X-Ortho: Fuzzy Rule Based Expert System for Diagnosing Infective Diseases of Hinge Joint Knee

Gagandeep Kaur
School of Computer Science Engineering
Lovely Professional University
Phagwara, Punjab, India
gagan.dhoofer@gmail.com

Anshu Vashisth
School of Computer Science Engineering
Lovely Professional University
Phagwara, Punjab, India
anshu.parents@gmail.com

Ranbir Singh Batth
School of Computer Science Engineering
Lovely Professional University
Phagwara, Punjab, India
ranbir.21123@lpu.co.in

***Abstract*-Various Medical expert systems are designed to diagnose the different kinds of diseases by using facts related to disease. Knee is the main weight bearing joint in our body. The proposed work is for the diagnosis of the infective diseases of the knee joint. The major focus is given to Acute Septic Arthritis, Chronic Septic Arthritis and Osteomyelitis of the knee joint. MATLAB fuzzy logic controller is used to handle the vague values. Knowledge acquisition is done with the help of orthopaedic expert. Survey method is used for the data collection and to evaluate the performance of proposed system various defuzzification methods are used. The proposed system is tested on 75 patients and gives 96% efficient results.**

Keywords: Fuzzy logic, acute septic arthritis, chronic septic arthritis, inference engine, defuzzification.

I. INTRODUCTION

Human skeleton system is comprising of 206 bones, where the major weight bearing joint is knee. All the diseases which are related to bones, comes under Orthopaedic Diseases [1]. Knee which is a hinge joint, comprises of three bones, named Femur, Tibia and Patella. Femur is lower bone of thigh, Tibia is upper part of the leg bone and the knee cap bone is called as Patella. The knee joint is enhanced by MCL (Medial Collateral Ligament) and lateral collateral ligament. All these structures along with popliterus muscle and various tendons at the back of the knee (popliteus tossa), helps the knee to be a complex and stable joint of body during various motions. The main movements of the knee joint are flexion and extension. The varying degree of extension at the knee depends upon quadriceps tendon, anterior cruciate ligament, posterior cruciate ligament and menisci. The flexion of the knee depends upon the hamstring tendons [2]. The medial and lateral movements at the knee are prevented by medial collateral ligament and lateral collateral ligament as shown in Figure 1.

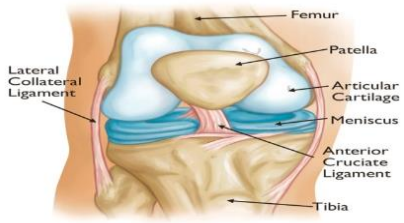

Fig. 1. Parts of knee [12]

As knee is an essential part of human body, the main area of interest in this research is to develop an expert system to diagnose infective diseases of knee like Septic Arthritis, Osteomyelitis. Septic arthritis can be acute septic arthritis and chronic septic arthritis. There is resemblance in symptoms of inflammatory and infective pathology, slight variation of symptoms can be helpful for diagnosis of diseases. Moreover, some investigations like x-rays, MRI and blood investigations can make the diagnosis to its perfect correction. Similarly, infective pathology differs on symptoms and various investigations are also needed to diagnose the disease. Table 1 shows the category of knee joint.

Table 1. Knee Category

Category name	Disease 1	Disease 2	Disease 3
Inflammatory	Osteoarthritis (OA)	Rheumatoid Arthritis (RA)	Osteonecrosis (ON)
Infective	Acute Septic	Chronic Septic	Osteomyelitis (OM)

1.1 Infective Diseases

When the joint is invaded by bacteria (disease produces germs), then it is known as infective pathology. [2] Under this category, various diseases are Acute septic arthritis, Chronic septic arthritis and Osteomyelitis of the knee. Rule base expert system is designed to diagnose the following diseases:

Septic Arthritis: Knee is very superficial joint, so it is more commonly invaded by bacteria externally, no doubt haematogenous spread in the knee joint also exist. This is known as Septic arthritis.

Acute Septic Arthritis: Knee commonest site usually in children. Acute outset with higher fever and rigor, hot and tender joint, aspiration of pus from the joint and ESR raised from mild to moderate makes the diagnose. This reflects it is Acute septic arthritis.

Chronic Septic Arthritis: This disease is usually in adults. In this disease, presence of active and healed sinuses, minimal swelling associated deformity present in the knee joint, Inguinal lymph nodes enlarged, firm and may be tender. With these symptoms chronic septic can be diagnosed.

Osteomyelitis: The word Osteomyelitis is derived from Greek words ‘osteon’ + ‘myelo’+ ‘litis’, where osteon means bone, myelo means marrow and litis means inflammation [3]. OM disease is inflammation and infection of the bone marrow which is caused by bacteria called Staphylococcus aureus. It can affect any age group. The main symptoms are pain, swelling, deformity and tenderness.

II. LITERATURE REVIEW

Fuzzy set theory and Fuzzy logic are an exceptionally appropriate and relevant reason for creating learning based frameworks for understanding of sets of orthopaedic discoveries and disorder separation. With the advancement of the science, discovery of Roentgen's rays (X-rays) and discovery of bacteria used to diagnose orthopaedic diseases. Previously, it was an art of straightening the deformities of children. In 1970s, MYCIN is the first rule base expert system, which is developed for infectious blood diseases. As, it is rule base system, all 500 rules are implemented in LISP (List processing) and deals with certain degree of belief using combining functions [4]. With the ennoblement of science, various expert systems in diverse field is designed like DENDRAL, PROSPECTOR, cancer, gynecology, tumor, asthma and diabetes.

F. Başçiftçi and E. Avuçlu (2018), designed a medical expert system using Boolean Function minimization, to diagnose the different types of cancers like Breast cancer, Lung cancer, Renal and Cervical opening cancer. This system takes 13 symptoms for input by considering it as risk factor and 4 outputs used to diagnose the type of cancer. For the interactive interface an android application was used. Breast cancer and renal cancer diagnosis 100% diagnosis speed gain, in cervical cancer and lung cancer diagnosis rate gain of 99% was obtained [5]. Peter Buba Zirra (2016), developed a medical expert system that diagnosis the severity level of osteomyelitis which is bone infection disease. It usually affects the long bones in children and adults. Fuzzy Expert system took four parameters (pain, fever, age, swelling) as input and severity level of disease as output. Range was taken from 0 to 1 for all partitioned functions. There were 500 rules for the diagnosis of severity level of osteomyelitis [3].

Adewole K. S., Hambali M. A., and Jimoh M. K. (2015), designed a rule base expert system to diagnose five type of diseases which were Malaria, Typhoid Fever, Cholera, Tuberculosis, and Breast Cancer. For the output of disease, total 46 rules were made in IF-THEN format. For interface login page was opened, after registration user tick the symptoms and on submit button, disease will show [8]. I Ketut Gede Darma Putra (2012), developed a fuzzy expert system to diagnose the seven types of diseases by using fuzzy logic and certainty factor. There were 17 inputs as clinical symptoms and 5 fuzzy values. With the combination of these all inputs total 1524 rules were made to diagnose the disease [9].

III. RESEARCH METHODOLOGY

The proposed system is developed in MATLAB toolbox. For the whole process five steps are followed.

1. Acquire all the input parameters with the help of expert, comes under knowledge acquisition phase.
2. In fuzzification, select the membership function and range for the linguistic variables. Crisp value is mapped into selected membership function.
3. Rules are made in IF-THEN format.
   IF (Condition) Then (Action)
   Condition is Antecedent part of the rule and action is consequent part of rule which is fire by agenda.
4. Inference phase is the main processing phase where agenda fire the active rule. This phase is invisible to user.
5. The last step is defuzzification, the output is obtained in crisp form.

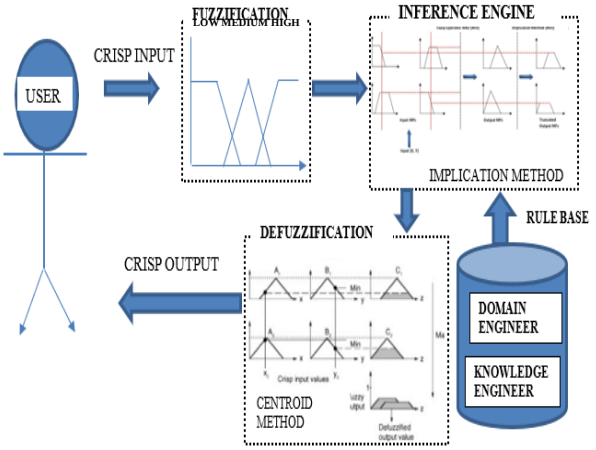

Figure 2. Proposed Methodology

3.1 *Knowledge Engineering*

This is information gathering phase where all the input and output parameters are collected carefully with the help of expert. In the field of medical, identification of symptoms plays important role as single wrong symptom may leads to diagnose wrong disease. For the infective diseases of knee, collected symptoms and output are described in Figure 3.

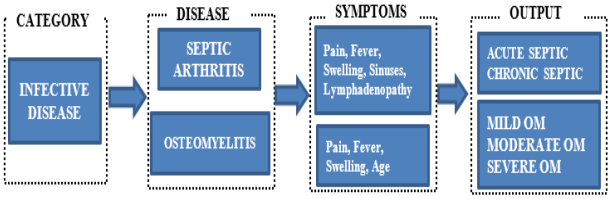

Fig. 3. Knee categories and diseases

3.2 *Fuzzification Of Vague Values*

For the collected vague input symptoms, membership function is selected in fuzzy logic toolbox. There are many types of membership functions. Triangular and trapezoidal membership functions are used in proposed model. Figure 4 and figure 5 shows the membership function of input variable pain and output variable Osteomyelitis. A trapezoidal membership function can be defined as Eq. (1).

$$\mu(x;i,j,k,l) = \max\left(\min\left(\frac{x-i}{j-i}, 1\frac{l-x}{l-k}\right), 0\right) \quad \text{Eq. (1)}$$

The triangular membership function can be defined as Eq. (2) .

$$\mu(x;i,j,k) = \max\left(\min\left(\frac{x-i}{j-i}, \frac{k-x}{k-j}\right), 0\right) \quad \text{Eq. (2)}$$

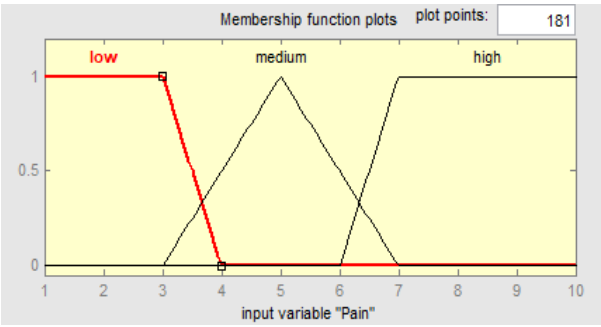

Fig. 4. Membership function for input parameter Pain

$$\mu_{LOW}(x)=\begin{cases}\frac{4-x}{1}, & 3\le x\le 4\\ 1, & x\le 3\end{cases} \quad \text{Eq. (3) [9]}$$

$$\mu_{HIGH}(x)=\begin{cases}\frac{x-6}{1}, & 6\le x\le 7\\ 1, & x\ge 7\end{cases} \quad \text{Eq. (4) [9]}$$

$$\mu_{MEDIUM}(\boldsymbol{X})=\begin{cases}\frac{x-3}{4-3}, & 3\le x\le 4\\ 1, & x=5\\ \frac{7-x}{7-6}, & 6\le x\le 7\end{cases} \quad \text{Eq. (5) [9]}$$

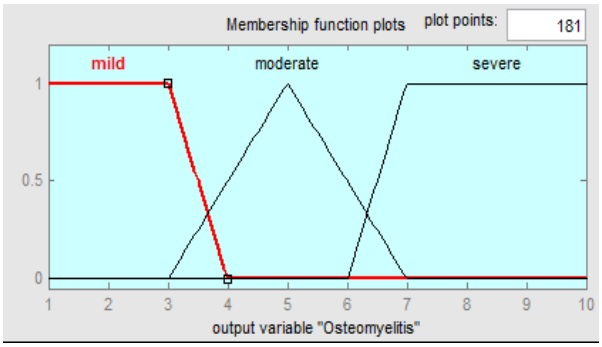

Fig. 5. Membership function for output parameter

$$\mu_{MILD}(x)=\begin{cases}\frac{4-x}{1}, & 3\le x\le 4\\ 1, & x\le 3\end{cases} \quad \text{Eq. (6) [9]}$$

$$\mu_{SEVERE}(x)=\begin{cases}\frac{x-6}{1}, & 6\le x\le 7\\ 1, & x\ge 7\end{cases} \quad \text{Eq. (7) [9]}$$

$$\mu_{MODERATE}(\boldsymbol{X})=\begin{cases}\frac{x-3}{4-3}, & 3\le x\le 4\\ 1, & x=5\\ \frac{7-x}{7-6}, & 6\le x\le 7\end{cases} \quad \text{Eq. (8) [9]}$$

All the linguistic variable has some membership with range. Table 2 and Table 3 shows the fuzzified input and output symptoms for septic and osteomyelitis disease.

Table 2. Fuzzified input symptoms and output for Septic Arthritis disease

Inputs							Output
Age	*Fever*	*Pain*	*Swelling and Tenderness*	*Deformity*	*Lympha-Denopathy*	*Sinuses*	*Septic Arthritis*
Child (1-22.5)	Low Grade (1-4)	Mild (1-4)	Low (0-4)	Low (0-4)	Mild to Moderate (0-4)	Discharge (1-4)	Acute Septic (1-5)
Adult (20-100)	High Grade (3-10)	Moderate (3-7)	Medium (3-7)	Medium (3-7)	Moderate to Severe (3-10)	Healed (3-10)	Chronic Septic (4-10)
		High (6-10)	Severe (6-10)	High (6-10)			

Table 3. Fuzzified input symptoms and output for Osteomyelitis disease

Inputs				**Output**
Pain	*Swelling & tenderness*	*Fever*	*Age*	*Osteomyelitis*
Low (1-4)	Low (1-4)	Mild (1-4)	Child (1-4)	Mild (1-4)
Medium (3-7)	Medium (3-7)	Moderate (3-7)	Adult (3-7)	Moderate (3-7)
High (6-10)	High (6-10)	Severe (6-10)	Old (6-10)	Severe (6-10)

3.3 Fuzzy Rule Formation

For the specific type of knowledge base, list of rules in IF-THEN rule format are formed with the help of expert. These rules are training dataset. The fact will match with these rules in inference engine to diagnose the disease. IF (Condition1… AND/OR Condition2) THEN (Action). In the antecedent part, linguistic variables are used and in consequent part linguistic values are obtained. For the OM disease there are 81 rules and for Septic arthritis 68 rules are made with the help for expert. Figure 6 and Figure 7 shows the rules and rule viewer.

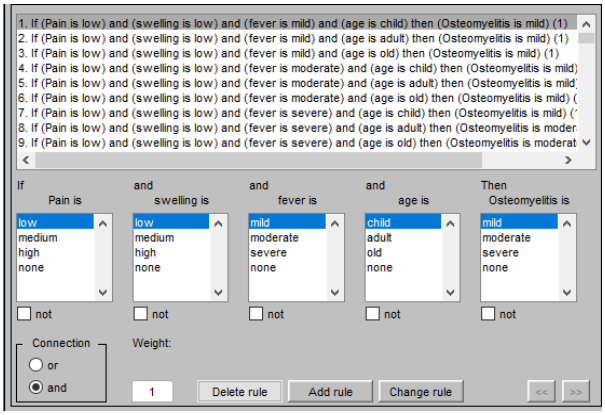

Fig. 6. Rules

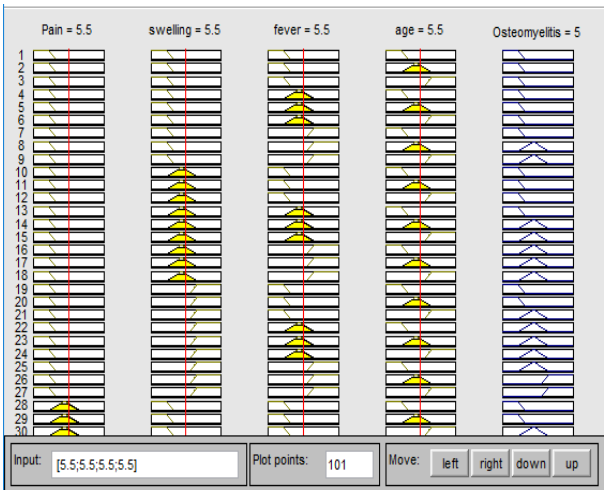

Fig. 7. Rule Viewer

3.4 Fuzzy Inference Process

There are two fuzzy inference systems named Mamdani and Sugeno. In this proposed system Mamdani Inference system is used. It checks the user input and all the corresponding rules in knowledge based. Agenda is list of rules which are satisfied or matches with the user input. All the facts related to rules are stored in working memory. Inference engine pick the matched rules from agenda which is going to be fire. Figure 8 shows there are four input parameters and one output parameters.

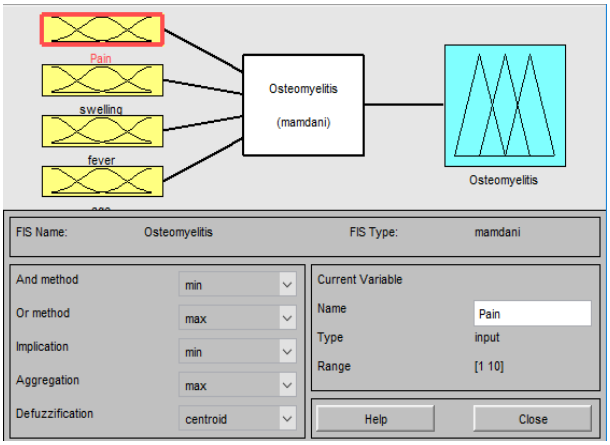

Fig. 8. fuzzy inference

Fuzzy logic Operators

For the rule formation two operators AND and OR are used between the linguistic values. The AND operator is used as fuzzy intersection, pick minimum value and OR operator is used as fuzzy union which picks maximum value. These are applied on two fuzzy sets named as fuzzy set P and fuzzy set Q aggregates two membership functions as described below. IF (0.0 OR 0.7) THEN 0.7 will be result as OR return max value.

$$\mu_{P\cap Q}(x) = \min\left(\mu_P(x), \mu_Q(x)\right) \qquad \text{Eq. (9)}$$

$$\mu_{P\cup Q}(x) = \max\left(\mu_P(x), \mu_Q(x)\right) \qquad \text{Eq. (10)}$$

Implication

Each rule has weight from 0 to 1. For the same output membership functions, the inference engine may have more than one rules which are activate, but there should be single output. There are two operators AND, OR. If there is AND operator between the input variable, then minimum input value is picked up. Similarly, if OR operator is used then the maximum input value is selected for the output of the rule. This is known as implication method.

Aggregation

The next step in inference process is to combine the outputs of each fired rule into a single fuzzy set. This is called as the aggregation process.

3.5 Defuzzification

This is the final step, where the output of all linguistic variables is aggregated, and then final output is obtained in crisp value, which is user understandable. There are different methods of defuzzification as mentioned below [11]:

1. Center of area (COA): This defuzzification method calculates the centroid under the aggregation function for that area. It is calculated with the below mentioned formula:

$$Z_{COA} = \frac{\int \mu_A(z) z dz}{\int \mu_A(z) z dz} \qquad \text{Eq. (11)}$$

2. Bisector of area (BOA): BOA divides the whole region of aggregation function vertically, where complete area is divided into two equal parts. Sometime, the center of area and bisector of area lies on same line but not always.

$$\int_a^{BOA} \mu_A \, dz = \int_{BOA}^{\beta} \mu_A(z) dz \qquad \text{Eq. (12)}$$

3. Largest of Maximum (LOM): Largest value will be return.
4. Smallest of Maximum (SOM): It returns smallest value of aggregation output partition function.
5. Mean of Maximum(MOM): This function calculates arithmetic mean of the aggregated partition functions and return the maximum value with the below mentioned formula.:

$$Z_{mom} = \frac{\int z dz}{\int dz} \qquad \text{Eq. (13)}$$

Table 4. Defuzzified values and ranks for different inputs for Septic Arthritis disease

Inputs Symptoms							Defuzzified values and ranks according to different defuzzification methods									
Age	Fever	Pain	Swelling & Tenderness	Deformity	Lymphadenopathy	Sinuses	SOM	RANK	LOM	RANK	MOM	RANK	CENTROID	RANK	BISECTOR	RANK
15	2	6	5	2	8.5	7	4.51	2	10	1	7.25	2	7.15	2	7.12	2
53	7	5	8	9	9	9	5.05	1	10	1	7.52	1	7.26	1	7.3	1
20	8	7.5	8	6	2.5	2	1	3	4.6	2	2.8	3	2.9	3	2.89	3
61	2.5	6	3	4	4.5	8	4.51	2	10	1	7.25	2	7.15	2	7.12	2
41	9	8	6.5	7	1	2.5	1	3	4.42	3	2.71	4	2.86	4	2.89	3

Table 5. Defuzzified values and ranks for different inputs for Osteomyelitis disease

Inputs Symptoms				Defuzzified values and ranks according to different defuzzification methods									
Pain	Swelling	Fever	Age	SOM	RANK	LOM	RANK	MOM	RANK	CENTROID	RANK	BISECTOR	RANK
5	7	6	8	6.58	2	10	1	8.29	2	8.14	2	8.11	2
8	4	6	4	4.06	3	5.95	2	5	3	5	3	4.96	3
2	3	1.5	3	1	4	2.98	4	1.99	5	2.24	5	2.26	5
8.5	9	8	9	7.03	1	10	1	8.52	1	8.26	1	8.29	1
1	4	1	5	1	4	3.43	3	2.21	4	2.36	4	2.35	4

IV. PROPOSED EXPERT SYSTEM

For the interaction of user and expert system, graphical user interface is designed in user friendly manner. User can enter the symptoms and after diagnosing, type of disease and severity level of disease are shown as output.

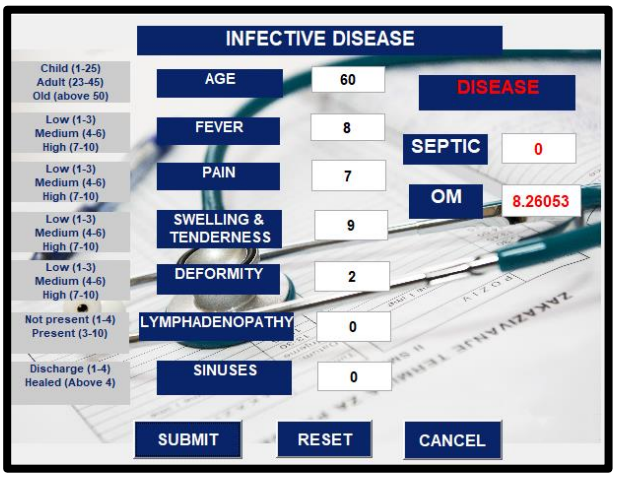

Fig. 9. Graphical User Interface for Infective Diseases of Knee

Fig.9 Shows the GUI for infective diseases of knee, where the user has to enter the input in form of symptoms. The range of all the symptoms is mentioned and user must enter value (within range). The output will be shown in the text box and Fig 10 shows the treatment plan corresponding to the disease. In the treatment plan, name of the disease is shown and Stage of the disease (Mild, Moderate and Severe). According to the Stage, some medicine and Exercise is recommended as shown in fig. 10.

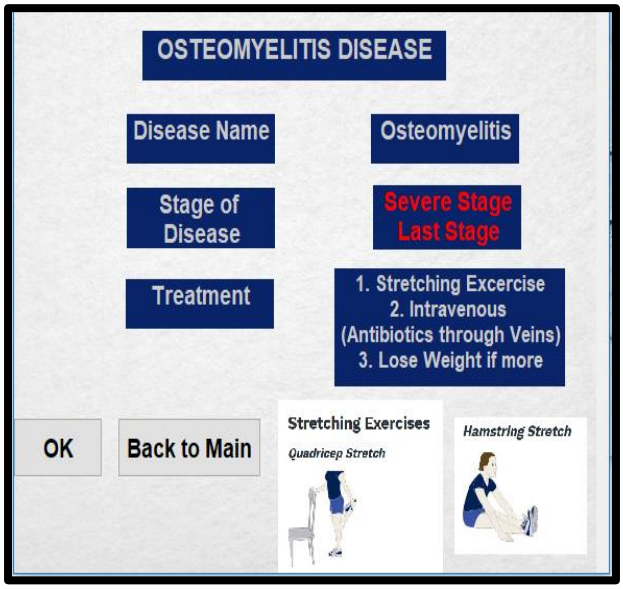

Fig. 10. Graphical User Interface for Treatment of Infective Diseases of Knee

V. TESTING

In the medical field, accuracy is very important. The proposed system is tested by matching the system output and expert's output.

5.1 Predictive values

False positive means when the proposed system diagnose the result but there is no disease. False negative means a patient is suffering from disease, but the proposed system gives result as there is no disease. Sensitivity is percentage of the patients with disease have positive test where specificity is the percentage of the patients without disease have negative test.

Mathematically,

Positive Predictive value (PPV) = True Positive / (True Positive + False Positive)

Negative Predictive value (NPV) = True Negative / (True Negative + False Negative)

Sensitivity: True Positive / (True Positive + False Negative)

Specificity: True Negative / (True Negative + False Positive)

PPV = TP / (TP + FP) = 48 / (48 + 1) = 0.97

NPV = TN / (TN + FN) = 24 / (24 + 2) = 0.92

SENSITIVITY = TP / (TP + FN) = 48 / (48 + 2) = 0.96

SPECIFICITY = TN / (TN + FP) = 24 / (24 + 1) = 0.96

Table 6. Sample test results

TEST	DISEASE PRESENT	DISEASE ABSENT
TEST POSITIVE	TRUE POSITIVES (48)	FALSE NEGATIVES (1)
TEST NEGATIVE	FALSE POSITIVES (2)	TRUE NEGATIVES (24)
TOTAL	50	25

Table 7. Sample test results for fuzzy inference system

Input Symptoms							OUTPUT BY SYSTEM	OUTPUT BY EXPERT	RESULT
Age	Fever	Pain	Swelling & Tenderness	Deformity	Lymphadenopathy	Sinuses			
40	2	2.5	3	2	6	8	7.26 (Septic)	Chronic Septic	True
4	1.5	2.5	3	2	0	0	2.35 (OM)	Mild OM	True
62	2	6	3.5	4	4.5	8	7.14 (Septic)	Chronic Septic	True
8	6	5	7	1	0	0	8.14 (OM)	Severe OM	True
51	3	6	8	8	2	3	2.85 (Septic)	Acute Septic	True
20	4.5	5	6	8	8.5	6	7.10 (Septic)	Chronic Septic	True

Table 8. System testing on Patient's data

input symptoms							expected output (disease)	
Age	Fever	Pain	Swelling & tenderness	Deformity	Lymph-adenopathy	Sinuses	Septic	Osteomyelits
adult	low	severe	low	medium	not present	discharge	acute	
child	high	moderate	high	medium	not present	heal	chronic	
adult	medium	low	low	nill	nill	nill		mild
child	high	severe	low	high	yes	discharge	acute	
old	medium	moderate	high	low	nill	nill		severe
adult	low	moderate	low	medium	present	heal	chronic	
old	high	low	low	low	nill	nill		moderate

VI. DISCUSSION AND CONCLUSION

The proposed expert system is designed to diagnose the orthopaedic diseases of knee for the infective category and the severity of disease. This fuzzy rule base technique gives accurate results. This proposed medical expert system could be used as a tool, which can abet the Orthopaedic doctors as well as learning system for Orthopaedic Medical students and Practioners. An ordinary person who doesn't have any knowledge of Artificial intelligence, can use this proposed system to identify stage of disease. The system is validated and tested, which gives Specificity and Sensitivity as 96%.

This proposed research work can further be extended using different technique like Neuro-Fuzzy for another category like neoplastic diseases.

VII. ACKNOWLEDGEMENT

The authors would like to acknowledge the expert Dr. Surjit Singh Dardi, Orthopaedic Medical Officer (SMO) at Sant Sarwan Dass Charitable hospital, kathar, Hoshiarpur, Punjab, India. He supports throughout the development of proposed expert system.

REFERENCES

[1] Moskowitz, R., Altman, R. and Buckwalter, J. (2006). *Osteoarthritis*. 4th ed.

[2] Pandey, S. and Pandey, A. (2009). *Clinical orthopaedic diagnosis.* New Delhi: Jaypee Brothers Medical Publishers.

[3] P. B. Zirra, "A Fuzzy Based System for Determining the Severity Level of Osteomyelitis," *Int. J. Adv. Res. Comput. Sci. Softw. Eng.*, vol. 6, no. 6, pp. 174–183, 2016.

[4] M. Daniel, P. Hájek, and P. H. Nguyen, "CADIAG-2 and MYCIN-like systems," *Artif. Intell. Med.*, vol. 9, no. 3, pp. 241–259, 1997.

[5] F. Başçiftçi and E. Avuçlu, "An expert system design to diagnose cancer by using a new method reduced rule base," *Comput. Methods Programs Biomed.*, vol. 157, pp. 113–120, 2018.

[6] E. O.Justice and T. K.F, "Fuzzy-Based System for Determining the Severity Level of Knee Osteoarthritis," *Int. J. Intell. Syst. Appl.*, vol. 4, no. 9, pp. 46–53, 2012.

[7] N. Walia, S. K. Tiwari, and R. Malhotra, "Design and Identification of Tuberculosis using Fuzzy Based Decision Support System," *Adv. Comput. Sci. Inf. Technol.*, vol. 2, no. 8, pp. 57–62, 2015.

[8] C. Paper, "Rule-Based Expert System for Disease Conference Paper · March 2015," no. March,2015.

[9] I. K. G. D. Putra and P. M. Prihatini, "Fuzzy Expert System for Tropical Infectious Disease by Certainty Factor," *Telkomnika*, vol. 10, no. 4, pp. 825–836, 2012.

[10] Mantzaris, Dimitrios H., George C. Anastassopoulos, and Dimitrios K. Lymberopoulos. "Medical disease prediction using artificial neural networks." *BioInformatics and BioEngineering, 2008. BIBE 2008. 8th IEEE International Conference on*. IEEE, 2008.

[11] L. A. Zadeh, "The role of fuzzy logic in the management of uncertainty in expert systems", *Fuzzy Sets Syst.*, vol. 1, pp. 3-28, 1978.

[12] https://www.webmd.com/pain-management/knee-pain/picture-of-the-knee#1