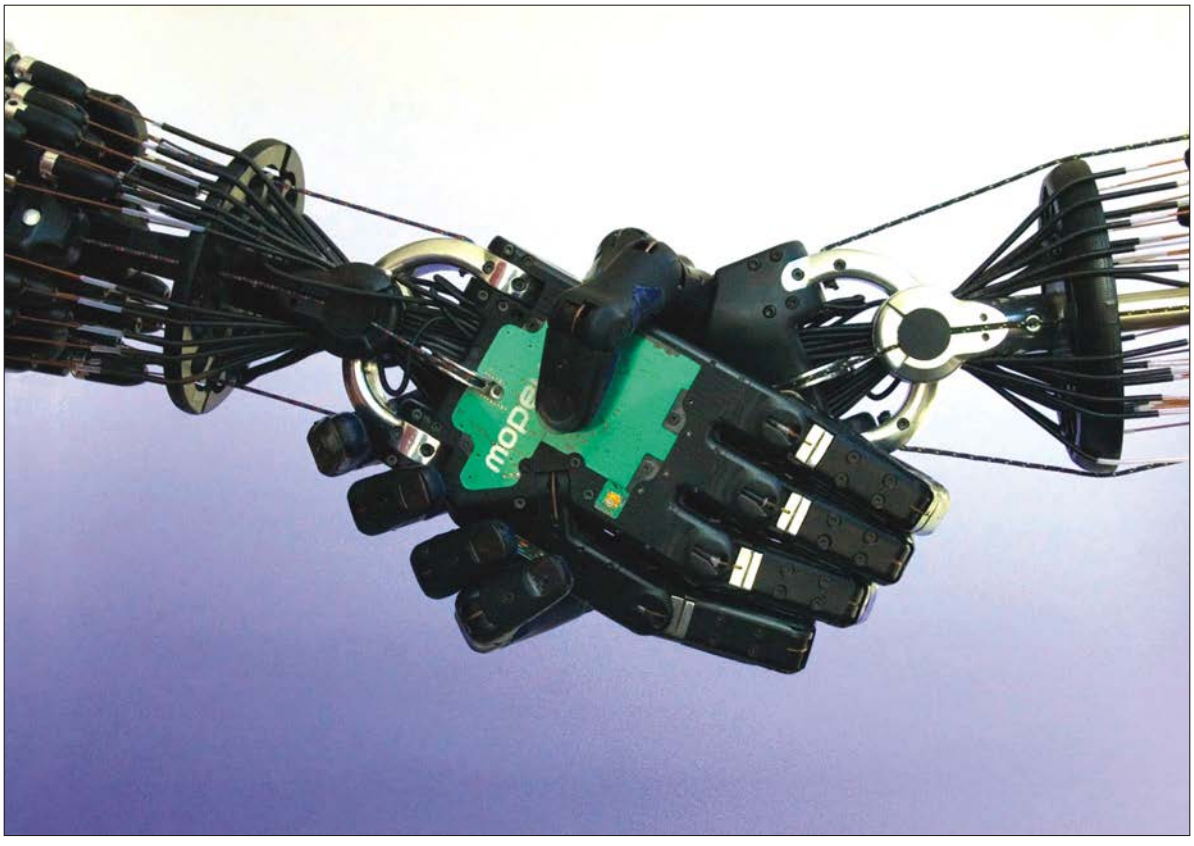

Journal of Artificial Intelligence

ISSN 1994-5450

science alert

ANSInet
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Journal of Artificial Intelligence 4 (1): 45-54, 2011
ISSN 1994-5450 / DOI: 10.3923/jai.2011.45.54

A Fuzzy Inference System for Diagnosis of Hypothyroidism

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ABSTRACT

Fuzzy sets have been applied in medical field where uncertainty plays a major role. Medicine, often on the borderline between science and art, is an excellent example where vagueness, hesitation, linguistic uncertainty, measurement imprecision, natural diversity and subjectivity are prominently present in medical diagnosis. Medical diagnosis is a problem complicated by many and manifold factors and its solution involve all of a human's abilities including intuition and the subconscious. Fuzzy logic is used in diagnosis of pulmonary embolism, cortical malformations, rheumatic and pancreatic diseases, hepatitides and diabetes. Fuzzy inference system is a linguistic frame work by which human thinking process can be modeled. In this study we are presenting a fuzzy inference system that will diagnose the thyroid disease specially a major disorder known as Hypothyroidism. It is the most common thyroid disorder today. Because of uncertain symptoms, it is very difficult to diagnose the disease. Particularly in rural part of India, the correct diagnosis of the disease for female patients takes place at a very later stage and hence the patient suffers physically and economically. An accuracy of 88% is achieved in diagnosis of hypothyroidism. Such system is helpful for patients and doctors to identify disease at early stage.

Key words: Clinical prediction, fuzzy diagnosis, imprecise knowledge, medical disorder, soft computing, uncertainty handling

INTRODUCTION

The thyroid hormones deliver energy to cells of the body. Thyroid hormone is carried through the blood to every tissue in the body. Thyroid hormone is essential to help each cell in each tissue and organ to work right. Thyroid hormone helps the body use energy, stay warm and keep the brain, heart, muscles and other organs working as they should. The most common problem that occurs with thyroid is hypothyroidism (ATA, 2010). Hypothyroidism occurs when the thyroid gland produces too little thyroid hormone. When the thyroid gland is under-active, improperly formed at birth, surgically removed all or in part, or becomes incapable of producing enough thyroid hormone, a person is said to be hypothyroid. The most severe form of hypothyroidism is myxedema, which is a medical emergency. It may affect all body functions. The rate of metabolism slows causing mental and physical sluggishness (BTA, 2010). The symptoms of hypothyroidism are general and changing from one person to another. It includes dry skin, fatigue, loss of energy and memory problem. The detection of disease is difficult at early stage. The patient suffers a lot by getting a wrong treatment. A kind of uncertainty is involved in diagnosis of disease.

Fuzzy logic and fuzzy set theory exhibits immense potential for effective solving of the uncertainty in the problem. The application of fuzzy logic in medicine started in the early 70's, soon

after the, paper published by Zadeh (1965). One of the most important areas of application of fuzzy set theory as developed by Zadeh is Fuzzy Rule-Based System (FRBS) also called Fuzzy Inference System (FIS) (Alayon *et al*., 2007). Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic (Kwiatkowska, 2006). The mapping then provides a basis from which decisions can be made, or patterns discerned.

Several researchers have used fuzzy logic in medical diagnosis such as diagnosis of the pulmonary embolism (Serpen *et al*., 2000), cortical malformations (Alayon *et al*., 2007), rheumatic and pancreatic diseases (Moein *et al*., 2006), hepatitides (Moein *et al*., 2006) and diabetes (Soula *et al*., 1983; Turnin *et al*., 1992; Zahlmann *et al*., 1997).

Historically, two phases of general applications can be distinguished. Initially the fuzzy member functions were added to rule-based expert systems, the main data were numerical and the fuzzy sets were used to model medical terms and verbal expressions. The second phase can be characterized by various factors such as, new approaches to generation of membership functions using extraction techniques from data mining; processing of biomedical signals and images and, merging several AI techniques for knowledge representation and medical decision support (Hennessey and Scherger, 2007).

DESIGN OF FUZZY INFERENCE SYSTEM

The Fuzzy Inference System is a rule-based system where fuzzy logic is used as a tool for representing different forms of knowledge about a problem, as well as for modeling the interactions and relationships that exist between its variables (Alayon *et al*., 2007). The proposed fuzzy inference system is to be used for assisting Doctor in the diagnosis of hypothyroidism. The functions of this system are: first, to collect all information that is usually analyzed in these cases by the expert, second, to study the relations between the different considered factors and the possible hypothyroidism types and third, to offer an automated diagnostic aid. Rule-based systems have been successfully used to model human problem-solving activity and adaptive behavior, where the classical way to represent human knowledge is the use of if-then rules. The proposed system uses the Mamdani fuzzy inference system for implementation. Figure 1 shows the flow diagram of the system. The whole system is developed under the supervision of medical expert Dr. D.V. Rajurkar, Vyankatesh Hospital, Aurangabad, India during the period March 2008 to March 2010.

The proposed system consists of 3 input, 1 output and 18 rules and actual fuzzy inference diagram for the system is shown in Fig. 2. The present system is used for diagnose of hypothyroidism. The diagnosis is based on three input variables (1) SymptomScore expressed as a percentage of severity of symptoms, (2) T4 and (3) TSH are nothing but the values obtained from blood report of the patients. The system output is the actual diagnosis of the patient which gives the severity of the hypothyroidism which is divided into four types. The Knowledge base describing the system's behavior is represented by the membership functions designing the linguistic variables. Hence, for the proposed system's behavior, four linguistic variables are defined. Out of these four, three variables are input variables namely-SymptomScore, T4, TSH and one output variable called hypothyroidism. Fuzzifier unit computes the membership values of each input variable in accordance with the fuzzy values defined in the database. Inference engine interprets the rules combined in the rule base. The inference engine is performed in three steps, (1) antecedent activation, (2) implication and (3) aggregation. Finally, defuziffier converts the fuzzy output into crisp value using any defuzzification method.

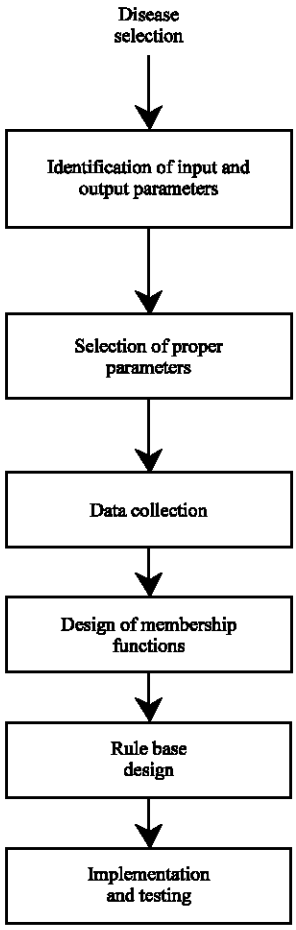

Fig. 1: Flow diagram of fuzzy inference system

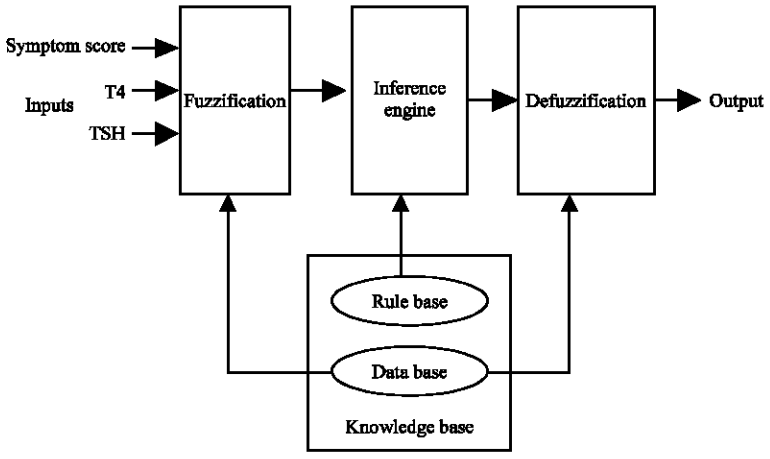

Fig. 2: Block diagram of FIS

Data collection: A form was designed to collect the patient's symptoms. Figure 3 shows the form. Based on severity of symptoms, a symptom score is computed which is in the range of 0-100. Data of 45 patients from Aurangabad city of Maharashtra state, India are collected.

Patient No. Name of the patient: _____

Sex: M / F Age :

Sr. No.	Symptoms	Severity		
1	Fatigue/weakness	Low	Modrate	High
2	Weight gain	2 to 4 kg	5 to 7 kg	8 to 10 kg
3	Low basal temperature or feeling cold (Cold hand and feet	Absent	Sensitive to cold	Extreme sensitive to cold
4	Drier, itchier shin	Normal skin/ Dry and Itchy		
5	Forgetfulness, dementia	Yes/ No		
6	Mebstrual problems	No	Scanty	Heavy flow amenormoea
7	Muscle cramps/ joint aches	Absent	Occasionally	Daily work hampers
8	Hair loss	Scanty	More	Producing pathalopecia
9	Hypersomnlance	Light	Day time	Unbearable, daily activity disturbed
10	Constipation	Yes/ No		
11	Nervousness feel	Occasionally	More frequeny	Daily
12	Swelling in front of the neck	Yes/ No		
13	Any thyroid disorder/ family history	Yes/ No		
14	Other glandular failure	Yes/ No		
	Total score			

Blood tests:

Test	Value
T4	0 to 2.5
TSH	0 to 25

Fig. 3: Patient's symptoms check form

MEMBERSHIP FUNCTIONS FOR INPUTS AND OUTPUT

The fuzzy variable SymptomScore has been represented using three fuzzy sets to classify the inputs given by:

- **Low risk:** The range is between 0 to 30
- **Med risk:** Fifteen to 65 is the range for MedRisk
- **High risk:** The range for this fuzzy set from 45 to 100

The shape of membership function used for this lowrisk and highrisk are of trapezoidal type and for med risk is of triangular type shown in Fig. 4.

The second input is the value of T4. This value can be directly obtained from the blood report of patient. Normally every pathological reports has some reference range, we called it as a normal. T4 also have reference range between 0.6 to 2.0 ng dL^{-1}. If the value of T4 is below this range then it is termed as low. On the basis of this terminology, there are two membership functions for T4 namely low and normal as shown in Fig. 5.

The third input for the system is TSH. For this type of input three membership functions are chosen which is based on the reference range of TSH. (0.5 to 4.6 mlU mL^{-1}). The membership function curve is shown in Fig. 6.

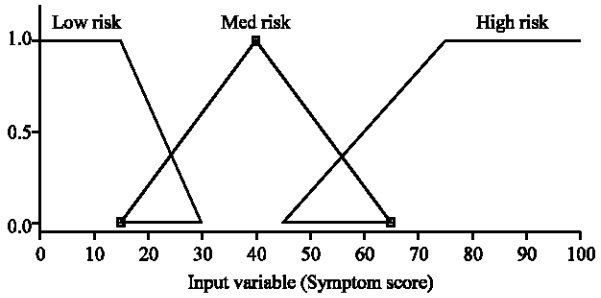

Fig. 4: Membership function for symptom score

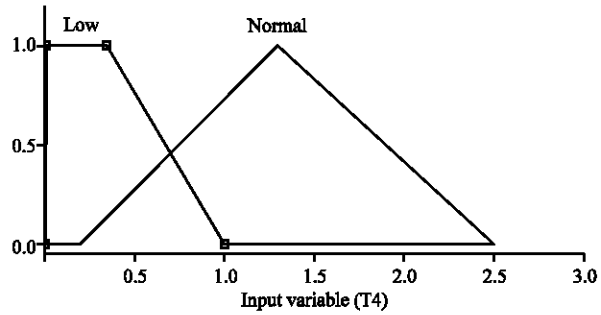

Fig. 5: Membership function for T4

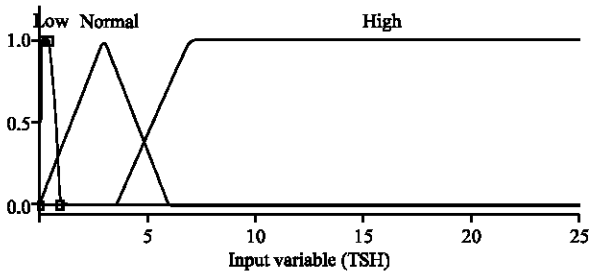

Fig. 6: Membership function for TSH

The output variable is hypothyroidism which gives the diagnosis of patient which is nothing but the type of hypothyroidism. There are three classes of hypothyroidism namely subclinical, primary and secondary. NoHypo indicates normal. The range for this membership function is from 0 to 100. The fuzzy sets NoHypo and Secondary are of trapezoidal in shape and other two are of Triangular shape as in Fig. 7. The 4 classes and their ranges are defined by:

NoHypo : 0 to 20
Subclinical : 10 to 40
Primary : 25 to 65
Secondary : 50 to 100

Figure 7 shows membership function for output.

Every rule in fuzzy rule base system consists of rule antecedents (inputs) and rule consequents (output or result). Table 1 shows the rule antecedents and consequent for this system.

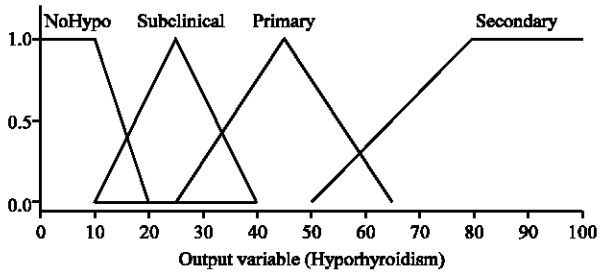

Fig. 7: Membership function for output

Table 1: Rule antecedents and rule consequents

	Antecedent			
Rule No.	Symptom score	T4	TSH	Consequence hypothyroidism
1	HighRisk	Low	Low	Secondary
2	HighRisk	Low	Normal	Secondary
3	HighRisk	Low	High	Primary
4	HighRisk	Normal	Low	Secondary
5	HighRisk	Normal	High	Subclinical
6	LowRisk	Normal	Normal	NoHypo
7	MedRisk	Low	Low	Secondary
8	MedRisk	Low	Normal	Secondary
9	MedRisk	Low	High	Primary
10	MedRisk	Normal	Low	Secondary
11	MedRisk	Normal	High	Subclinical
12	MedRisk	Normal	Normal	NoHypo
13	LowRisk	Low	Low	Secondary
14	LowRisk	Low	Normal	Secondary
15	LowRisk	Low	High	Primary
16	LowRisk	Normal	Low	Secondary
17	LowRisk	Normal	High	Subclinical
18	HighRisk	Normal	Normal	Subclinical

Rule antecedent uses three input parameters symptom score, T4 and TSH along with their linguistic variables. Rule consequent gives output of Hypothyroidism category.

The first parameter is symptom score which gives the risk for developing hypothyroidism. There are three types of risks defined which are low risk, medium risk and high risk depending on the patients' symptoms and its severity, family history, risk factors etc. Other two inputs which are useful for constructing rules are actual values of T4 and TSH. As every blood test has some specific range of values which we can map into normal, low, below normal, high, very high etc. These ranges indicate the severity of disease and/or percentage of that particular hormone. The importance of these ranges plays an important role in diagnosing the disease. We have considered the three values of TSH, i.e., low, normal and high, two for T4, i.e., low and normal. The output of the system is final diagnosis categorized into four categories Nohypo, subclinical, primary and secondary.

TESTING OF THE SYSTEM

About 45 patients' data are collected and tested for results. As hypothyroidism is more prone to female patients, out of 45 patients 37 are female and remaining are males.

Table 2 shows the data about all patients, its output obtained from the proposed FIS, which is nothing but a crisp value and diagnosis made by doctor.

Table 2: Diagnosis of patient done by FIS and doctor

Patient No.	Age and sex	Symptom score	T4	TSH	Output of FIS	Doctors' diagnosis
1	62/M	76	2.00	5.71	25.00	Subclinical
2	45/F	82	0.12	0.05	81.69	Secondary
3	38/F	90	1.88	0.049	78.89	Secondary
4	40/F	64	0.25	0.24	79.63	Secondary
5	35/F	68	2.00	0.05	78.23	Secondary
6	29/F	72	1.72	8.16	25.00	Subclinical
7	45/F	19	1.00	4.23	13.26	NoHypo
8	45/F	27	1.75	4.26	21.50	NoHypo
9	37/F	88	0.15	10.40	45.00	Primary
10	44/F	90	1.30	9.30	25.00	Subclinical
11	29/M	82	0.90	8.58	30.90	Subclinical
12	40/F	25	1.38	4.13	19.11	Subclinical
13	30/F	30	0.92	8.28	29.94	Subclinical
14	32/F	83	1.32	0.064	81.61	Secondary
15	35/F	71	1.27	5.05	25.00	Subclinical
16	38/F	82	0.20	6.52	45.00	Primary
17	34/F	20	1.14	3.35	13.42	NoHypo
18	26/F	75	1.26	7.24	25.00	Subclinical
19	38/F	69	1.28	6.35	25.00	Primary
20	45/F	67	0.98	0.33	31.34	Primary
21	45/F	36	2.10	9.38	25.00	Subclinical
22	40/F	25	1.76	1.28	18.58	NoHypo
23	25/F	63	0.89	10.10	31.45	Subclinical
24	35/F	81	0.93	0.010	79.82	Secondary
25	20/F	72	1.77	0.50	75.44	Secondary
26	30/F	86	1.50	9.75	25.00	Subclinical
27	40/F	58	2.20	0.014	31.34	Subclinical
28	65/F	15	1.87	1.80	8.51	NoHypo
29	49/M	24	2.00	3.85	17.93	Subclinical
30	29/F	68	1.85	0.04	79.06	Secondary
31	41/F	80	0.083	0.035	81.69	Secondary
32	58/M	63	2.10	5.30	25.00	Subclinical
33	62/M	59	0.18	7.45	45.00	Primary
34	39/F	30	1.24	4.70	25.00	Subclinical
35	43/M	52	1.19	8.65	25.00	Subclinical
36	48/F	23	1.81	3.64	16.78	NoHypo
37	29/F	84	0.08	0.10	81.69	Secondary
38	55/F	70	0.95	8.35	28.32	Subclinical
39	32/F	84	1.74	10.10	25.00	Subclinical
40	43/M	76	0.24	3.73	78.39	Secondary
41	31/F	82	0.85	6.20	32.92	Primary
42	27/F	69	0.18	3.45	80.63	Secondary
43	34/M	76	0.21	12.50	44.82	Primary
44	32/F	74	0.58	0.27	79.72	Secondary
45	34/F	23	1.14	0.67	66.71	Primary

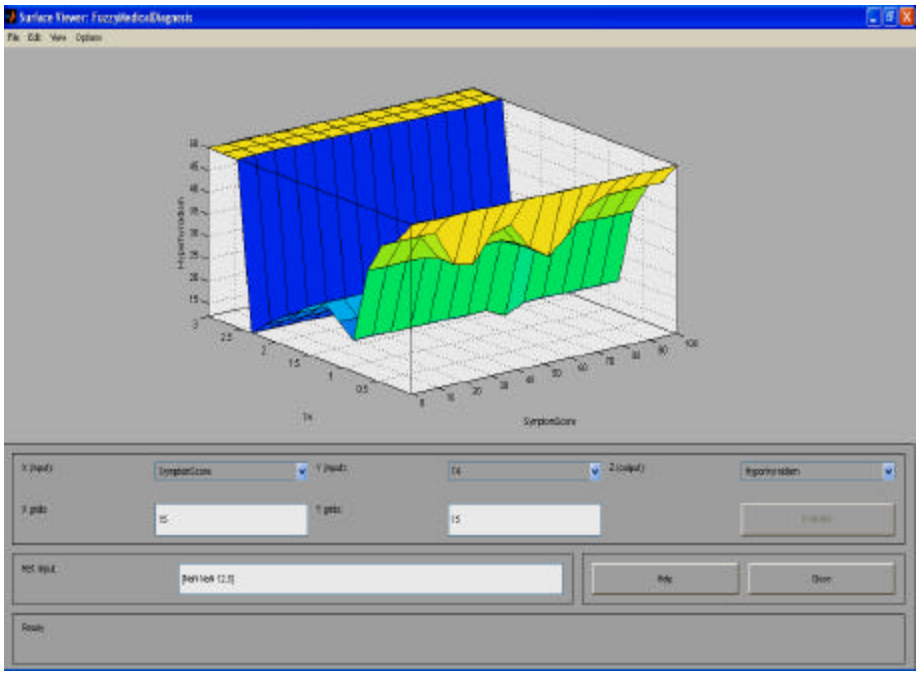

Fig. 8: Surface viewer diagram for inputs symptom score, T4and output

Table 3: Percentage of final diagnosis

	No. of patients		
Types of hypothyroidism	Diagnosed by FIS	Diagnosed by doctor	Percentage
Subclinical	17	15	88.23
Primary	7	6	85.71
Secondary	14	13	92.85
NoHypo	7	6	85.71
Average			88.15

Figure 8 shows surface viewer diagram for inputs symptom score, T4 and output Hypothyroidism. It allows us to see output surface for the two inputs.

The impact on the variation in the output due to the input values of T4 and TSH can be observed in Fig. 9. It is the surface viewer diagram for inputs T4, TSH and output.

The performance of the FIS is given in Table 3. Observe that diagnosis made by FIS is compared with the diagnosis made by medical expert. Out of 45 patients FIS diagnosed 17 in the category of subclinical, 7 in primary, 14 in secondary and 7 in Nohypo. When compared with the classification to that of human medical expert, 88% accuracy is given by the system.

Medical diagnosis of Hypothyroidism is very critical considering uncertainty involved in symptoms. Particularly in India it is normally late diagnosed. Several researchers have attempted to develop medical diagnosis system for other diseases and have achieved accuracy up to 93%. But, no attempt is made for hypothyroidism. We are able to achieve accuracy up to 88%.

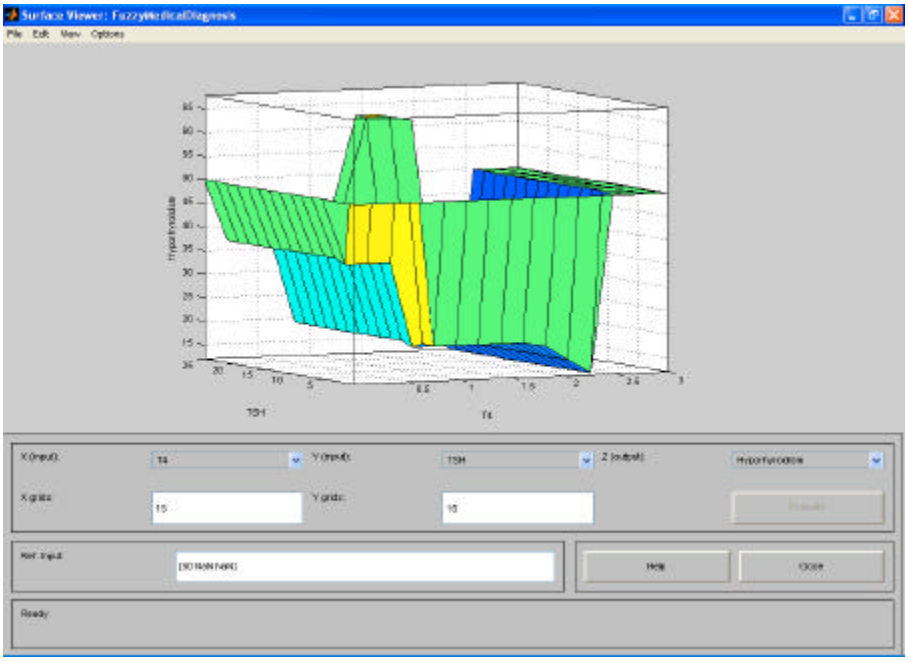

Fig. 9: Surface viewer for inputs T4, TSH and output

CONCLUSION

A medical diagnosis accuracy up to 83% is reported in earlier works (Moein *et al*., 2006). Our system has analyzed data of 45 patients in India. Out of 45 patients the FIS diagnosed 17 patients as Subcilincal (15 by doctor), 7 under primary category (6 by doctor) 14 are of secondary type (13 by doctor) and 7 are categorized as Nohypo (6 by doctor), i.e., normal. The average percentage of diagnosis made by doctor is 88.15% against the diagnosis made by the system. The secret of such fuzzy systems is that they are easy to implement, easy to maintain, robust and cheap.

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