Hindawi Publishing Corporation
ISRN Biomathematics
Volume 2013, Article ID 342970, 11 pages
http://dx.doi.org/10.1155/2013/342970

Research Article

A Note on Hypertension Classification Scheme and Soft Computing Decision Making System

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Received 22 July 2013; Accepted 28 August 2013

Academic Editors: V. P. Emerenciano and J. R. C. Piqueira

Nowadays young professionals are a soft target of hypertension due to the increased work pressure and poor tolerance. Many people have high blood pressure for years without knowing it. Most of the time, there are no symptoms, but when this condition goes untreated it damages arteries and vital organs throughout the body and that is why it is also termed as the silent killer. Complications arising from hypertension could lead to stroke and heart failure. Soft computing approach provides a sharper conclusion from vague, ambiguous, and imprecise data (generally found in medical field) using linguistic variables. In this study, a soft computing diagnostic support system for the risk assessment of hypertension is proposed.

1. Introduction

A human body is a complex system and there are a number of variables that affect its functioning. The abnormality in its functioning causes a number of symptoms in the form of primary stages of different diseases although the recognition of these symptoms and their mapping with the diseases precisely is not an easy one. Sometimes compications in human body may be caused by improper diagnosis or improper management of the disease or due to the inaccessibility of medical personnel [1]. The quickening speed of change and adoption of western lifestyles by people in developing countries have led to a sharp rise in the incidence of hypertension [2]. Hypertension is a medical term for high blood pressure which is a condition that occurs when the pressure in the arteries is above the normal range. According to one of the studies "Recession has had an adverse impact on jobs in India and perhaps this is one of the reasons why cases of Hypertension have gone up in past two years among young IT professionals". Recent analysis has predicted that more than 1.56 billon people will be living with hypertension worldwide by the year 2025. It has been declared by a survey report that one of four adults in India has high BP which kills 7.5 million people worldwide each year; moreover, AIDS, diabetes, road accidents, and tuberculosis are put together. In India 23.1% men and 22.6% women have high BP a notch lower than the global prevalence of one in three adults says the World Health statistics 2012 released, 16 May 2012. Jain [3] established a decision making process phenomenon in the presence of fuzzy variables. Poli et al. [4] developed a neural network expert system for diagnosing and treating hypertension. Degani [5] discussed computerized electrocardiogram diagnosis using fuzzy approach. Charbonnier et al. [6] proposed the statistical and fuzzy models of ambulatory systolic blood pressure for hypertension diagnosis. Jena et al. [7] discussed the application of soft computing in medical science. Pandey et al. [8] proposed a rule based system for cardiac analysis based on electrocardiography. Further, Allahverdi et al. [9] proposed a fuzzy expert system for the determination of coronary heart disease risk (CHD) of patient for the next ten years. Nalayini and Wahidabanu [10] were of the view that most of the cardiac diseases are characterized by varied degrees of intricacy and the conventional procedures are not capable of dealing with these intricacies very efficiently. Djam and Kimbi [1] developed a

Table 1

	Systolic BP in mm Hg	Diastolic BP in mm Hg
Desirable	90–120	60–80
Above desirable	120–130	80–85
Moderate	130–140	85–90
Above moderate	140–150	90–95
Little high	150–160	95–100
High	160–170	100–110
Very high	>168	>108

fuzzy expert system for the management of hypertension. Recently, P. Srivastava and A. Srivastava [11] proposed a soft computing diagnostic system to evaluate the risk factor for coronary heart disease (CHD). Srivastava and Sharma [12] designed a soft computing diagnostic system that classifies ECG beats in different phases and enables us to identify the status of cardiac health as per available ECG graphs. The present paper introduces a new soft computing model that measures risk factor on the basis of newly designed algorithm; a number of cases have been discussed as per available database.

2. Methodology

For complex systems, fuzzy tools are quite suitable because of its tolerance to some imprecision. In the present study, the inputs consist of age, systolic blood pressure (SBP), diastolic blood pressure (DBP), body mass index (BMI), heart rate, low density lipoprotein (LDL), high density lipoprotein (HDL), triglyceride, smoking, and exercise, while the output is the risk grade of hypertension.

In order to design a user friendly informative system for evaluating risk percentage of hypertension, we propose fuzzy Algorithm 1.

2.1. Input Variables

2.1.1. Blood Pressure. In this field we use systolic BP (SBP) and diastolic BP (DBP). The input variables for SBP and DBP were classified into seven fuzzy sets (see Table 1).

Systolic Blood Pressure (SBP). Consider

$$\mu_{\text{desirable}} = \begin{cases} 1 & x \le 90 \\ \left(\dfrac{x-90}{15}\right)^2 & 90 \le x < 105 \\ 1-\left(\dfrac{x-105}{15}\right)^2 & 105 \le x < 120 \\ 0 & x \ge 120, \end{cases}$$

$$\mu_{\text{above desirable}} = \begin{cases} 0 & x \le 120 \\ \dfrac{x-120}{3} & 120 < x \le 123 \\ 1 & 123 < x \le 127 \\ \dfrac{130-x}{3} & 127 < x \le 130 \\ 0 & x \ge 130, \end{cases}$$

$$\mu_{\text{moderate}} = \begin{cases} 0 & x \le 130 \\ \dfrac{x-130}{3} & 130 < x \le 133 \\ 1 & 133 < x \le 137 \\ \dfrac{140-x}{3} & 137 < x \le 140 \\ 0 & x \ge 140, \end{cases}$$

$$\mu_{\text{above moderate}} = \begin{cases} 0 & x \le 140 \\ \dfrac{x-140}{3} & 140 < x \le 143 \\ 1 & 143 < x \le 147 \\ \dfrac{150-x}{3} & 147 < x \le 150 \\ 0 & x \ge 150, \end{cases}$$

$$\mu_{\text{little high}} = \begin{cases} 0 & x \le 150 \\ \dfrac{x-150}{3} & 150 < x \le 153 \\ 1 & 153 < x \le 157 \\ \dfrac{160-x}{3} & 157 < x \le 160 \\ 0 & x \ge 160, \end{cases}$$

$$\mu_{\text{high}} = \begin{cases} 0 & x \le 160 \\ \dfrac{x-160}{3} & 160 < x \le 163 \\ 1 & 163 < x \le 167 \\ \dfrac{170-x}{3} & 167 < x < 170 \\ 0 & x \ge 170, \end{cases}$$

$$\mu_{\text{very high}} = \begin{cases} 0 & x \le 168 \\ \left(\dfrac{x-168}{6}\right)^2 & 168 \le x < 174 \\ 1-\left(\dfrac{x-174}{6}\right)^2 & 174 \le x < 180 \\ 1 & x \ge 180. \end{cases} \quad (1)$$

Diastolic Blood Pressure (DBP)

$$\mu_{\text{normal}} = \begin{cases} 1 & x \le 60 \\ \left(\dfrac{x-60}{10}\right)^2 & 60 \le x < 70 \\ 1-\left(\dfrac{x-70}{10}\right)^2 & 70 \le x < 80 \\ 0 & x \ge 80, \end{cases}$$

(I) Initial fuzzification mechanism
BEGIN
(1) Input-Fuzzy system with suitable "n" parameters A_i
(2) Initialize $i \leftarrow 1$
DO UNTIL $(i > n)$
Categorize n_i fuzzy sets in X_j linguistic variables
DO UNTIL $(j > n_i)$
(1) Construction of suitable membership function μ_{X_j}
(2) Increment j
END DO UNTIL
Increment i
END
(II) Construction of Fuzzy Strings
BEGIN
(1) Input: "n_i" fuzzy sets in linguistic variables
X_j; $i = 1, 2, \ldots, n$ and $j = 1, 2, \ldots, n_i$
(2) Input: m output parameters Y_o, $o = 1, 2, \ldots, m$.
(3) Develop $t = k_1, k_2, \ldots, k_r$ linguistic strings J_k; $k = 1, 2, \ldots, t$
using AND operation on each linguistic term X_j; $j = 1, 2, \ldots, n_i$
(4) Initialize $k \leftarrow 1$
DO UNTIL $(k > t)$
Increment j
END DO UNTIL
Increment k
END
(III) Output Evaluation
BEGIN
(1) Construct Utility matrix U of pxq order.
(2) Construct r utility fuzzy sets U_I; $I = 1, 2, \ldots r$
using $x \oplus y = x + y - xy$ for each $x, y \in U$
(3) Initialize $I \leftarrow 1$
DO UNTIL $(I > r)$
(4) Construct r maximizing sets U_{MI}, $I = 1, 2 \ldots r$
corresponding to each alternative.
(5) Develop r optimal fuzzy utility sets U_{OI}, $I = 1, 2 \ldots r$.
Each optimal fuzzy set U_{OI} is obtained by fuzzy
intersection $\bigwedge$ on fuzzy utility set and maximizing
set such that $\mu_{U_{OI}}(x) = \mu_{U_I}(x) \bigcap \mu_{U_{MI}}(x) = \min(\mu_{U_I}(x), \mu_{U_{MI}}(x))$
for each utility value x.
(6) Take maximum membership value from each optimal utility fuzzy set.
(7) The optimal alternative A_O with corresponding maximum
membership grades obtained in step 10 such as
$A_O = \left\{\left((\max)\, \mu_{U_{OI}}(x), B_I\right) : \bigvee x \in U_{OI}\right\}$ for $I = 1, 2 \ldots r$.
END DO UNTIL
Increment I
END

Algorithm 1

$$\mu_{\text{above normal}} = \begin{cases} 0 & x \leq 80 \\ \dfrac{x-80}{2} & 80 < x \leq 82 \\ \dfrac{85-x}{3} & 82 < x \leq 85 \\ 0 & x \geq 85, \end{cases}$$

$$\mu_{\text{moderate}} = \begin{cases} 0 & x \leq 85 \\ \dfrac{x-85}{2} & 85 < x \leq 87 \\ \dfrac{90-x}{3} & 87 < x \leq 90 \\ 0 & x \geq 90, \end{cases}$$

Table 2

Cholesterol (mg/dL)			
LDL		HDL	
Normal	≤100	Very high	≤30
Above normal	100–130		
Borderline high	130–160	High	30–50
High	160–190	Nearly normal	50–60
Very high	≥180	Normal	≥58

$$\mu_{\text{above moderate}} = \begin{cases} 0 & x \le 90 \\ \dfrac{x-90}{2} & 90 < x \le 92 \\ \dfrac{95-x}{3} & 92 < x \le 95 \\ 0 & x \ge 95, \end{cases}$$

$$\mu_{\text{little high}} = \begin{cases} 0 & x \le 95 \\ \dfrac{x-95}{2} & 95 < x \le 97 \\ \dfrac{100-x}{3} & 97 < x \le 100 \\ 0 & x \ge 100, \end{cases}$$

$$\mu_{\text{high}} = \begin{cases} 0 & x \le 100 \\ \dfrac{x-100}{5} & 100 < x \le 105 \\ \dfrac{110-x}{5} & 105 < x \le 110 \\ 0 & x \ge 110, \end{cases}$$

$$\mu_{\text{very high}} = \begin{cases} 0 & x \le 108 \\ \left(\dfrac{x-108}{6}\right)^2 & 108 \le x < 114 \\ 1-\left(\dfrac{x-114}{6}\right)^2 & 114 \le x < 120 \\ 1 & x \ge 120. \end{cases} \quad (2)$$

2.1.2. Cholesterol. In this study we have classified total cholesterol into low density lipoprotein (LDL) cholesterol and high density lipoprotein (HDL). HDL cholesterol level has been classified into four fuzzy sets. LDL cholesterol level has been classified into five fuzzy sets. High levels of LDL are associated with coronary artery disease, whereas high levels of HDL appear to protect against coronary artery disease. These fuzzy sets have been shown in Table 2.

Low Density Lipoprotein (LDL). Consider

$$\mu_{\text{normal}} = \begin{cases} 1 & x \le 50 \\ \left(\dfrac{x-50}{25}\right)^2 & 50 \le x < 75 \\ 1-\left(\dfrac{x-75}{25}\right)^2 & 75 \le x < 100 \\ 0 & x \ge 100, \end{cases}$$

$$\mu_{\text{above normal}} = \begin{cases} 0 & x \le 100 \\ \dfrac{x-100}{10} & 100 < x \le 110 \\ 1 & 110 \le x \le 120 \\ \dfrac{130-x}{10} & 120 < x \le 130 \\ 0 & x \ge 130, \end{cases}$$

$$\mu_{\text{borderline high}} = \begin{cases} 0 & x \le 130 \\ \dfrac{x-130}{10} & 130 < x \le 140 \\ 1 & 140 \le x \le 150 \\ \dfrac{160-x}{10} & 150 < x \le 160 \\ 0 & x \ge 160, \end{cases}$$

$$\mu_{\text{high}} = \begin{cases} 0 & x \le 160 \\ \dfrac{x-160}{10} & 160 < x \le 170 \\ 1 & 170 \le x \le 180 \\ \dfrac{190-x}{10} & 180 < x \le 190 \\ 0 & x \ge 190, \end{cases}$$

$$\mu_{\text{very high}} = \begin{cases} 0 & x \le 180 \\ \left(\dfrac{x-190}{20}\right)^2 & 180 \le x < 200 \\ 1-\left(\dfrac{x-200}{20}\right)^2 & 200 \le x < 220 \\ 1 & x \ge 220. \end{cases} \quad (3)$$

High Density Lipoprotein (HDL). Consider

$$\mu_{\text{very high}} = \begin{cases} 0 & x \le 0 \\ \dfrac{x-0}{10} & 0 < x \le 10 \\ 1 & 10 < x \le 20 \\ \dfrac{30-x}{10} & 20 < x \le 30 \\ 0 & x \ge 30, \end{cases}$$

$$\mu_{\text{high}} = \begin{cases} 0 & x \le 30 \\ \dfrac{x-30}{5} & 30 < x \le 35 \\ 1 & 35 < x \le 45 \\ \dfrac{50-x}{5} & 45 < x \le 50 \\ 0 & x \ge 50, \end{cases}$$

$$\mu_{\text{nearly normal}} = \begin{cases} 0 & x \le 50 \\ \dfrac{x-50}{3} & 50 < x \le 53 \\ 1 & 53 < x \le 57 \\ \dfrac{60-x}{3} & 57 < x \le 60 \\ 0 & x \ge 60, \end{cases}$$

$$\mu_{\text{normal}} = \begin{cases} 0 & x \le 58 \\ \left(\dfrac{x-58}{7}\right)^2 & 58 \le x < 65 \\ 1-\left(\dfrac{x-65}{5}\right)^2 & 65 \le x < 70 \\ 1 & x \ge 70. \end{cases} \tag{4}$$

2.1.3. Age. This input field is classified into six fuzzy sets. The fuzzy sets with their range are shown in Table 3. Consider

$$\mu_{\text{young}} = \begin{cases} 1 & x \le 0 \\ \left(\dfrac{x-0}{15}\right)^2 & 0 \le x < 15 \\ 1-\left(\dfrac{x-15}{15}\right)^2 & 15 \le x < 30 \\ 0 & x \ge 30, \end{cases}$$

$$\mu_{\text{adult}} = \begin{cases} 0 & x < 25 \\ \dfrac{x-25}{5} & 25 \le x \le 30 \\ 1 & 30 \le x \le 40 \\ \dfrac{48-x}{8} & 40 \le x \le 48 \\ 0 & x \ge 48, \end{cases}$$

$$\mu_{\text{mid aged}} = \begin{cases} 0 & x < 45 \\ \dfrac{x-45}{5} & 45 \le x \le 50 \\ 1 & 50 \le x \le 56 \\ \dfrac{60-x}{4} & 56 \le x \le 60 \\ 0 & x \ge 60, \end{cases}$$

$$\mu_{\text{aged}} = \begin{cases} 0 & x < 58 \\ \dfrac{x-58}{4} & 58 \le x \le 62 \\ 1 & 62 \le x \le 66 \\ \dfrac{72-x}{6} & 66 \le x \le 72 \\ 0 & x \ge 72, \end{cases}$$

Table 3

Age (in years)	
Young	<30
Adult	25–48
Midaged	45–60
Aged	58–72
Old	70–86
Very old	>80

Table 4

Body mass index (kg/m^2)	
Low (underweight)	10–18
Medium (normal weight)	15–26
Above medium (overweight)	25–34
High (obese)	32–40
Very high (severe obese)	38–46
Very very high (super obese)	44–50

$$\mu_{\text{old}} = \begin{cases} 0 & x < 70 \\ \dfrac{x-70}{4} & 70 \le x \le 74 \\ 1 & 74 \le x \le 78 \\ \dfrac{86-x}{8} & 78 \le x \le 86 \\ 0 & x \ge 86, \end{cases}$$

$$\mu_{\text{very old}} = \begin{cases} 0 & x \le 80 \\ \left(\dfrac{x-80}{7}\right)^2 & 80 \le x < 87 \\ 1-\left(\dfrac{x-87}{8}\right)^2 & 87 \le x < 95 \\ 1 & x \ge 95. \end{cases} \tag{5}$$

2.1.4. BMI. Body mass index is defined as the individual's body weight divided by square of his or her height. This input field is classified into four fuzzy sets. The fuzzy sets with their range are shown in Table 4. Consider

$$\mu_{\text{low}} = \begin{cases} 1 & x \le 10 \\ \left(\dfrac{x-10}{4}\right)^2 & 10 \le x < 14 \\ 1-\left(\dfrac{x-14}{4}\right)^2 & 14 \le x < 18 \\ 0 & x \ge 18, \end{cases}$$

$$\mu_{\text{medium}} = \begin{cases} 0 & x \le 15 \\ \dfrac{x-15}{3} & 15 < x \le 18 \\ 1 & 18 < x \le 24 \\ \dfrac{26-x}{2} & 24 < x \le 26 \\ 0 & x \ge 26, \end{cases}$$

Table 5

Heart rate (beats/min)	
Low	50–65
Normal	60–80
High	78–110
Very high	105–125

$$\mu_{\text{above medium}} = \begin{cases} 0 & x \le 25 \\ \dfrac{x-25}{2} & 25 < x \le 27 \\ 1 & 27 < x \le 30 \\ \dfrac{34-x}{4} & 30 < x \le 34 \\ 0 & x \ge 34, \end{cases}$$

$$\mu_{\text{high}} = \begin{cases} 0 & x \le 32 \\ \dfrac{x-32}{2} & 32 < x \le 34 \\ 1 & 34 < x \le 38 \\ \dfrac{40-x}{2} & 38 < x \le 40 \\ 0 & x \ge 40, \end{cases}$$

$$\mu_{\text{very high}} = \begin{cases} 0 & x \le 38 \\ \dfrac{x-38}{2} & 38 < x \le 40 \\ 1 & 40 < x \le 44 \\ \dfrac{46-x}{2} & 44 < x \le 46 \\ 0 & x \ge 46, \end{cases}$$

$$\mu_{\text{very very high}} = \begin{cases} 0 & x \le 44 \\ \left(\dfrac{x-44}{3}\right)^2 & 44 \le x < 47 \\ 1-\left(\dfrac{x-47}{3}\right)^2 & 47 \le x < 50 \\ 1 & x \ge 50. \end{cases} \tag{6}$$

2.1.5. Heart Rate. This input field is classified into four linguistic variables.The fuzzy sets with their range are shown in Table 5. Consider

$$\mu_{\text{low}} = \begin{cases} 1 & x \le 50 \\ \left(\dfrac{x-50}{6}\right)^2 & 50 \le x < 56 \\ 1-\left(\dfrac{x-56}{9}\right)^2 & 56 \le x < 65 \\ 0 & x \ge 65, \end{cases}$$

$$\mu_{\text{normal}} = \begin{cases} 0 & x \le 60 \\ \dfrac{x-60}{10} & 60 < x \le 70 \\ 1 & 70 < x \le 75 \\ \dfrac{80-x}{5} & 75 < x \le 80 \\ 0 & x \ge 80, \end{cases}$$

$$\mu_{\text{high}} = \begin{cases} 0 & x \le 78 \\ \dfrac{x-78}{12} & 78 < x \le 90 \\ 1 & 90 < x \le 100 \\ \dfrac{110-x}{10} & 100 < x \le 110 \\ 0 & x \ge 110, \end{cases}$$

$$\mu_{\text{very high}} = \begin{cases} 0 & x \le 105 \\ \left(\dfrac{x-105}{10}\right)^2 & 105 \le x < 115 \\ 1-\left(\dfrac{x-115}{10}\right)^2 & 115 \le x < 125 \\ 1 & x \ge 125. \end{cases} \tag{7}$$

Table 6

Triglyceride (mg/dL)	
Normal	<150
A little bit high	150–200
High	200–500
Very high	≥500

2.1.6. Triglyceride. Triglycerides have been identified to play a major role in heart disease and hypertension. This input field is classified into four fuzzy sets. The fuzzy sets with their range are shown in Table 6. Consider

$$\mu_{\text{normal}} = \begin{cases} 1 & x \le 0 \\ \left(\dfrac{x-75}{75}\right)^2 & 0 \le x < 75 \\ 1-\left(\dfrac{x-75}{75}\right)^2 & 75 \le x < 150 \\ 0 & x \ge 150, \end{cases}$$

$$\mu_{\text{a little bit high}} = \begin{cases} 0 & x \le 150 \\ \dfrac{x-150}{15} & 150 < x \le 165 \\ 1 & 165 \le x \le 185 \\ \dfrac{200-x}{15} & 185 < x \le 200 \\ 0 & x \ge 200, \end{cases}$$

Table 7

Exercise (in Min)	
Low effective	5–30
medium effective	30–60
High effective	60–100
Very high effective	90–120

$$\mu_{\text{high}} = \begin{cases} 0 & x \le 200 \\ \dfrac{x-200}{100} & 200 < x \le 300 \\ 1 & 300 \le x \le 400 \\ \dfrac{500-x}{100} & 400 < x \le 500 \\ 0 & x \ge 500, \end{cases}$$

$$\mu_{\text{very high}} = \begin{cases} 0 & x \le 500 \\ \left(\dfrac{x-500}{100}\right)^2 & 500 \le x < 600 \\ 1-\left(\dfrac{x-600}{100}\right)^2 & 600 \le x < 700 \\ 1 & x \ge 700. \end{cases} \quad (8)$$

2.1.7. Physical Exercise. This input field is classified into four fuzzy sets. The fuzzy sets with their range are shown in Table 7. If a person is not doing exercise, then input value is zero. Consider

$$\mu_{\text{low}} = \begin{cases} 1 & x \le 5 \\ \left(\dfrac{x-5}{12}\right)^2 & 5 \le x < 17 \\ 1-\left(\dfrac{x-17}{13}\right)^2 & 17 \le x < 30 \\ 0 & x \ge 30, \end{cases}$$

$$\mu_{\text{medium}} = \begin{cases} 0 & x \le 30 \\ \dfrac{x-30}{10} & 30 < x \le 40 \\ 1 & 40 \le x \le 50 \\ \dfrac{60-x}{10} & 50 < x \le 60 \\ 0 & x \ge 60, \end{cases}$$

$$\mu_{\text{high}} = \begin{cases} 0 & x \le 60 \\ \dfrac{x-60}{10} & 60 < x \le 70 \\ 1 & 70 \le x \le 90 \\ \dfrac{100-x}{10} & 90 < x \le 100 \\ 0 & x \ge 100, \end{cases}$$

$$\mu_{\text{very high}} = \begin{cases} 0 & x \le 90 \\ \left(\dfrac{x-90}{15}\right)^2 & 90 \le x < 105 \\ 1-\left(\dfrac{x-105}{15}\right)^2 & 105 \le x < 120 \\ 1 & x \ge 120. \end{cases} \quad (9)$$

Table 8

Smoking (per day)	
Low smoker	5–10 cigarettes
Medium smoker	8–20 cigarettes
High smoker	18–30 cigarettes
Very high smoker	28–35 cigarettes

2.1.8. Smoking. This input field is classified into four fuzzy sets. The fuzzy sets with their range are shown in Table 8. If person is not smoking, then input value is zero. Consider

$$\mu_{\text{low}} = \begin{cases} 1 & x \le 5 \\ \left(\dfrac{x-5}{2}\right)^2 & 5 \le x < 7 \\ 1-\left(\dfrac{x-7}{3}\right)^2 & 7 \le x < 10 \\ 0 & x \ge 10, \end{cases}$$

$$\mu_{\text{medium}} = \begin{cases} 0 & x \le 8 \\ \dfrac{x-8}{6} & 8 < x \le 14 \\ \dfrac{20-x}{6} & 14 < x \le 20 \\ 0 & x \ge 20, \end{cases}$$

$$\mu_{\text{high}} = \begin{cases} 0 & x \le 18 \\ \dfrac{x-18}{6} & 18 < x \le 24 \\ \dfrac{30-x}{6} & 24 < x \le 30 \\ 0 & x \ge 30, \end{cases}$$

$$\mu_{\text{very high}} = \begin{cases} 0 & x \le 28 \\ \left(\dfrac{x-28}{4}\right)^2 & 28 \le x < 32 \\ 1-\left(\dfrac{x-32}{3}\right)^2 & 32 \le x < 35 \\ 1 & x \ge 35. \end{cases} \quad (10)$$

2.2. Output Variable. The output contains risk grade of hypertension which is classified in five linguistic variables, very low, low, moderate, high, and very high. The output optimal alternatives indicate patient's present grade of hypertension. These optimal alternatives have been graphically shown in the form of Sugeno's spikes.

3. Result

Now we have developed various linguistic strings to represent the state of the patient using the input variables such as age, LDL, HDL, SBP, DBP, triglyceride, BMI, HR, exercise, and smoking. Some of the linguistic strings are given as follows.

$J_1 = \text{Young}_{\text{Age}}\text{Normal}_{\text{LDL}}\text{Normal}_{\text{HDL}}\text{Desirable}_{\text{SBP}}\text{Desirable}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\ \text{M}_{\text{BMI}}\text{Normal}_{\text{HR}}\text{No}_{\text{Excercise}}\text{No}_{\text{Smoking}}$

$J_2 = \text{Young}_{\text{Age}}\text{Normal}_{\text{LDL}}\text{Normal}_{\text{HDL}}\text{Desirable}_{\text{SBP}}\text{Desirable}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\ \text{M}_{\text{BMI}}\text{Normal}_{\text{HR}}\text{Low}_{\text{Excercise}}\text{Low}_{\text{Smoking}}$

$J_3 = \text{Young}_{\text{Age}}\text{Normal}_{\text{LDL}}\text{Normal}_{\text{HDL}}\ \text{Desirable}_{\text{SBP}}\text{Desirable}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\ \text{M}_{\text{BMI}}\text{Normal}_{\text{HR}}\text{Medium}_{\text{Excercise}}\text{Low}_{\text{Smoking}}$

$J_{400} = \text{Young}_{\text{Age}}\text{Normal}_{\text{LDL}}\text{Normal}_{\text{HDL}}\text{Normal}_{\text{SBP}}\text{Normal}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\text{AM}_{\text{BMI}}\ \text{Normal}_{\text{HR}}\text{Medium}_{\text{Excercise}}\text{Low}_{\text{Smoking}}$

$J_{401} = \text{Young}_{\text{Age}}\text{Normal}_{\text{LDL}}\text{Normal}_{\text{HDL}}\text{Desirable}_{\text{SBP}}\text{Desirable}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\text{AM}_{\text{BMI}}\ \text{High}_{\text{HR}}\text{Medium}_{\text{Excercise}}\text{Med}_{\text{Smoking}}$

$J_{2500} = \text{Adult}_{\text{Age}}\text{Normal}_{\text{LDL}}\text{Normal}_{\text{HDL}}\text{Desirable}_{\text{SBP}}\text{ADesirable}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\text{M}_{\text{BMI}}\ \text{Normal}_{\text{HR}}\text{No}_{\text{Excercise}}\text{No}_{\text{Smoking}}$

$J_{6500} = \text{Adult}_{\text{Age}}\text{High}_{\text{LDL}}\text{High}_{\text{HDL}}\text{Desirable}_{\text{SBP}}\ \text{Moderate}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\ \text{AM}_{\text{BMI}}\text{High}_{\text{HR}}\text{Low}_{\text{Excercise}}\text{Low}_{\text{Smoking}}$

$J_{10001} = \text{Adult}_{\text{Age}}\text{High}_{\text{LDL}}\text{High}_{\text{HDL}}\text{Desirable}_{\text{SBP}}\ \text{Moderate}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\text{AM}_{\text{BMI}}\ \text{High}_{\text{HR}}\text{Low}_{\text{Excercise}}\text{Medium}_{\text{Smoking}}$

$J_{17009} = \text{Midaged}_{\text{Age}}\text{Normal}_{\text{LDL}}\text{Normal}_{\text{HDL}}\ \text{Desirable}_{\text{SBP}}\text{Desirable}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\text{M}_{\text{BMI}}\ \text{Normal}_{\text{HR}}\text{No}_{\text{Excercise}}\text{No}_{\text{Smoking}}$

$J_{17010} = \text{Midaged}_{\text{Age}}\text{Normal}_{\text{LDL}}\text{Normal}_{\text{HDL}}\ \text{Desirable}_{\text{SBP}}\text{Desirable}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\text{M}_{\text{BMI}}\ \text{High}_{\text{HR}}\text{No}_{\text{Excercise}}\text{Low}_{\text{Smoking}}$

$J_{200080} = \text{Aged}_{\text{Age}}\text{Normal}_{\text{LDL}}\text{Normal}_{\text{HDL}}\text{Desirable}_{\text{SBP}}\ \text{ADesirable}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\text{M}_{\text{BMI}}\ \text{Normal}_{\text{HR}}\text{No}_{\text{Excercise}}\text{No}_{\text{Smoking}}$

$J_{405001} = \text{Aged}_{\text{Age}}\text{High}_{\text{LDL}}\text{High}_{\text{HDL}}\text{Moderate}_{\text{SBP}}\ \text{Moderate}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\text{VH}_{\text{BMI}}\ \text{VH}_{\text{HR}}\text{Low}_{\text{Excercise}}\text{Medium}_{\text{Smoking}}$

$J_{966080} = \text{Aged}_{\text{Age}}\text{VeryHigh}_{\text{LDL}}\text{NVeryhigh}_{\text{HDL}}\text{Veryhigh}_{\text{SBP}}\text{Veryhigh}_{\text{DBP}}\text{Veryhigh}_{\text{Triglyceride}}\text{VH}_{\text{BMI}}\text{Normal}_{\text{HR}}\text{Low}_{\text{Excercise}}\text{high}_{\text{Smoking}}$

$J_{1200200} = \text{Old}_{\text{Age}}\text{High}_{\text{LDL}}\text{Normal}_{\text{HDL}}\ \text{AboveDesirable}_{\text{SBP}}\text{Moderate}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\ \text{AM}_{\text{BMI}}\ \text{Normal}_{\text{HR}}\text{Low}_{\text{Excercise}}\ \text{No}_{\text{Smoking}}$

$J_{2344569} = \text{Old}_{\text{Age}}\text{VeryHigh}_{\text{LDL}}\text{NVeryhigh}_{\text{HDL}}\ \text{Veryhigh}_{\text{SBP}}\text{high}_{\text{DBP}}\text{Veryhigh}_{\text{Triglyceride}}\ \text{AM}_{\text{BMI}}\text{High}_{\text{HR}}\text{No}_{\text{Excercise}}\text{Very high}_{\text{Smoking}}$

$J_{5676880} = \text{VeryOld}_{\text{Age}}\text{Veryhigh}_{\text{LDL}}\text{Normal}_{\text{HDL}}\ \text{Moderate}_{\text{SBP}}\text{ADesirable}_{\text{DBP}}\text{Normal}_{\text{Triglyceride}}\ \text{AM}_{\text{BMI}}\text{Normal}_{\text{HR}}\text{Low}_{\text{Excercise}}\ \text{Low}_{\text{Smoking}}$

$J_{7566780} = \text{Veryold}_{\text{Age}}\text{High}_{\text{LDL}}\text{High}_{\text{HDL}}\ \text{Veryhigh}_{\text{SBP}}\text{Veryhigh}_{\text{DBP}}\text{Veryhigh}_{\text{Triglyceride}}\ \text{High}_{\text{BMI}}\text{VH}_{\text{HR}}\text{No}_{\text{Excercise}}\text{Veryhigh}_{\text{Smoking}}$

$J_{8545200} = \text{Veryold}_{\text{Age}}\text{VeryHigh}_{\text{LDL}}\text{Veryhigh}_{\text{HDL}}\text{Veryhigh}_{\text{SBP}}\text{High}_{\text{DBP}}\text{V.high}_{\text{Triglyceride}}\ \text{VH}_{\text{BMI}}\text{High}_{\text{HR}}\text{No}_{\text{Excercise}}\text{high}_{\text{Smoking}}$

$J_{9031678} = \text{Veryold}_{\text{Age}}\text{VeryHigh}_{\text{LDL}}\text{Veryhigh}_{\text{HDL}}\text{Veryhigh}_{\text{SBP}}\text{Veryhigh}_{\text{DBP}}\text{Veryhigh}_{\text{Triglyceride}}\ \text{VH}_{\text{BMI}}\text{VH}_{\text{HR}}\text{Low}_{\text{Excercise}}\text{Very high}_{\text{Smoking}}$

$J_{9031680} = \text{Veryold}_{\text{Age}}\text{VeryHigh}_{\text{LDL}}\text{Veryhigh}_{\text{HDL}}\text{Veryhigh}_{\text{SBP}}\text{Veryhigh}_{\text{DBP}}\text{Veryhigh}_{\text{Triglyceride}}\text{MVVH}_{\text{BMI}}\text{VH}_{\text{HR}}\text{No}_{\text{Excercise}}\text{Very high}_{\text{Smoking}}.$

On the basis of our proposed technique to investigate the health status of a person whose medical data is available, three different cases have been discussed as follows.

Case 1. The input variables of first patient are

(1) Age = {(0, young), (0.8, adult), (0, midaged), (0, aged), (0, old), (0, very old)}.

(2) LDL = {(0.71, normal), (0, above normal), (0, borderline high), (0, high), (0, very high)}.

(3) HDL = {(0, very high), (0, high), (0, nearly normal), (1, normal)}.

(4) SBP = {(0, desirable), (0.8, above desirable), (0, moderate), (0, above moderate), (0, little high), (0, high), (0, very high)}.

(5) DBP = {(0, desirable), (1, above desirable), (0, moderate), (0, above moderate), (0, little high), (0, high), (0, very high)}.

(6) Triglyceride = {(0.72, normal), (0, a little bit high), (0, high), (0, very high)}.

(7) BMI = {(0, low), (0.99, medium), (0, above medium), (0, high), (0, very high), (0, very very high)}.

(8) HR = {(0, low), (0.86, normal), (0, high), (0, very high)}.

(9) Exercise = {(1, low), (0, medium), (0, high), (0, very high)}.

(10) Smoking = {(1, low), (0, medium), (0, high), (0, very high)}.

This is the fuzzy set which represents the state of concerned patient:

$$X = \{(0.71, J_{A,N,N,AD,AD,N,M,N,L,L})\}. \tag{11}$$

The utility matrix U of order $5x$ 9031680 by using the fuzzy rule base designed is as follows:

$$U = \begin{pmatrix} 98 & 95 & \cdots & 10 & \cdots & 10 & \cdots & 05 \\ 68 & 80 & \cdots & 20 & \cdots & 30 & \cdots & 10 \\ 30 & 25 & \cdots & 45 & \cdots & 62 & \cdots & 40 \\ 20 & 20 & \cdots & 92 & \cdots & 90 & \cdots & 86 \\ 10 & 10 & \cdots & 55 & \cdots & 20 & \cdots & 95 \end{pmatrix}. \tag{12}$$

The five fuzzy utilities are

(1) $U_1 = \{(0.71, 98)\}$,

(2) $U_2 = \{(0.71, 68)\}$,

(3) $U_3 = \{(0.71, 30)\}$,

(4) $U_4 = \{(0.71, 20)\}$,

(5) $U_5 = \{(0.71, 10)\}$.

The maximum sets corresponding to each alternative are

(1) $U_{1m} = \{(1, 98)\}$,

(2) $U_{2m} = \{(0.69, 68)\}$,

(3) $U_{3m} = \{(0.30, 30)\}$,

(4) $U_{4m} = \{(0.20, 20)\}$,

(5) $U_{5m} = \{(0.10, 10)\}$.

Now, the optimal fuzzy utilities using fuzzy utilities and maximizing sets are

(1) $U_{1o} = \{(0.71, 98)\}$,

(2) $U_{2o} = \{(0.69, 68)\}$,

(3) $U_{3o} = \{(0.30, 30)\}$,

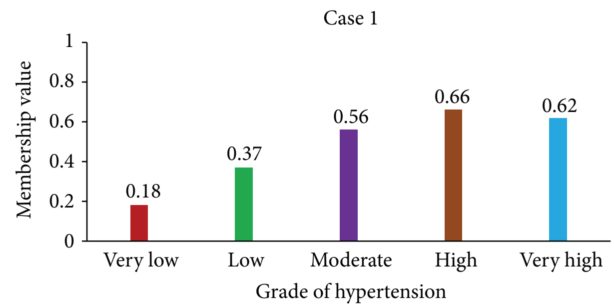

Figure 1: View of Sugeno's spikes.

(4) $U_{4o} = \{(0.20, 20)\}$,

(5) $U_{5o} = \{(0.10, 10)\}$.

Using these utilities, the optimal alternatives are given by

$$A_o = \{(0.71, \text{very low}), (0.69, \text{low}), (0.30, \text{moderate}), (0.20, \text{high}), \text{and } (0.10, \text{very high})\}. \tag{13}$$

This optimal alternative indicates that the patient presently is in very low grade of hypertension. The optimal alternatives have been graphically shown in Figure 1 in the form of Sugeno's spikes.

Case 2. The input variables of the second patient are as follows.

(1) Age = {(0, young), (0, adult), (1, midaged), (0, aged), (0, old), (0, very old)}.

(2) LDL = {(1, normal), (0, above normal), (0, borderline high), (0, high), (0, very high)}.

(3) HDL = {(0, very high), (0.6, high), (0, nearly normal), (0, normal)}.

(4) SBP = {(0, desirable), (0.8, above desirable), (0, moderate), (0, above moderate), (0, little high), (0, high), (0, very high)}.

(5) DBP = {(0, desirable), (0.66, above desirable), (0, moderate), (0, above moderate), (0, little high), (0, high), (0, very high)}.

(6) Triglyceride = {(0.66, normal), (0, a little bit high), (0, high), (0, very high)}.

(7) BMI = {(0, low), (0, medium), (0.86, above medium), (0, high), (0, very high), (0, very very high)}.

(8) HR = {(0, low), (0.76, normal), (0, high), (0, very high)}.

(9) Exercise = {(0, low), (0.79, medium), (0, high), (0, very high)}.

(10) Smoking = {(1, low), (0, medium), (0, high), (0, very high)}.

This is the fuzzy set which represents the state of concerned patient:

$$X = \{(0.6, J_{MA,N,H,AD,AD,N,AM,N,M,L})\}. \tag{14}$$

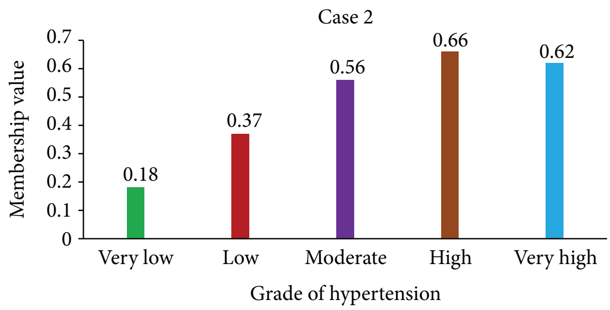

FIGURE 2: View of Sugeno's spikes.

The utility matrix is the same as in Case 1.

The five fuzzy utilities are

(1) $U_1 = \{(0.6, 55)\}$,

(2) $U_2 = \{(0.6, 92)\}$,

(3) $U_3 = \{(0.6, 40)\}$,

(4) $U_4 = \{(0.6, 24)\}$,

(5) $U_5 = \{(0.6, 10)\}$.

The maximum sets corresponding to each alternative are

(1) $U_{1m} = \{(0.59, 55)\}$,

(2) $U_{2m} = \{(1, 92)\}$,

(3) $U_{3m} = \{(0.43, 35)\}$,

(4) $U_{4m} = \{(0.26, 24)\}$,

(5) $U_{5m} = \{(0.10, 10)\}$.

Now, the optimal fuzzy utilities using fuzzy utilities and maximizing sets are

(1) $U_{1o} = \{(0.59, 55)\}$,

(2) $U_{2o} = \{(0.6, 92)\}$,

(3) $U_{3o} = \{(0.43, 35)\}$,

(4) $U_{4o} = \{(0.26, 24)\}$,

(5) $U_{5o} = \{(0.10, 10)\}$.

Using these utilities, the optimal alternatives are given by

$$A_o = \{(0.59, \text{very low}), (0.60, \text{low}), (0.43, \text{moderate}), (0.26, \text{high}), \text{and } (0.10, \text{very high})\}. \tag{15}$$

This optimal alternative indicates that the patient presently is in low grade of hypertension. The optimal alternatives have been graphically shown in Figure 2 in the form of Sugeno's spikes.

Case 3. The input variables of the third patient are as follows.

(1) Age = {(0, young), (0, adult), (0, midaged), (0, aged), (0.75, old), (0, very old)}.

(2) LDL = {(0, normal), (0, above normal), (0, borderline high), (0.8, high), (0, very high)}.

(3) HDL = {(0, very high), (1, high), (0, nearly normal), (0, normal)}.

(4) SBP = {(0, desirable), (0, above desirable), (0.8, moderate), (0, above moderate), (0, little high), (0, high), (0, very high)}.

(5) DBP = {(0, desirable), (1, above desirable), (0, moderate), (0, above moderate), (0, little high), (0, high), (0, very high)}.

(6) Triglyceride = {(1, normal), (0.66, a little bit high), (0, high), (0, very high)}.

(7) BMI = {(0, low), (0, medium), (0, above medium), (0.78, high), (0, very high), (0, very very high)}.

(8) HR = {(0, low), (0, normal), (0.96, high), (0, very high)}.

(9) Exercise = {(0, low), (1, medium), (0, high), (0, very high)}.

(10) Smoking = {(1, low), (0, medium), (0, high), (0, very high)}.

This is the fuzzy set which represents the state of concerned patient:

$$X = \{(0.66, J_{O,H,H,M,AD,LH,H,H,M,L})\}. \tag{16}$$

The utility matrix U is the same as in Case 1.

The five fuzzy utilities are

(1) $U_1 = \{(0.66, 15)\}$,

(2) $U_2 = \{(0.66, 30)\}$,

(3) $U_3 = \{(0.66, 45)\}$,

(4) $U_4 = \{(0.66, 80)\}$,

(5) $U_5 = \{(0.66, 50)\}$.

The maximum sets corresponding to each alternative are

(1) $U_{1m} = \{(0.187, 15)\}$,

(2) $U_{2m} = \{(0.375, 30)\}$,

(3) $U_{3m} = \{(0.562, 45)\}$,

(4) $U_{4m} = \{(1, 80)\}$,

(5) $U_{5m} = \{(0.62, 50)\}$.

Now, the optimal fuzzy utilities using fuzzy utilities and maximizing sets are

(1) $U_{1o} = \{(0.187, 15)\}$,

(2) $U_{2o} = \{(0.375, 30)\}$,

(3) $U_{3o} = \{(0.562, 45)\}$,

(4) $U_{4o} = \{(0.66, 80)\}$,

(5) $U_{5o} = \{(0.62, 50)\}$.

Using these utilities, the optimal alternatives are given by

$$A_o = \{(0.187, \text{very low}), (0.375, \text{low}), (0.562, \text{moderate}), (0.66, \text{high}), \text{ and } (0.62, \text{very high})\}. \tag{17}$$

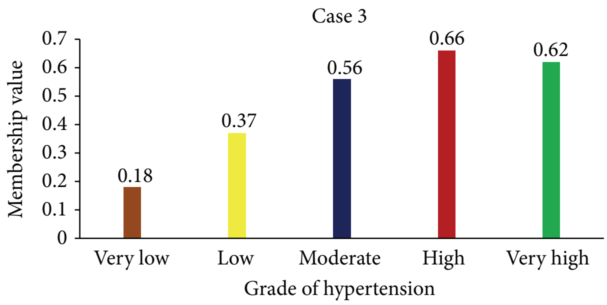

FIGURE 3: View of Sugeno's spikes.

This optimal alternative indicates that the patient is presently in high grade of hypertension.

The optimal alternatives have been graphically shown in the form of Sugeno's spikes in Figure 3.

4. Conclusion

The present research paper confirms that the soft computing diagnostic system can represent the expert's thinking in an efficient manner to handle complex cases. The design and development of soft computing risk assessment system on the basis of the proposed technique will assist medical experts to measure grade classification of hypertension efficiently.

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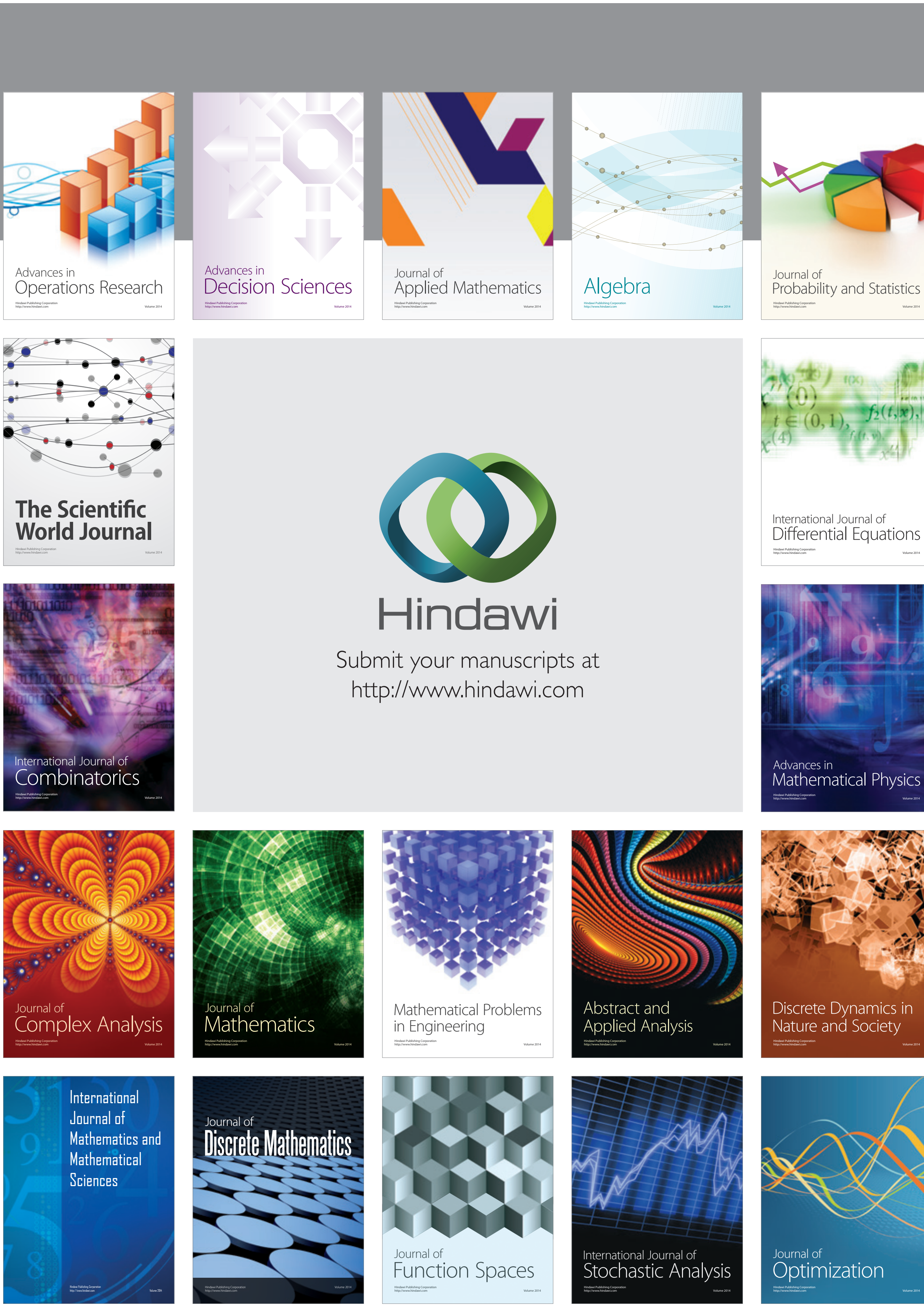
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