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Use of Fuzzy Matrices for the Diagnosis of Diabetes, Anaemia and Hypertension

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ABSTRACT— *The mathematical model presented here aims to enhance the precision in diagnostic process of diabetes, anaemia and hypertension by means of fuzzy interface. In real life, the imprecise nature of medical documentation and uncertain information provided by patients often do not give the desired degree of confidence to the diagnosis. To that end using the capability of fuzzy logic in representing, interpreting and utilizing data and information that are vague and lack certainty, a new algorithm based on different fuzzy matrices and fuzzy relations is developed. In the process a medical knowledge base is developed with the help of 51 doctors. The model achieved 94.44% accuracy in the diagnosis, which shows its usefulness. To implement this model-based diagnosis procedure a user-friendly Excel program is designed.*

Keywords— Fuzzy logic, fuzzy matrices, max-min product, Chi-square test.

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1. INTRODUCTION

The idea of fuzzy logic as a scientific concept was first used by the computer scientist Zadeh [12]. Medicine is one field in which the applicability of fuzzy logic was recognised quite early in mid 1970s. Within this field, it is the uncertainty found in the process of diagnosis of disease that has most frequently been the focus of application of fuzzy set theory. Imprecise nature of medical documentation and uncertain information supplied by patients make complications in diagnosis of diseases. The best and most useful descriptions of symptoms of diseases often use linguistic terms that are invariably vague [4].

Fuzzy mathematics is a branch of mathematics which captures uncertainty in real life and tries to extract precise meaning from the given vague information. It is a powerful tool for decision-making systems. The fuzzy set framework has been utilized in several ways for modelling medical diagnosis processes. The basic idea in a medical diagnosis is to relate symptoms or patient's signs with possible diseases according to an expert's medical knowledge. In the approach adopted by Sanchez [6], the physician's medical knowledge is represented as a fuzzy relation between symptoms and diseases. Adlassing [1] introduced fuzzy relation model for diagnostic process. Meenakshi and Kaliraja [5] have extended Sanchez's approach for medical diagnosis using the representation of an interval-valued fuzzy matrix. Elizabeth and Sujatha [2] have developed Sanchez's approach of medical diagnosis using the representation of triangular fuzzy membership matrix. Saravanan and Prasanna [7] presented the application of fuzzy matrices in medicine in which they have used the concept network and concept matrices. Raich et al. [8] established the application of fuzzy matrix in the study of diabetes.

In this paper, we have used fuzzy logic and fuzzy matrices in order to make medical diagnosis more precise. It incorporates the knowledge and experience of 51 physicians and based on that information this mathematical model arrives at the diagnostic conclusions. We have established the distinguishing way to check indication relations for the diagnosis which can be illustrated as 'non-symptom indication - non-occurrence indication - conformability indication'. The comparison of the diagnostic conclusion drawn from our model with actual diagnosis made by doctors gives 94.44% compatibility and thus establishes a fairly good accuracy of our model.

2. RESEARCH METHOD

This section describes the architecture of the proposed mathematical model which consists of:

2.1 Formulation of Medical Knowledge Base:

The physicians' knowledge is represented as a fuzzy relation between symptoms and diseases. Two types of fuzzy relations are defined between symptoms and diseases:

1) *An occurrence relation* R_o*:*

It provides knowledge about the tendency or frequency of appearance of a symptom when the specific disease is present, i.e. how often does the symptom *s* occur with disease *d*.

2) *A conformability relation* R_c*:*

It describes the discriminating power of the symptoms to confirm the presence of the disease, i.e. how strongly does the symptom *s* confirm disease *d*.

The distinction between occurrence and conformability is useful because though the symptom common to several diseases is present, its occurrence and conformability are different in different diseases.

The above relations are determined from expert medical documentation.

2.2 Fuzzification:

Membership grades of all the symptoms of the diseases are determined based on intensity or frequency of the symptom observed in patients inflicted by the selected diseases. This step transforms linguistic terms used to describe the symptoms into numbers.

2.3 Fuzzy interface:

Let D be the set of the selected diseases, S be the set of the symptoms of the diseases and P be the set of patients to be diagnosed.

A fuzzy relation R_s is defined on the set P×S in which membership grades $R_s(p, s)$ (where p∈P, s∈S) indicate the degree to which the symptom *s* is present in patient *p*. A fuzzy relation R_o is defined on the set S×D where $R_o(s, d)$ (where s∈S, d∈D) indicates the frequency of occurrence of symptom *s* with disease *d*. A fuzzy relation R_c is also defined on the same set, where $R_c(p, d)$ corresponds to the degree to which symptom *s* confirms the presence of disease *d*.

Using relations R_s, R_o and R_c, the following four different indication relations defined on set P×D are calculated:

1) Occurrence indication relation $R_1 = R_s \circ R_o$

2) Conformability indication relation $R_2 = R_s \circ R_c$

3) Non-occurrence indication relation $R_3 = R_s \circ (1-R_o)$

4) Non-symptom indication relation $R_4 = (1-R_s) \circ R_o$.

For composition of fuzzy relations, max-min product of fuzzy matrices is used.

For an illustration, let D= $\{d_1, d_2\}$, S= $\{s_1, s_2, s_3\}$, P= $\{p_1, p_2\}$

$$R_s = \begin{array}{c} \\ p_1 \\ p_2 \end{array} \begin{array}{c} \begin{array}{ccc} s_1 & s_2 & s_3 \end{array} \\ \begin{pmatrix} \mathbf{0.1} & \mathbf{0.2} & \mathbf{0.3} \\ \mathbf{0.4} & \mathbf{0.5} & \mathbf{0.6} \end{pmatrix} \end{array} \qquad R_o = \begin{array}{c} \\ s_1 \\ s_2 \\ s_3 \end{array} \begin{array}{c} \begin{array}{cc} d_1 & d_2 \end{array} \\ \begin{pmatrix} \mathbf{0.2} & \mathbf{0.4} \\ \mathbf{0.8} & \mathbf{0.7} \\ \mathbf{0.4} & \mathbf{0.5} \end{pmatrix} \end{array}$$

Let $R_1 = R_s \circ R_o$

So for every i=1, 2 and j= 1, 2, $R_1(p_i, d_j) = \max_{s \in S}\{\min\{ R_s(p_i, s), R_o(s, d_j)\}\}$

For example, $R_1(p_1,d_1) = \max\{\min\{0.1,0.2\}, \min\{0.2,0.8\}, \min\{0.3,0.4\}\}= \max\{0.1, 0.2, 0.3\}= 0.3$.

Similarly, we can calculate $R_1(p_i, d_j)$ for every *i* and *j*.

Hence, we get $R_1 =$

$$R_1 = \begin{array}{c} \\ p_1 \\ p_2 \end{array} \begin{array}{c} \begin{array}{cc} d_1 & d_2 \end{array} \\ \begin{pmatrix} \mathbf{0.3} & \mathbf{0.3} \\ \mathbf{0.5} & \mathbf{0.5} \end{pmatrix} \end{array}$$

Other indication relations are calculated in the same way.

2.4 Defuzzification:

To draw diagnostic conclusions from the above four indication relations, the following rules are developed:

1) Make an excluded diagnosis for a disease *d* in patient *p*, if $R_4(p, d) \geq 0.80$.

2) If for any patient *p* and any disease *d*, $R_4(p, d) < 0.80$, find mean of $R_3(p, d)$ and $(1- R_1(p, d))$, denoted by *m*. Make an excluded diagnosis for a disease *d* in patient *p*, if $m \geq 0.80$.

3) If $m < 0.80$, make diagnosis as follows:

If $0 \leq R_2(p, d) < 0.30$ - Nil (The disease *d* is not present in patient *p*.)
If $0.30 \leq R_2(p, d) < 0.40$ - Slight (The disease *d* is slightly present in patient *p*.)
If $0.40 \leq R_2(p, d) < 0.60$ - Moderate (The disease *d* is moderately present in patient *p*.)
If $0.60 \leq R_2(p, d) < 0.80$ - High (The disease *d* is highly present in patient *p*.)
If $0.80 \leq R_2(p, d) \leq 1$ - Severe (The disease *d* is severely present in patient *p*.)

These conclusions are compared with doctors' diagnosis and accuracy of the model is checked. Chi- square test is used as a statistical support for this.

Excel program is developed in order to do above mentioned calculations and make the model user-friendly.

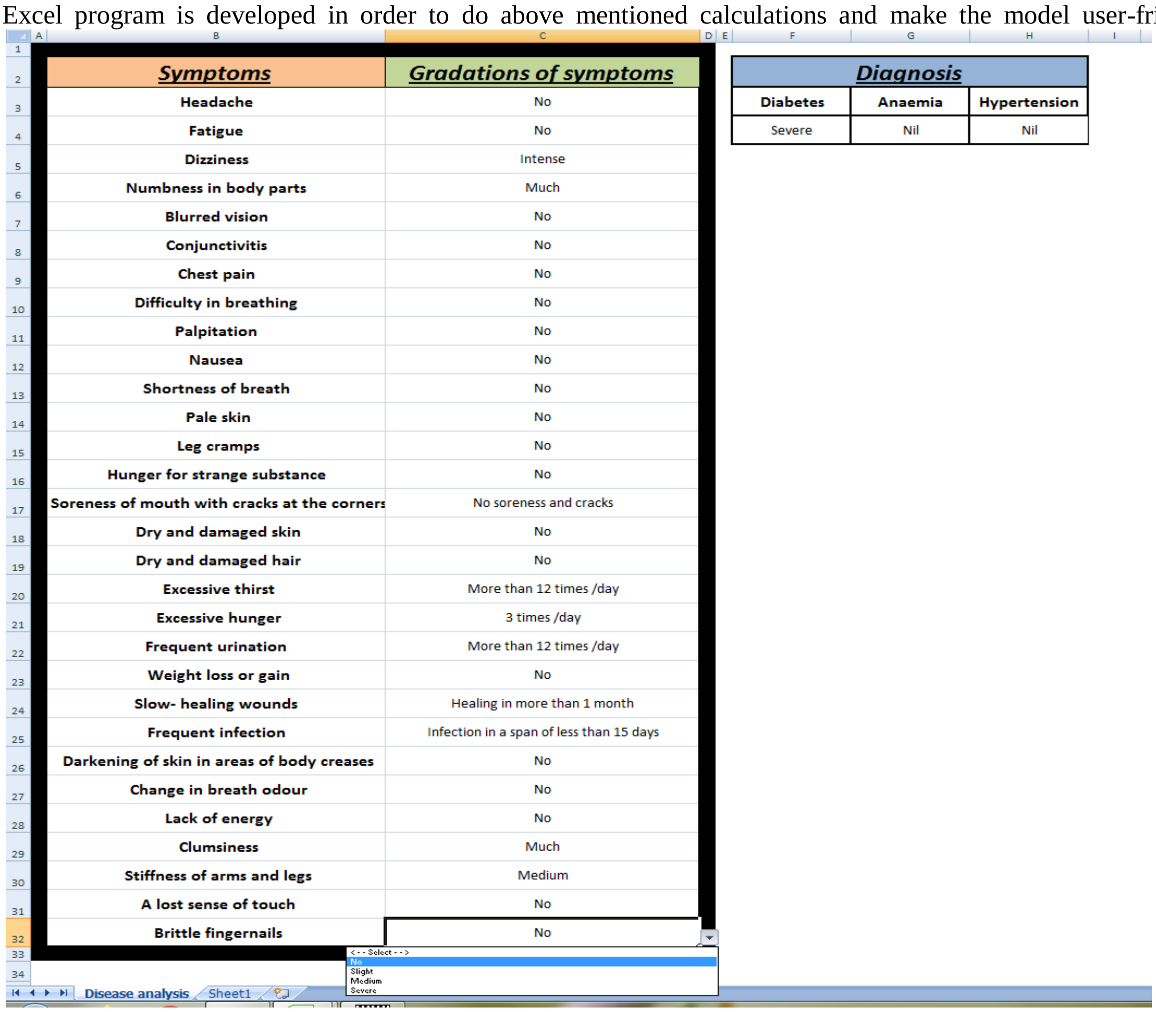

Figure 1: Excel program designed to make the diagnosis

The Excel program consists of two separate tables as shown in the image above (Figure 1). First table (on the left hand side) contains two columns, viz. symptoms and gradations of symptoms. Second table (on the right hand side) is an indicator of diagnostic conclusions for the three diseases. The first table is used to input the intensity of the user's symptoms and the second table simply gives diagnostic conclusions based on the inputs taken from the first table.

Each cell in the column of gradations of symptoms is provided with a drop-down menu. A user can access the drop-down menu merely by clicking the arrow on the right of the corresponding cell. The drop-down menu consists of the gradations of the symptom based on frequency and intensity of the symptom (like slight, severe etc.) observed in the patients. A user is supposed to opt for a gradation which is observed for that particular symptom. Similarly a user can select gradations for all the thirty symptoms. When a user inputs his gradations of symptom, the diagnostic results for the three diseases can be immediately seen in the second table. The diagnostic results are in the form of linguistic terms like nil, slight, moderate etc. which are easy to interpret.

3. PROCEDURE EMPLOYED

Here we have selected three diseases viz., Diabetes, Anaemia and Hypertension as a case study. The reason for choice of these diseases is that they are the most prevalent diseases in India as we can see from WHO (World Health Organization) reports. In India, according to WHO reports in the year 2016, the prevalence of diabetes in adults is 7.8% [9], prevalence of anaemia among women of reproductive age is 51.43% [10] and according to WHO report in the year 2018, prevalence of hypertension in adults is 24% [11].

After selecting the three diseases, we listed 30 symptoms of these diseases which are commonly observed in patients suffering by them.

Then we developed medical knowledge base with the help of the doctors. For the formulation of the knowledge base, we considered occurrence of a symptom in corresponding disease and confirmation of a disease from corresponding symptom. Occurrence of a symptom in corresponding disease explains tendency or frequency of appearance of symptom when the specific disease is present; it corresponds to the question, 'how often does symptom *s* occur with disease *d*?'. Confirmation of a disease from corresponding symptom describes the discriminating power of the symptom to confirm the presence of the disease; it corresponds to the question, 'how strongly does symptom *s* confirm disease *d*?'. We provided blank charts (Appendix) to randomly selected 51 doctors in Ratnagiri district to develop a knowledge base consisting of occurrence of a symptom in corresponding disease and the confirmation of a disease from particular symptom. For occurrence of a symptom, we asked the doctors to write the number of patients in which that particular symptom is observed out of 100 patients of the corresponding disease. For instance, if a doctor has examined 100 patients of diabetes and if he/she finds 'excessive thirst' in 90 patients out of 100, he/she has to write 90 as occurrence of excessive thirst in diabetes. For confirmation of a disease, we asked the doctors to write the percentage by which he/she confirms the presence of that particular disease when he/she observes the corresponding symptom in the patient. E.g., if a doctor observes 'pale skin' of a patient and if he/she thinks that the possibility that the patient would be suffering from anaemia is 80%, then he/she has to write 80 as confirmation of anaemia from pale skin. We divide these numbers by 100 so that they lie in [0, 1].

We calculated mean of the data collected to find central tendency of the doctors' data as shown in table 1.

For fuzzification, we assigned membership grades to each of the 30 symptoms based on intensity or frequency of the symptom observed in a patient. The grades are as follows:

1) Headache:
- Continuous severe: 1.00 — Continuous mild: 0.75
- Daily: 0.50 — Occasionally: 0.25 — No: 0.00

2) Fatigue:
- Very much: 1.00 — Medium: 0.66
- Slight: 0.33 — No: 0.00

3) Dizziness:
- Intense: 1.00 — Medium: 0.66
- Slight: 0.33 — No: 0.00

4) Numbness in body parts:
- Much: 1.00 — Medium: 0.66
- Vey less: 0.33 — No: 0.00

5) Blurred vision:
- High: 1.00 — Medium: 0.66
- Very slight: 0.33 — No: 0.00

Table 1: Mean of knowledge-base obtained from experts

Sr. No.	SYMPTOMS	DIABETES		ANAEMIA		HYPERTENSION	
		O	**C**	**O**	**C**	**O**	**C**
1.	Headache	0.02	0.02	0.49	0.37	0.8	0.7
2.	Fatigue	0.71	0.64	0.85	0.75	0.33	0.22
3.	Dizziness	0.39	0.36	0.66	0.59	0.58	0.46
4.	Numbness in body parts	0.65	0.54	0.32	0.27	0.35	0.24
5.	Blurred vision	0.52	0.45	0.25	0.19	0.37	0.27
6.	Conjunctivitis	0.28	0.12	0.04	0.04	0.04	0.03
7.	Chest pain	0.15	0.12	0.13	0.11	0.75	0.65
8.	Difficulty in breathing	0.16	0.07	0.5	0.37	0.51	0.41
9.	Palpitation	0.18	0.07	0.47	0.41	0.63	0.49
10.	Nausea	0.14	0.11	0.31	0.18	0.38	0.28
11.	Shortness of breath	0.16	0.12	0.6	0.52	0.52	0.49
12.	Pale skin	0.2	0.1	0.89	0.8	0.09	0.05
13.	Leg cramps	0.48	0.41	0.6	0.56	0.21	0.11
14.	Hunger for strange substance	0.15	0.09	0.37	0.24	0.02	0.01
15.	Soreness of mouth with cracks at the corners	0.15	0.05	0.55	0.54	0.04	0.02
16.	Dry and damaged skin	0.25	0.2	0.53	0.4	0.04	0.02
17.	Dry and damaged hair	0.17	0.08	0.52	0.43	0.03	0.02
18.	Excessive thirst	0.85	0.81	0.29	0.18	0.08	0.03
19.	Excessive hunger	0.86	0.74	0.08	0.05	0.05	0.02
20.	Frequent urination	0.87	0.88	0.16	0.1	0.15	0.09
21.	Weight loss or gain	0.79	0.66	0.6	0.54	0.13	0.06
22.	Slow- healing wounds	0.79	0.84	0.25	0.15	0.07	0.02
23.	Frequent infection	0.77	0.81	0.3	0.23	0.09	0.09
24.	Darkening of skin in areas of body creases	0.29	0.23	0.22	0.14	0.09	0.04
25.	Change in breath odour	0.47	0.36	0.17	0.11	0.07	0.03
26.	Lack of energy	0.66	0.6	0.83	0.73	0.32	0.23
27.	Clumsiness	0.26	0.15	0.39	0.32	0.23	0.08
28.	Stiffness of arms and legs	0.19	0.15	0.39	0.27	0.04	0.03
29.	A lost sense of touch	0.39	0.38	0.16	0.11	0.08	0.09
30.	Brittle fingernails	0.34	0.24	0.61	0.54	0.1	0.07

6) Conjunctivitis:
Vision affecting: 1.00 Medium: 0.66
Insignificant: 0.33 No: 0.00

7) Chest pain:
Severe and intolerable: 1.00 High but tolerable: 0.75
Moderate: 0.50 Slight: 0.25 No: 0.00

8) Difficulty in breathing:
Very much: 1.00 Medium: 0.66
Slight: 0.33 No: 0.00

9) Palpitation:
Drastic: 1.00 Medium: 0.66
Slight: 0.33 No: 0.00

10) Nausea:
Extreme: 1.00 Medium: 0.66
Mild: 0.33 No: 0.00

11) Shortness of breath:
High: 1.00 Medium: 0.66
Slight: 0.33 No: 0.00

12) Pale skin:
Very much: 1.00 Medium: 0.66
Slight: 0.33 No: 0.00

13) Leg cramps:
2-3 times /day: 1.00 4-13 times /week: 0.75
1-3 times /week: 0.50 Occasionally: 0.25 No: 0.00

14) Hunger for strange substance:
Adversely health affecting: 1.00 | Medium: 0.66
Slight: 0.33 | No: 0.00

15) Soreness of mouth with cracks at the corners:
This lasts for-
More than 14 days: 1.00 | 7-14 days: 0.75
3-6 days: 0.50 | Less than 3 days: 0.25 | No soreness and cracks: 0.00

16) Dry and damaged skin:
Cracked skin: 1.00 | Severe: 0.75
Medium: 0.50 | Slight: 0.25 | No: 0.00

17) Dry and damaged hair:
Brittle hair: 1.00 | Severe: 0.75
Medium: 0.50 | Slight: 0.25 | No: 0.00

18) Excessive thirst:
More than 12 times /day: 1.00 | 8-12 times /day: 0.75
6-7 times /day: 0.50 | 4-5 times /day: 0.25 | Less than 4 times /day: 0.00

19) Excessive hunger:
More than 5 times /day: 1.00 | 5 times /day: 0.75
4 times /day: 0.50 | 3 times /day: 0.25 | Less than 3 times /day: 0.00

20) Frequent urination:
More than 12 times /day: 1.00 | 9-12 times /day: 0.75
6-8 times /day: 0.50 | 4-5 times /day: 0.25 | Less than 4 times /day: 0.00

21) Weight loss/gain:
Extreme: 1.00 | High: 0.75
Moderate: 0.50 | Slight: 0.25 | No: 0.00

22) Slow-healing wounds:
Healing in more than 1 month: 1.00 | Healing in 1 month: 0.75
Healing in 16-30 days: 0.50 | Healing in 8-15 days: 0.25 | Healing in less than 8 days: 0.00

23) Frequent infection:
Infection in a span of-
Less than 15 days: 1.00 | 15 days-1 month: 0.75
1 month- 2 months: 0.50 | 2 months- 3 months: 0.25 | More than 3 months: 0.00

24) Darkening of skin in areas of body creases:
Severe: 1.00 | Very much: 0.75
Medium: 0.50 | Slight: 0.25 | No: 0.00

25) Change in breath odour:
Strong: 1.00 | Medium: 0.66
Slight: 0.33 | No: 0.00

26) Lack of energy:
Much: 1.00 | More: 0.66
Slight: 0.33 | No: 0.00

27) Clumsiness:
Much: 1.00 | More: 0.66
Slight: 0.33 | No: 0.00

28) Stiffness of arms and legs:
Severe: 1.00 | Medium: 0.66
Slight: 0.33 | No: 0.00

29) A lost sense of touch:
Severe: 1.00 | Medium: 0.66
Slight: 0.33 | No: 0.00

30) Brittle fingernails:
Severe: 1.00 | Medium: 0.66
Slight: 0.33 | No: 0.00

In this case, D= {Diabetes, Anaemia, Hypertension}, S= set of 30 symptoms = $\{s_1, s_2,\ldots, s_{30}\}$.

For illustration of our methodology of diagnosis, we are taking example of three dummy patients here. So, P = $\{p_1, p_2, p_3\}$.

By considering intensity or frequency of symptoms observed in these three patients, we have defined a fuzzy relation R_s on the set P×S in which membership grades $R_s(p, s)$ (where pϵP, sϵS) indicate the degree to which the symptom *s* is present in patient *p* as follows:

By considering the knowledge base, we defined fuzzy relations R_o and R_c on the set S×D where $R_o(s, d)$ (s∈S, d∈D) indicates the frequency of occurrence of symptom *s* with disease *d* and $R_c(p, d)$ corresponds to the degree to which symptom *s* confirms the presence of disease *d* as follows:

Patients \ Symptoms	s_1	s_2	s_3	s_4	s_5	s_6	s_7	s_8	s_9	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}	s_{15}
p1	**0.75**	**0.33**	**0.66**	**1.00**	**0.33**	**0.00**	**0.50**	**0.33**	**0.66**	**0.66**	**0.33**	**0.00**	**0.25**	**0.00**	**0.00**
p2	**0.00**	**0.66**	**0.66**	**1.00**	**0.33**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.50**	**0.00**	**0.25**
p3	**0.25**	**1.00**	**0.66**	**0.66**	**0.00**	**0.00**	**0.25**	**0.33**	**0.33**	**0.33**	**0.66**	**0.66**	**0.75**	**0.33**	**0.75**

Patients \ Symptoms	s_{16}	s_{17}	s_{18}	s_{19}	s_{20}	s_{21}	s_{22}	s_{23}	s_{24}	s_{25}	s_{26}	s_{27}	s_{28}	s_{29}	s_{30}
p1	**0.00**	**0.00**	**0.00**	**0.00**	**0.25**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.33**	**0.66**	**0.33**	**0.33**	**0.00**
p2	**0.25**	**0.00**	**0.75**	**0.50**	**0.75**	**0.50**	**0.50**	**0.75**	**0.00**	**0.66**	**0.66**	**0.66**	**0.00**	**0.33**	**0.33**
p3	**0.50**	**0.50**	**0.25**	**0.00**	**0.00**	**0.50**	**0.25**	**0.25**	**0.25**	**0.33**	**1.00**	**0.66**	**0.00**	**0.00**	**0.66**

R_o: Diseases

Symptoms	Diabetes	Anaemia	Hypertension
s_1	**0.02**	**0.49**	**0.8**
s_2	**0.71**	**0.85**	**0.33**
s_3	**0.39**	**0.66**	**0.58**
s_4	**0.65**	**0.32**	**0.35**
s_5	**0.52**	**0.25**	**0.37**
s_6	**0.28**	**0.04**	**0.04**
s_7	**0.15**	**0.13**	**0.75**
s_8	**0.16**	**0.5**	**0.51**
s_9	**0.18**	**0.47**	**0.63**
s_{10}	**0.14**	**0.31**	**0.38**
s_{11}	**0.16**	**0.6**	**0.52**
s_{12}	**0.2**	**0.89**	**0.09**
s_{13}	**0.48**	**0.6**	**0.21**
s_{14}	**0.15**	**0.37**	**0.02**
s_{15}	**0.15**	**0.55**	**0.04**
s_{16}	**0.25**	**0.53**	**0.04**
s_{17}	**0.17**	**0.52**	**0.03**
s_{18}	**0.85**	**0.29**	**0.08**
s_{19}	**0.86**	**0.08**	**0.05**
s_{20}	**0.87**	**0.16**	**0.15**
s_{21}	**0.79**	**0.6**	**0.13**
s_{22}	**0.79**	**0.25**	**0.07**
s_{23}	**0.77**	**0.3**	**0.09**
s_{24}	**0.29**	**0.22**	**0.09**
s_{25}	**0.47**	**0.17**	**0.07**
s_{26}	**0.66**	**0.83**	**0.32**
s_{27}	**0.26**	**0.39**	**0.23**
s_{28}	**0.19**	**0.39**	**0.04**
s_{29}	**0.39**	**0.16**	**0.08**
s_{30}	**0.34**	**0.61**	**0.1**

R_c : Diseases

Symptoms	Diabetes	Anaemia	Hypertension
s_1	**0.02**	**0.37**	**0.7**
s_2	**0.64**	**0.75**	**0.22**
s_3	**0.36**	**0.59**	**0.46**
s_4	**0.54**	**0.27**	**0.24**
s_5	**0.45**	**0.19**	**0.27**
s_6	**0.12**	**0.04**	**0.03**
s_7	**0.12**	**0.11**	**0.65**
s_8	**0.07**	**0.37**	**0.41**
s_9	**0.07**	**0.41**	**0.49**
s_{10}	**0.11**	**0.18**	**0.28**
s_{11}	**0.12**	**0.52**	**0.49**
s_{12}	**0.1**	**0.8**	**0.05**
s_{13}	**0.41**	**0.56**	**0.11**
s_{14}	**0.09**	**0.24**	**0.01**
s_{15}	**0.05**	**0.54**	**0.02**
s_{16}	**0.2**	**0.4**	**0.02**
s_{17}	**0.08**	**0.43**	**0.02**
s_{18}	**0.81**	**0.18**	**0.03**
s_{19}	**0.74**	**0.05**	**0.02**
s_{20}	**0.88**	**0.1**	**0.09**
s_{21}	**0.66**	**0.54**	**0.06**
s_{22}	**0.84**	**0.15**	**0.02**
s_{23}	**0.81**	**0.23**	**0.09**
s_{24}	**0.23**	**0.14**	**0.04**
s_{25}	**0.36**	**0.11**	**0.03**
s_{26}	**0.6**	**0.73**	**0.23**
s_{27}	**0.15**	**0.32**	**0.08**
s_{28}	**0.15**	**0.27**	**0.03**
s_{29}	**0.38**	**0.11**	**0.09**
s_{30}	**0.24**	**0.54**	**0.07**

Using these relations R_s, R_o and R_c, we calculated four different indication relations viz. R_1, R_2, R_3, R_4 as defined in section 2.3 above.

The calculated indication relations are as follows:

$R_1 = R_s \circ R_o$ $\qquad$ $R_2 = R_s \circ R_c$

$$R_1 = \begin{array}{c} \\ p_1 \\ p_2 \\ p_3 \end{array} \begin{array}{c} \begin{array}{ccc} D & A & H \end{array} \\ \begin{pmatrix} \mathbf{0.65} & \mathbf{0.64} & \mathbf{0.75} \\ \mathbf{0.75} & \mathbf{0.66} & \mathbf{0.56} \\ \mathbf{0.67} & \mathbf{0.83} & \mathbf{0.56} \end{pmatrix} \end{array} \qquad R_2 = \begin{array}{c} \\ p_1 \\ p_2 \\ p_3 \end{array} \begin{array}{c} \begin{array}{ccc} D & A & H \end{array} \\ \begin{pmatrix} \mathbf{0.47} & \mathbf{0.56} & \mathbf{0.68} \\ \mathbf{0.75} & \mathbf{0.66} & \mathbf{0.43} \\ \mathbf{0.52} & \mathbf{0.69} & \mathbf{0.43} \end{pmatrix} \end{array}$$

$R_3 = R_s \circ (1\text{-}R_o)$ $\qquad$ $R_4 = (1\text{-}R_s) \circ R_o$

$$R_3 = \begin{array}{c} \\ p_1 \\ p_2 \\ p_3 \end{array} \begin{array}{c} \begin{array}{ccc} D & A & H \end{array} \\ \begin{pmatrix} \mathbf{0.75} & \mathbf{0.76} & \mathbf{0.66} \\ \mathbf{0.66} & \mathbf{0.76} & \mathbf{0.75} \\ \mathbf{0.75} & \mathbf{0.66} & \mathbf{0.75} \end{pmatrix} \end{array} \qquad R_4 = \begin{array}{c} \\ p_1 \\ p_2 \\ p_3 \end{array} \begin{array}{c} \begin{array}{ccc} D & A & H \end{array} \\ \begin{pmatrix} \mathbf{0.84} & \mathbf{0.87} & \mathbf{0.50} \\ \mathbf{0.50} & \mathbf{0.87} & \mathbf{0.78} \\ \mathbf{0.85} & \mathbf{0.50} & \mathbf{0.75} \end{pmatrix} \end{array}$$

To draw diagnostic conclusions from the above mentioned four indication relations, we developed some rules. The rules are as follows:

1) Make an excluded diagnosis for a disease *d* in patient *p* if $R_4(p, d) \geq 0.80$.

2) If for any patient *p* and any disease *d*, $R_4(p, d) < 0.80$, find mean of $R_3(p, d)$ and $(1- R_1(p, d))$, denoted by *m*. Make an excluded diagnosis for a disease *d* in patient *p* if $m \geq 0.80$.

3) If m< 0.80, make diagnosis as follows:

If $0 \leq R_2(p, d) < 0.30$ - Nil
If $0.30 \leq R_2(p, d) < 0.40$ - Slight
If $0.40 \leq R_2(p, d) < 0.60$ - Moderate
If $0.60 \leq R_2(p, d) < 0.80$ - High
If $0.80 \leq R_2(p, d) \leq 1$ - Severe

If we make diagnosis of p_1, p_2 and p_3 using above rules, we infer that patient p_1 has High hypertension, patient p_2 has High diabetes and patient p_3 has High anaemia and Moderate hypertension.

To perform these calculations, an excel program is designed in which the linguistic description of one's symptoms can be given as input and diagnosis can be obtained as an output.

Using this program, we diagnosed 30 patients by using this model and compared this diagnosis with doctors' diagnosis. Our diagnosis matched perfectly with doctors' diagnosis in case of diabetes and anaemia and in case of hypertension it matched in 25 patients out of 30 patients.

The level of accuracy of the model can be calculated as:

Accuracy= [(The number of accurate data)/ (The number of total data)]*100 = (85/90)*100 = 94.44%

We used Chi square test [3] for hypothesis testing as follows:

- For testing the reliability of our mathematical model statistically, we took the help of Chi-square test, popularly known as 'goodness of fit test'. Before applying the Chi-square test, we mainly assumed that the diagnosis made by doctors is 100% correct.
- Our null hypothesis H_0 is given as:
  H_0: There is no difference between the diagnosis of the doctors' and ours.
- Corresponding alternative hypothesis H_1 is given as:
  H_1: Our diagnosis is different from doctors'.
- Accepted significance level (α) = 0.05,
- Degrees of freedom= 2
- Critical value= 5.991

Table 2: Contingency Table for Chi square test

	Observed	**Expected**
Diabetes	30	30
Anaemia	30	30
Hypertension	25	30

- Formula for calculating Chi-square test is given as:

  $\chi^2 = \Sigma [(O - E)^2 / E]$ where O is observed frequency, E is expected frequency.

- From the contingency table, we calculated chi-square (χ^2) as
  $\chi^2 = ((30-30)^2/30) + ((30-30)^2/30) + ((25-30)^2/30) = 0.83$.

- Since 0.83< 5.991 i.e. $\chi^2 <$ critical value, hence null hypothesis H_0 is accepted.

We concluded that there is no difference between the diagnosis of the doctors' and ours.

4. CONCLUSION

Fuzzy logic can be efficiently used to make medical diagnosis more affirmatory and precise. The diagnosis made by 'max-min' composition of fuzzy relations formulated by using 'mean' of data collected from the doctors is in accordance with the doctors' diagnosis. The proposed mathematical model has 94.44% accuracy and chi- square test certifies its reliability statistically. The new algorithm presented in this research paper tries to represent the general idea behind the diagnostic process mathematically. The systematic way to check the indication relations, specifically 'non-symptom indication - non-occurrence indication - conformability indication' is the distinguishing feature of this algorithm.

This is an effort to capture experts' knowledge and make it available to layman and to general practitioners also. Surely this is not a substitute to doctor's diagnosis but it will help a doctor to confirm his/her diagnosis.

Diagnostic conclusions drawn from this mathematical model may be considered as second opinion to the doctor's diagnosis. Altogether this mathematical model aims to maximize the diagnostic accuracy. The excel program is developed to make this model free from tedious calculations and to make it user-friendly.

Incorrect inputs given by a patient will surely lead to incorrect diagnostic conclusions rendering the proposed mathematical model off target which is the main limitation.

Future works include the development of software and an android app after more data collection from doctors. Also, development of new algorithms for the sake of more precision is one of the future goals.

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7. APPENDIX

Table: Blank chart provided to doctors to formulate the knowledge base consisting of occurrence and confirmation

(O = Occurrence of a symptom, C =Confirmation of a disease)

Date: **Doctor's signature**

Sr. No.	**SYMPTOMS**	**DIABETES**		**ANAEMIA**		**HYPERTENSION**	
		O	**C**	**O**	**C**	**O**	**C**
1.	Headache						
2.	Fatigue						
3.	Dizziness						
4.	Numbness in body parts						
5.	Blurred vision						
6.	Conjunctivitis						
7.	Chest pain						
8.	Difficulty in breathing						
9.	Palpitation						
10.	Nausea						
11.	Shortness of breath						
12.	Pale skin						
13.	Leg cramps						
14.	Hunger for strange substance						
15.	Soreness of mouth with cracks at the corners						
16.	Dry and damaged skin						
17.	Dry and damaged hair						
18.	Excessive thirst						
19.	Excessive hunger						
20.	Frequent urination						
21.	Weight loss or gain						
22.	Slow- healing wounds						
23.	Frequent infection						
24.	Darkening of skin in areas of body creases						
25.	Change in breath odour						
26.	Lack of energy						
27.	Clumsiness						
28.	Stiffness of arms and legs						
29.	A lost sense of touch						
30.	Brittle fingernails						