element belonging to this set. In this case:

1. Crisp set A of X is a characteristic function C_A of A defined as follows:

$$C_A : X \rightarrow [0,1] \quad \text{where}$$

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

2. Fuzzy set A of X is a membership function μ_A of A defined as follows:

$$\mu_A : X \rightarrow [0,1] \quad \text{where}$$

$$\mu_A(x) = \begin{cases} 0, & \text{if} \quad x\ is\ not\ in\ A \\ 0 < \mu_A(x) < 1, & \text{if} \quad x\ is\ partly\ \text{in A} \\ 1, & \text{if} \quad x\ is\ totally\ in\ A \end{cases}$$

The cases show that fuzzy set increases the choices in daily life situations rather than crisp logic which limits the choices to only two (13).

There are many types of membership functions. However, the three common types are Triangular, Trapezoidal and Gaussian membership Functions (14). All these functions are depicted in figure 1, figure 2 and figure 3 respectively.

1. Triangular membership function is representing as follows:

$$\Delta(x: \alpha, \beta, \gamma, \delta) = \begin{cases} 0, & x \le \alpha \\ \dfrac{(x-\alpha)}{(\beta-\alpha)}, & \alpha < x \le \beta \\ \dfrac{(\gamma-x)}{(\gamma-\beta)}, & \beta < x \le \gamma \\ 0, & x > \gamma \end{cases}$$

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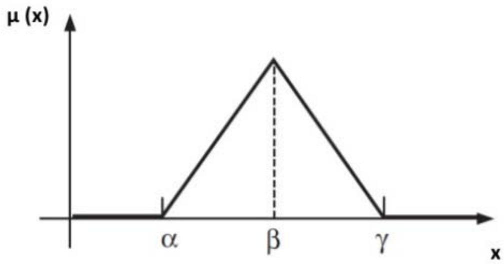

Figure 1: Triangular Membership Function

2. Trapezoidal membership function:

$$\Pi(x:\alpha,\beta,\gamma)=\begin{cases}0, & x\le\alpha\\ \dfrac{(x-\alpha)}{(\beta-\alpha)}, & \alpha<x\le\beta\\ 1\quad , & \beta<x\le\gamma\\ \dfrac{(\delta-x)}{(\delta-\gamma)}\ , & \gamma<x\le\delta\\ 0, & x>\delta\end{cases}$$

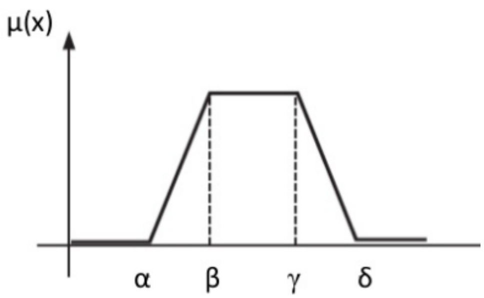

Figure 2: Trapezoidal Membership Function

3. Gaussian membership function:

$$Gaussian(x{:}\, x_c\,,\sigma)=exp\left[-\frac{1}{2}\left(\frac{x-x_c}{\sigma}\right)^2\right]$$

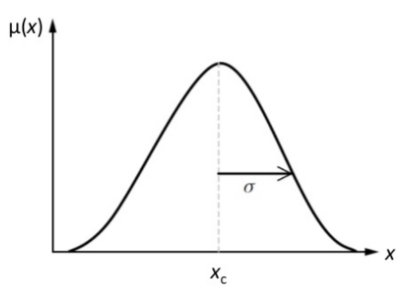

Figure 3: Gaussian Membership Function

2.2 Fuzzy Logic versus Probability Theory

Although fuzzy logic and probability theory are based on similar concept, the key difference is based on the meaning. Fuzzy logic is about the degree of truth, while the probability theory is about estimating the probability of an event.

To elaborate, fuzzy logic quantifies an existing truth or an occurrence that has already happened (i.e. a reality). To illustrate, both can be represented by sets of pairs (a, $f(a)$), where a is an element of a subset A from nonempty universal Ω, while $f(a)$ is an extent to which an event a is likely to occur in probability theory or it is the degree of truth or membership of a in fuzzy set theory (15).

For example, the score of a student in one exam after papers have been marked can be classified in the degree of success or failure as grade A, B, C, D or F. Similarly, the degree of difficulty for the exam can be described numerically (i.e. 0.7). This means results and discussion can be concluded after having a complete analysis. For instance, according to (16), the membership function for grade A classification is:

$$\mu_A(x)=\begin{cases}0, & \text{if}\quad x\le 80\\ \dfrac{x-80}{90-80}, & \text{if}\quad 80<x<90\\ 1, & \text{if}\quad x\ge 90\end{cases}$$

On the other hand, the probability theory attempts to describe the uncertainty of the specific event that has yet to took place (i.e. not yet a reality). For example, if we are discussing the grades of a student before the papers have been marked, we will rely only on partial knowledge. For instance, we can say Sam has70% chance to get A in this exam, which is a statement based on partial knowledge (Sam's abilities, speculations etc.)(16).

2.3 Fuzzy Logic vs. Mathematical Modeling

A mathematical model is a process to convert the data and information from the real-world situation to equations or inequalities. After this process, we use some mathematical concepts to solve the problem, typically with mathematical software. However, using mathematical models in medical problems may often be difficult, because mathematical models need correct input such as the number of working hours, daily calorie intake and duration of pain among other factors. The exact value of all these parameters may not be available in the cases of uncertainty. However, this can be solved using fuzzy logic. This does not negate the need of fuzzy logic for numerical quantities (13).

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3. MODEL AND METHOD

Fuzzy logic has a noticeable presence in the scientific research. In (17), a considerable effort has been made to enumerate the number of publications in fuzzy logic and its applications. According to (17), the total number of publications related to fuzzy logic was approximately 462 in the 20th century. Nevertheless, this number has almost tripled in 21st century, and the total number of papers in this field has exceeded 1400 different research papers. It is worth mentioning that there are currently several scientific journals dedicated solely to fuzzy logic and its applications.

Moreover, researchers in (18) conducted a systematic literature review using meta-analysis method. Eight different scientific databases have been investigated to identify the research work on fuzzy methods and its effect on reducing the difficulty of diagnosis. To acquire an accurate result, they included some enclosure and omission criteria discussed thoroughly in their work. Furthermore, they have clustered all qualified articles based on thirteen different factors including author, type of publication, applied fuzzy methods, tools utilized to model the fuzzy system and the impact of applied fuzzy methods to improve diagnosis. Accordingly, Figure 4 demonstrates the percentage of articles about fuzzy logic, according to their criteria, compared to all the articles published in that year in the targeted databases.

Moreover, in Figure 5 they compared the number of papers that have been published in conference proceedings compared to journal articles.

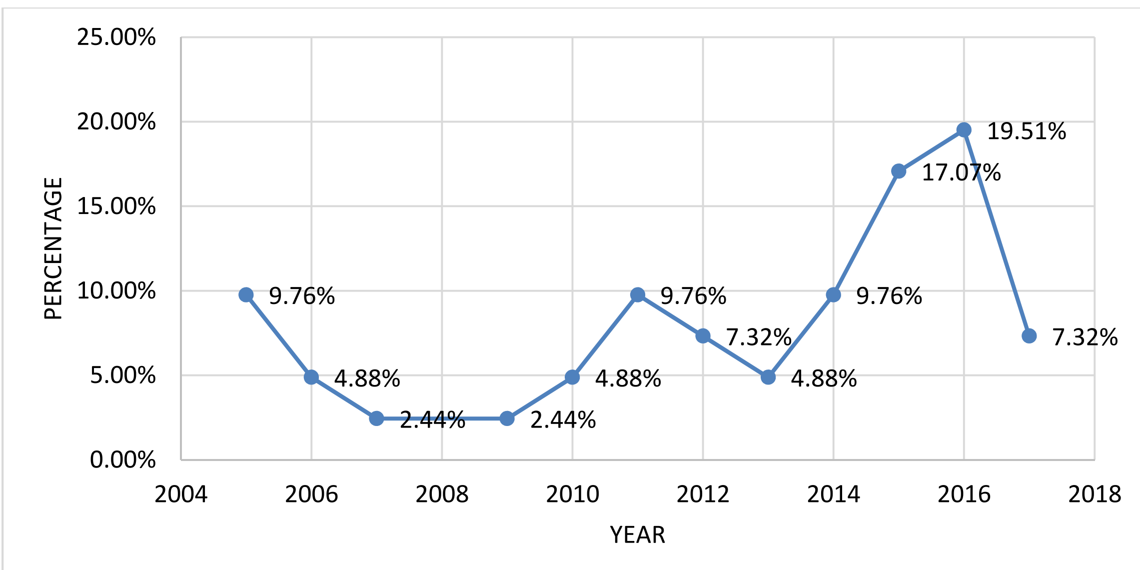

Figure 4: The Percentage Of Published Papers In Fuzzy Logic(18)

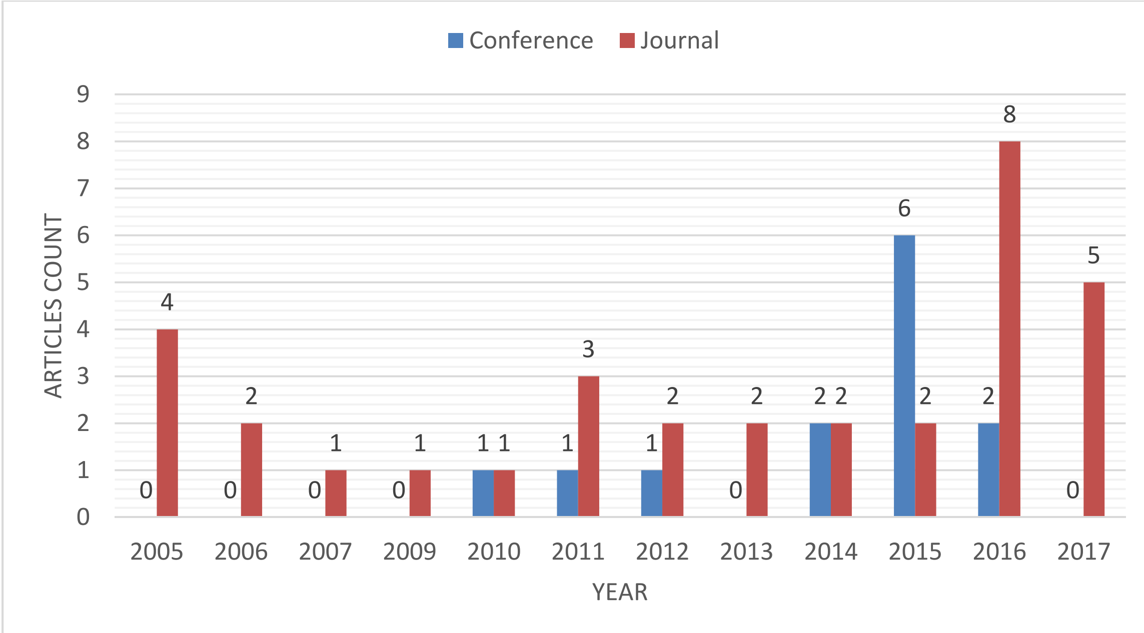

Figure 5: Numbers Of Published Papers In Fuzzy Logic (Conference Vs. Journals)(18)

Further research papers have investigated the possibility of utilizing fuzzy logic for diagnosing, forecasting and handling hypertension(19). In the rest of this research, we shall briefly highlight a number of the most relevant work conducted in this area.

3.1 Fuzzy Logic Controller

Proportional Integral and Derivative (PID) controller is widely used in different fields for many years ago. This is because the processes under control used to have simple design with linear system. In this case the PID has high performance. However, the PID control system is considered unsatisfactory when the process is complex. Thus, complex problem and nonlinear system need intelligent controller to cope with a wide range of input variations such as fuzzy control system (20).

Fuzzy logic controller is one of the applications of fuzzy logic consists of four conceptual components: knowledge base, fuzzification interface, inference engine, and defuzzification interface

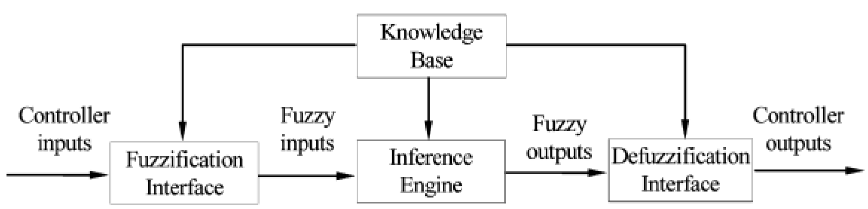

Figure 6: The Percentage Of Published Papers In Fuzzy Logic(20)

As described in (21), fuzzy control system can be used in a variety of medical applications to control injection doses, surgery and physical therapy. Furthermore, it can be used to control the behavior of the cardiovascular system during heart surgery. In relevance to our research focus, it has several applications related to hypertension management, such as drug administration, and improving the cardiovascular system performance.

3.2 Hypertension Classification

Hypertension is cardiovascular set of symptoms arising from complex and interrelated conditions. The signs of hypertension such as severe headache, fatigue or confusion, vision problems, chest pain, difficulty breathing and so forth often appear before sustainable rise of BP. Therefore, hypertension cannot be classified merely by discrete BP thresholds. Accordingly, the hypertension classification progress must be associated with functional and structural cardiovascular heart defect that damage the heart, kidneys, brain, and other organs (22). This complexity leads to the use fuzzy logic system in hypertension classification.

Fuzzy logic has several applications that attempt to mimic the human thinking and reasoning capabilities. This is generally implemented by defining a set of rules which suggest probable diagnosis according to the elicited symptoms, specifically in classifying the intensity of the hypertension (23). This technique has proven to be effective in providing accurate results without consuming much time. Consequently, it can help the physician to have a better performance, and to decrease human error.

Another approach for hypertension classification using fuzzy logic is to integrate fuzzy logic with neural networks to produce a hybrid neuro-fuzzy model that can help in curtailing the risk of hypertension. Neural networks are a well-known classification schemes that builds strong relations between input and output. Nowadays, Artificial Neural Networks (ANN) is a computing model of the function and structure of biological neural networks that invaded scientific research (24-26). Moreover, fuzzy inference systems are used to classify the blood pressure and the heart rate level. Due to the flexibility in handling uncertainty, fuzzy logic managed to successfully classify all testing cases, whilst traditional system can accurately classify only 53% of the same input, due to the rigid nature of traditional systems rules (27).

Another approach has been introduced by (28). In this research paper, they have used a fuzzy system to classify arterial hypertension. After they have built their model, they took 45 records for 40 patients. These readings have been passed as an input to their introduced fuzzy classifier model. To statistically measure the accuracy of the collected results, T-test has been utilized. After running this test, the T degree was -0.1 for systolic classification, and -0.23 for diastolic classification. Consequently, the introduced classifier provides results that are similar to the real data.

In (29) the researchers have developed a hypertension classification model using 10 inputs. To meet their objective, they assigned different classification fuzzy set to each input and output. To illustrate, the first and second inputs, which are systolic blood pressure and diastolic blood pressure, were classified into 7 fuzzy sets. The output is an estimation of the risk of hypertension. To better describe the risk, it has been classified to five linguistic variables: very low, low, moderate, high, and very high. Table 1 depicts the number and description of classification fuzzy sets:

Table 1: The Number And Description Of Classification Fuzzy Sets (29)

Inputs	# of fuzzy set	Fuzzy set
Systolic blood pressure	7	Desirable, above desirable, moderate, above moderate, little high, high and very high
Diastolic blood pressure	7	Normal, above normal, moderate, above moderate, little high, high and very high
low density lipoprotein	5	Normal, above normal, borderline high, high and very high
High density lipoprotein	4	Very high, high, nearly normal and normal
age	6	Young, adult, mid-aged, aged, old and very old
Body mass index	6	Low (underweight), Medium (normal weight), Above medium (overweight), High (obese), Very high (severe obese) and Very very high (super obese)
Heart rate	4	Low, normal, high and very high
Triglyceride	4	Normal, a little bit high, high and very high
Exercise	4	Low effective, medium effective, High effective and Very high effective
Smoking	4	Low smoker, Medium smoker, High smoker and Very high smoker

As an extension for (30), in (31) a neuro-fuzzy hybrid technique for diagnosing and classifying hypertension was introduced. Instead of using type-1 fuzzy system as has been suggested in (30), the authors have investigated using interval type-2 fuzzy system for hypertension classification. Consequently, the latter system has proven to provide more accurate results. To elucidate, they have used three different membership functions, triangular, trapezoidal and Gaussian with type-1 and interval type-2 fuzzy system. The results have been compared as depicted in Figure 7. It is clear that the interval type-2 fuzzy system results showed a more accurate classification system.

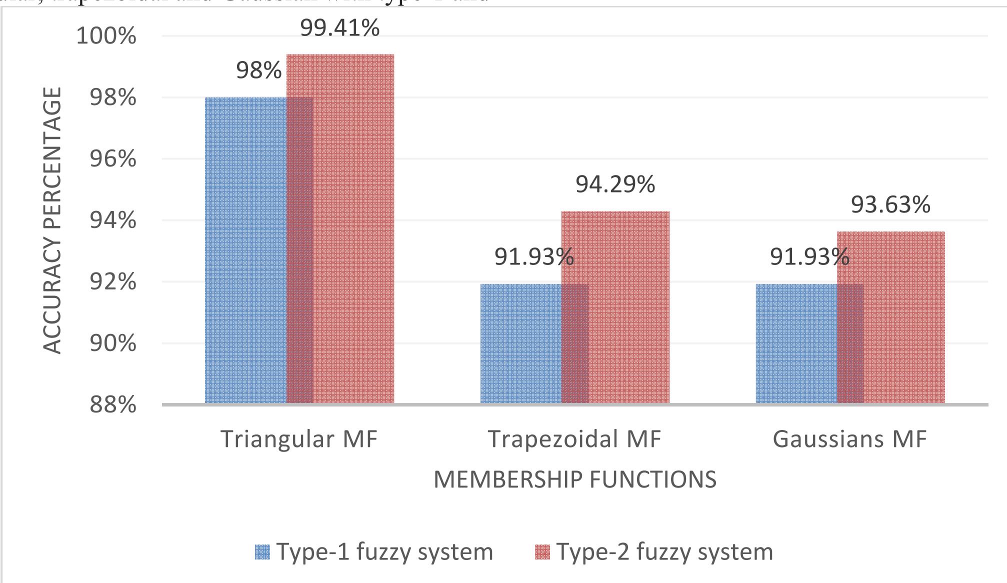

Figure 7: Correct Classification Percentage Of The Classifier(31)

3.3 Hypertension Diagnosing

Diagnosis of hypertension is a complicated process because blood pressure values vary with age, gender and height (32). Moreover, the tension of the patient when the physician introduces him or her to the difficulties and challenges of hypertension may lead to incorrect diagnosis (33). This can be avoided by using correct methods and systems.

In (34), the authors have designed two systems, namely the Fuzzy Expert System (FES) and Neuro Fuzzy System (NFS). Both systems are used to diagnose the potential risk of high blood pressure. To achieve their objective, they have included several parameters including blood pressure readings, Body Mass Index (BMI), Heart Beats per Second, and the patient's age. Using these parameters, both systems have been compared to identify which approach is the optimal one. Consequently, they have concluded that NFS are relatively more efficient for accurately forecasting the risk probability. It is worth pointing out that most of existing research work, including (34), depends on the European Hypertension Classification (35). Table 2 summarizes this classification.

Category	Systolic		Diastolic
Optimal	<120	And	<80
Normal	120 - 129	And / or	80 - 84
High Normal	130 - 139	And / or	85 - 89
Grade 1 Hypertension	140 - 159	And / or	90 - 99
Grade 2 Hypertension	160 - 179	And / or	100 - 109
Grade 3 Hypertension	≥ 180	And / or	≥ 110
Isolated Systolic Hypertension	≥ 140	And	< 90

Table 2: European Blood Pressure Classification (35)

Furthermore, a Neuro-Fuzzy Hybrid technique has been introduced in (30) that can be utilized for diagnosing various diseases including Hypertension. This has been conducted by screening the blood pressure readings for real patients for 24

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hours. After that, a simulation has been developed based on the collected data. Using this simulation, a fuzzy system has been developed for data classification. Furthermore, a genetic algorithm has been incorporated to minimize the classification error.

In (36), a fuzzy expert system has been developed to estimate the risk of hypertension using fuzzy inference system (FIS) tool. To illustrate, they have used Mamdani fuzzy methods to apply fuzzification on four inputs (age, blood pressure, BMI and heart rate). The objective was to calculate the hypertension risk percentage. Figure 8 shows the relation between these inputs and the risk of hypertension (the output).

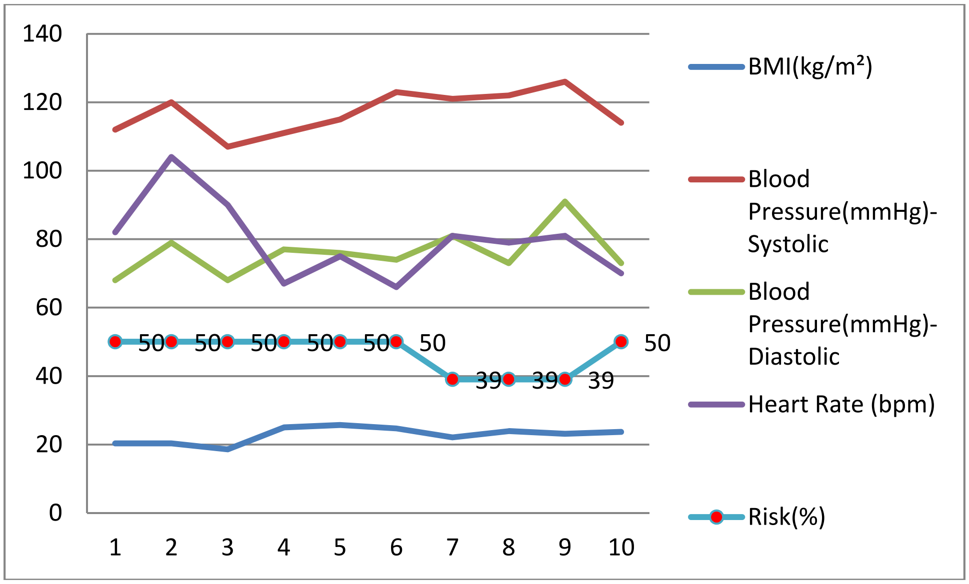

Figure 8: Relationship Between Factors And Risk Of Hypertension(36)

Moreover, in (37) Nohria and Mann have developed an adaptive neuro-fuzzy inference system for hypertension diagnosis and compared it with an existing fuzzy expert system for hypertension diagnosis. As shown in Figure 9, the results of their system were more accurate.

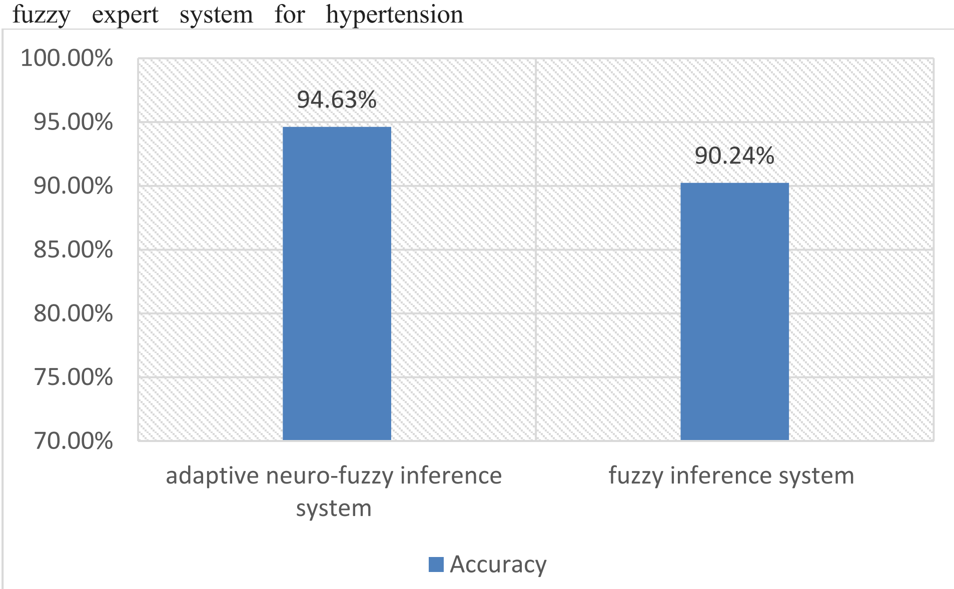

Figure 9: Comparison Of Systems Accuracy(37)

It worth mentioning that the previously discussed neuro-fuzzy hybrid model introduced in (27) has contributed to the hypertension classification as well. To illustrate, several soft computing methods were used to simulate the behavior of the blood pressure for different patients. More specifically, three fuzzy inference systems were used:

- A system for classifying Systolic blood pressure.
- A second system for classifying Diastolic blood pressure.
- A third system used for patient's night profile classification.

70% of the collected data has been used to train the network for the behavior of blood pressure and heart rate of the patients, and the remaining 30% of the data has been used to test the network. The learning accuracy for training and testing is illustrated in Figure 10.

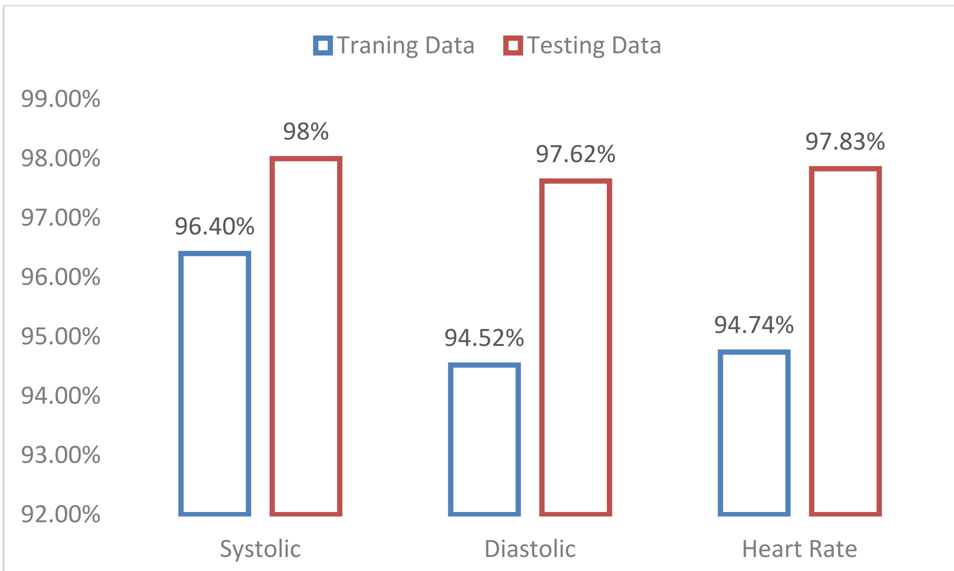

Figure 10: Percentage of Success in Training Vs Training Data(27)

This introduced hybrid provides diagnosis for the patient and the prediction for the hypertension risk in the upcoming four years. Consequently, it can help the patients to improve their health and to adopt a healthy lifestyle to decrease the potential risk.

4. DIRECTIONS FOR FURTHER INVESTIGATION

According to the above discussion, there are a number of possible directions for further research. For instance, it has been noted that when integrating fuzzy systems with neural networks, the diagnosis and classification results were generally better. Hence, the reader can think of other hybrids that can improve the performance of the bare fuzzy systems.

Furthermore, by incorporating other factors such as diet, work routine, encountered stress and so forth, an algorithm can be developed to proactively predict and diagnose the risk of hypertension. To illustrate, we can define hypertension risk attributes as $V_1, V_2, \ldots V_n$ with discourse Ω_j where $1 \leq j \leq n$ to develop a multidimensional space $\Omega_1, \Omega_2, \ldots \Omega_n$. Each element in this space is a vector $(v_1, v_2, \ldots v_n)$ that represents crisp measurements which describe the hypertension risk for the subject. This universal set can be represented as several fuzzy sets with different degrees of hypertension risk. For each attribute V_i, we can define a suitable membership function μ_j over Ω_j(38). Consequently, instead of considering only two dimensions of attributes, models of 3, 4 and up to n dimensions can be developed to enhance the accuracy of the classification and diagnosis of hypertension.

5. RESULT

Fuzzy logic can be used to develop an algorithm to identify the hypertension symptoms early enough, which can help in mitigating the risk of hypertension and ensure that the patient blood pressure will stay within normal limits. This is

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because blurred blood pressure readings make fuzzy logic an effective tool that can properly handle uncertainty. Various researches have suggested different approaches to utilize fuzzy system for improving the accuracy of classifying and diagnosing hypertension. These techniques include using fuzzy logic with different membership functions in different dimensions, using type-2 fuzzy system instead of type-1 and hybrids of neural network and fuzzy logic. Further research can be conducted in developing a membership function in *n* dimensions instead of only 2 dimensions.

6. Conclusion

The main objective of this research paper is to review the existing approaches for using fuzzy expert's system to deal with complex symptoms of hypertension. It worth noting that the ambiguity of these symptoms forms a serious threat to humans' life.

It can be concluded that fuzzy expert systems can be integrated with neural network to develop a hybrid model that can provide more accurate classification and diagnosis results. This hybrid can assist physicians in handling complicated and different types of symptoms and provide them with a handy tool for decision making.

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