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FUZZY MODEL FOR OSTEOMYELITIS SEVERITY PREDICTION

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ABSTRACT

Osteomyelitis (OM) is an infection and inflammation of the bone and bone marrow that poses serious health challenges if not diagnosed on time. It usually starts as an acute infection which if not diagnosed and treated on time can become chronic osteomyelitis, as the bones can become permanently damaged, resulting in persistent pain and loss of function. In this research, a fuzzy model for osteomyelitis severity level prediction has been proposed to aid in effective diagnosis and treatment options. The fuzzy based model was designed with six input variables and one output variable. The input variables are Fever, Redness (in the affected area), Irritability, Drainage (from the area) Swelling (in the affected area) and Stiffness (inability to use the affected area. The output variable (OsteomyelitisLevel) detects the severity levels of patients categorized into veryMild, mild, moderate, severe and verySevere. Fuzzy Inference Structure (FIS) was generated and used in obtaining a decision fuzzy set for the considered disease, and crisp decision values are obtained to state the severity level of the disease. The performance of the system was evaluated using patients' dataset from an orthopedic department and it shows that result corresponds with the physicians evaluation.

Keywords— Osteomyelitis, Fuzzy System, Fuzzification, Membership Function, Fuzzy Rule Base.

INTRODUCTION

Osteomyelitis is an infection of the bone and bone marrow that presents itself with vague, ambiguous and imprecise symptoms. It usually starts as an acute infection, which, if not diagnosed and treated on time can become chronic osteomyelitis, as the bones can become permanently damaged, resulting in persistent pain and loss of function. If diagnosed early, osteomyelitis can be treated with antibiotics, whereas surgery may be required in severe or chronic cases of osteomyelitis.

The rest of the article is organized as follows: a brief review of related works on fuzzy logic, the architecture of the Rule Based Fuzzy Model

The task of medical diagnosis, unlike other diagnostic processes is made more complex because a lot of vagueness, linguistic uncertainty, hesitation, measurement imprecision, natural diversity are all prominently present in medical diagnosis. With improvement in science technology, intelligent computing has been used in enhancing qualitative services, thereby reducing the mortality rate and also alleviating the economic burden placed on the society through lost working time as well as social and medical costs due to one ailment or the other of which ostemyelitis is not an exception.
for Osteomyelitis Severity Prediction, the fuzzy based design controller, model simulation, discussion and result

LITERATURE REVIEW

A. Fuzzy Logic

Fuzzy logic is a multi-valued logic introduced by Zadeh in 1965, which allows intermediate values to be defined between the conventional (Boolean) logic evaluations (Zadeh, (1965), (1978)). Fuzzy logic (a paradigm of artificial intelligence), has been used in assisting the medical personnel in making decision. Fuzzy Logic provides an inference mechanism that enables approximate human reasoning capabilities to be applied to knowledge-based systems.

Fuzzy Intelligent system has been used for solving different complex health problems:

Vishal and Pinki (2014) developed a web based fuzzy expert system for the management of hypertension (High Blood Pressure) using four input variables (Systolic blood pressure, diastolic blood pressure and body mass index (BMI)) and one output variable (hypertension risk). The system is capable of giving the possibility of being High blood pressure patient.

A fuzzy logic temperature controller for preterm Neonate incubator was designed by (Bajeh and Emuoybofarhe, (2008)). The goal was to attain thermoneutrality and also the efficient stabilization of the incubator temperature at a desired value and thereby prevention of hypothermia/hyperthermia related diseases/conditions and death. The system was not implemented.

Emuoyibofarhe and Taiwo, (2012) designed a fuzzy based system for determining the severity level of knee osteoarthritis where four input variables (knee pain, stiffness, crepitus and age) and one output variable (severity Level) were used to determine the severity level of patient knee osteoarthritis. However, they failed to take into consideration other symptoms (variable) like swelling that are of important in diagnosing the disease

A Fuzzy Inference system with four input variables and one output variable for diagnosing brain diseases with MATLAB using the Mandani Inference method was designed by Ayangbekun and Jimoh (2015). However, the twenty-five (25) fuzzy rules were not large enough to make a generalized verdict.

A Fuzzy expert system for diagnosing heart disease which can be viewed as an alternative for existing methods to distinguish the presence of heart disease was designed by Ali and Mehdi (2010) with thirteen (13) input variables and one output variable with MATLAB using the Mandani Inference method.

Zolnoori et al. (2012) present an intelligence fuzzy system which provides an appropriate solution for problems of evaluating asthma severity.

B. Osteomyelitis

Osteomyelitis is an inflammatory bone disorder caused by bacteria and other germs infection. It can affect all ages, involve any bone, become a chronic disease and cause persistent morbidity which can lead to bone destruction (Diana et al., 2013).

Osteomyelitis is an infection of the bone and bone marrow that presents itself with vague, ambiguous and imprecise symptoms. It usually starts as an acute infection which if not diagnosed and treated on time can become chronic osteomyelitis, as the bones can become permanently damaged, resulting in persistent pain and loss of function. If diagnosed early, osteomyelitis can be treated with antibiotics, whereas surgery may be required in severe or chronic cases of osteomyelitis (NHS, 2016).

While the diagnosis is usually straightforward in the majority of the patients, in some patients different conditions may present themselves with similar clinical features (Museru and Mcharo, 2001).

In the view of Hatzenbuehler and Thomas (2011), the symptoms range from fever, irritability, fatigue, nausea, lost range of motion, swelling, tenderness, redness and warmth in the area of the infection. It affects both old and young with approximately 50% of cases occurring in preschool-aged children (Sabah, 2016), hence, there is need for urgent intervention especially in these young ones to avoid degenerating into chronic cases which is one of the commonest orthopedic diseases among children and adolescents under the age of 12 (Ako-Nai et al., (2003).

MATERIAL AND METHODS

A. *Fuzzification*

This is the first step to be applied in a fuzzy inference system; it is the process of converting crisp input variables to fuzzy variables, and then apply fuzzy inference to process those data to

obtain the desired output. Fuzzification is done by the Fuzzifier. Given a fuzzy set A, defined as (1), represents osteomyelitis diagnostic variables with element denoted by x_i, the fuzzification process involves transforming raw input value of each variable to a fuzzy term obtained from set [Low High veryHigh] defined over the variables. That is, such values are derived from functions defined to determine the degree of membership of each variable in the fuzzy set

$$A = \{(x_i, \mu_A(x_i)) | x_i \in V, \mu_A(x_i) \quad (1)$$

Fuzzification is done using function defined in (2)

$$\mu_A(x_i) = \begin{cases} 0 & if\ x_i < a \\ \frac{x_i - a}{b - a} & if\ a \leq x_i \leq b \\ 1 & b \leq x_i \leq c \\ \frac{c - x_i}{c - b} & if\ c \leq x_i < d \\ 0 & if\ d < x_i \end{cases} \quad (2)$$

where $\mu_A(x_i)$ is the MF of x_i in A using trapezoid MF while μ_A is the degree of x_i in A, a, b, c and d are the parameters of the MF governing its trapezoidal shape and each attribute is described with linguistic terms

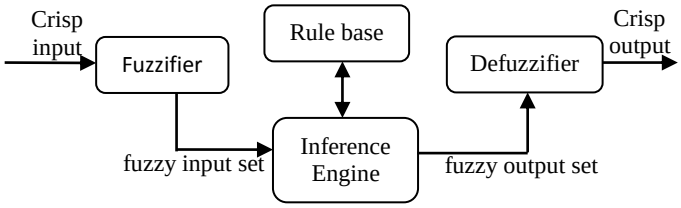

Figure 1 Fuzzy Model for Osteomyelitis SeverityLevel Prediction (Adapted from Taha et al. 2015)

B. *Fuzzy Rule Base*

The rule base for osteomyelitis diagnosis is characterized by a set of IF–THEN rules in which the antecedents (IF parts) and consequents (THEN parts) involve linguistic variables. The rules were formulated with assistance of experts in the management of osteomyelitis and on consultation to existing literature. A rule only fires if any of its precedence parameters such as very low, High, veryHigh evaluates to TRUE, otherwise it does not fire.

Based on the choice of inputs, the following fuzzy **IF-THEN** rules are extracted from the set of rules that represents an expert knowledge about how best to determine the OsteomyelitisLevel of the patient

IF (*Fever* is *High*) and (*Redness* is *BulgeOut*) and (*Irritability* is *mild*) and (*Drainage is Low*) and (*Swelling* is *Severe*) and (*stiffness is Moderate*) **THEN** (*OsteomyelitisLevel is Severe*).

IF (*Fever* is *veryHigh*) and (*Redness* is *FairlyVisible*) and (*Irritability* is *moderate*) and (*Drainage is Low*) and (*Swelling* is *moderate*) and (*stiffness is Moderate*) **THEN** (*OsteomyelitisLevel is verySevere*).

IF (*Fever* is *Low*) and (*Redness* is *Visible*) and (*Irritability* is Severe) and (*Drainage is Chronic*) and (*Swelling* is *mild*) and (*stiffness is mild*) **THEN** (*OsteomyelitisLevel is mild*).

IF (*Fever* is *High*) and (*Redness* is *BulgeOut*) and (*Irritability* is *mild*) and (*Drainage is Acute*) and (*Swelling* is *Severe*) and (*stiffness is Severe*) **THEN** (*OsteomyelitisLevel is verySevere*).

IF (*Fever* is *veryHigh*) and (*Redness* is *FairlyVisible*) and (*Irritability* is *Severe*) and (*Drainage* is *Low*) and (*Swelling* is *mild*) and (*stiffness* is *mild*) **THEN** (*OsteomyelitisLevel* is *Mild*)

C. *Fuzzy Inference Engine*

This component controls the decision making logic by applying suitable composition procedure from rule base to values of variable inputs received. The inference engine applies composition procedure on the inputs to produce desired output, and Root Sum Square (RSS) is applied to scale the functions at their respective magnitude and computes a composite area. RSS is a method used to combine the effects of fired rules in order to draw relevant inference. It is computed using (3).

$$RSS = \sum_{t=1}^{N} (R_t^2) \quad (3)$$

R_t is a fired rule where **t∀1,…, n** is the identity of the fired rule

D. Defuzzification

This is the process of translating result from the inference engine into crisp values which are, mostly, required by medical experts for proper analysis and interpretation, this aids efficient diagnosis It is a process in which membership functions are sampled to find the grade of membership; this grade is then used in the fuzzy logic equation(s) and an outcome region is defined, from which the output is deduced. Over the years, several defuzzification techniques have been suggested. The most frequently used ones are the centroid or centre of area (CoA), centre of sums, and mean of maxima. In this research the centre of area defuzzification technique was adopted (4).

$$CoA = \frac{\sum_{i=1}^{n} \mu Y(x_i)}{\sum_{i=1}^{n} \mu Y(x_i} \qquad (4)$$

where $\boldsymbol{\mu Y(x_i)}$ is degree of i in a membership function and x_i is the center value in function

FUZZY BASED DESIGN CONTROLLER

A. *Controller Input*

The function of the controller input in Fig. I is to determine the Osteomyelitis severityLevel of patient using the symptoms; Fever, stiffness, redness, irritability, swelling and drainage.

The researchers made use of **Fever**, which is graded into three (3) membership functions: **(**Low, High, veryHigh**)**; **Redness (**faintlyVisible, visible, bulgeOut); **Irritability** (mild, moderate, and severe); **Drainage** (low, acute, chronic); **Swelling** (mild, moderate, severe) and **Stiffness** (mild, moderate, severe).

B. *Controller Output*

Multiple input single output (MISO) fuzzy system was applied, with OsteomyelitisLevel graded into five variables [*veryMild*, *mild*, *moderate*, *Severe* and *verySevere*] as the only output variable which determine the level of severity of the patient's osteomyelitis giving the input variables.

During fuzzification, the fuzzy input variable, Fever ranging from 32 to 45 is converted into three linguistic grades namely *Low*, *High* and *VeryHigh*.

Similarly, the input variable Redness from 1 to 10 is converted into three linguistic variables namely: FaintlyVisible, Visible and BulgeOut. The input variable Drainage from 1 to 10 is converted into three linguistic variables namely: Low, Acute and Chronic.

The other three input variables; Irritability, Stiffness and Swelling ranging from 1 to 10 are converted into three linguistic variables: Mild, Moderate and Severe while the output variable OsteomyelitisLevel ranging from 1 to 10 are converted into five linguistic levels namely: VeryMild, Mild, Moderate, Severe and VerySevere. The trapezoidal membership function is used to perform the scale mapping. 729 rules were formed with the assistance of orthopedic experts. The Centre of Area defuzzification method was used in obtaining the non-fuzzy crisp output from the controller.

MODEL SIMULATION AND RESULT

The inference system accepts six input variables which are the symptoms: Fever, Redness, Irritability, Drainage, Swelling and Stiffness and the output given out is the severity level of the disease. The inference system compares the input to its rules and gives out the disease severity level. Fig 2 shows the structure of the fuzzy inference system.

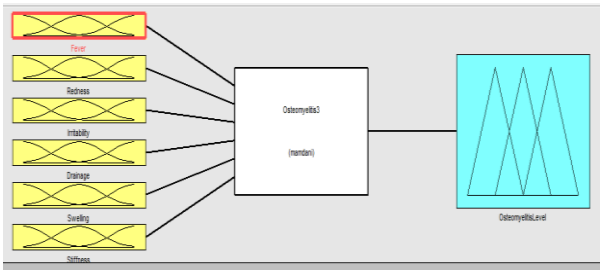

Figure 2: Outline of the proposed model

In order to evaluate the performance of the proposed model, 729 rules were generated represented by 6 linguistically designed input all having three (3) membership functions. This number results from the membership function say (x) raise to the number of input-variable, 3^6 = 729. Fuzzy rule generation follows human reasoning pattern which make it more flexible in composition. In the rule viewer provided by the Fuzzy inference System (FIS) in fig. 3a and 3b, sliding the red line changes the input values and, and generate a new output response, also, the inputs can be set explicitly using the edit field.

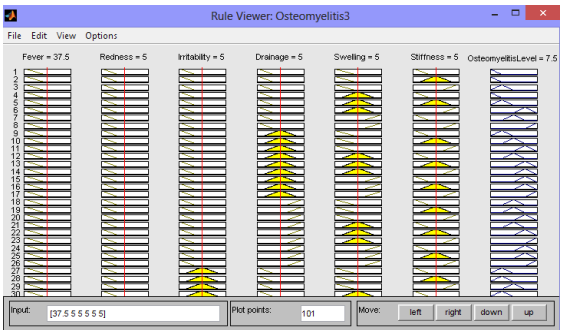

Figure 3a: Sample rule viewer

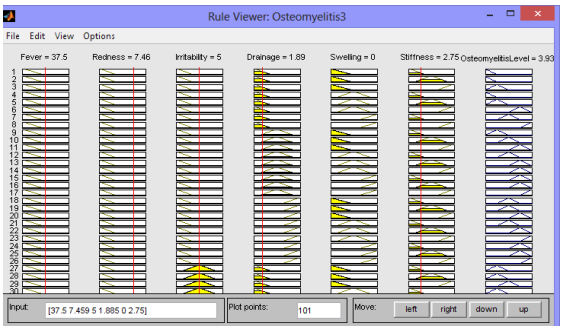

Figure 3b: Sample rule viewer

The simulation of the model was carried out using MATLAB 7.6.0 for windows. The membership function for the input variable 'Fever' and output variable OsteomyelitisLevel is as shown in Fig. 4a and Fig. 4b respectively:

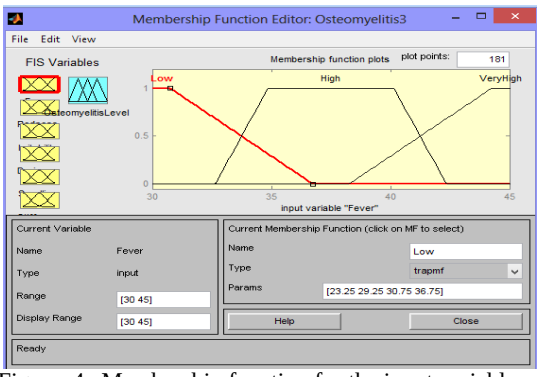

Figure 4a Membership function for the input variable 'Fever'

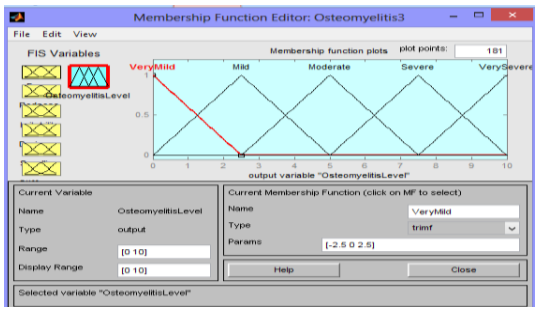

Figure 4b: Membership function for the output variable 'OsteomyelitisLevel'

The input variable 'Stiffness' was plotted against another variable 'Swelling' and variable 'Drainage' to observe the relationship among the parameter 'Stiffness', 'Swelling' and 'Drainage'. The relationship is as shown in Fig. 5a and Fig. 5b respectively:

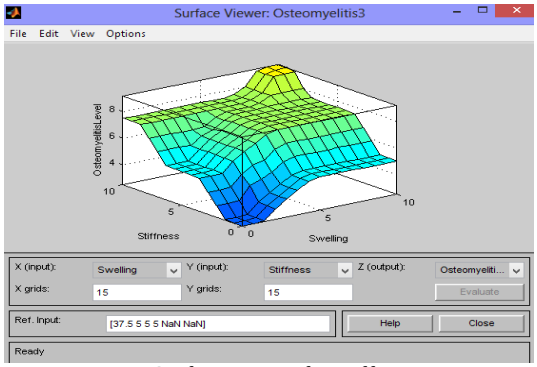

Figure 5a Surface viewer for stiffness versus Swelling

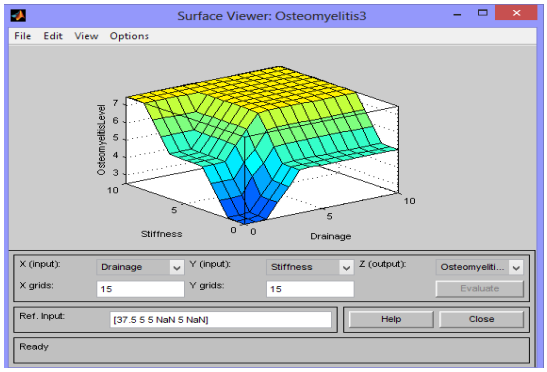

Figure 5b: Surface viewer for Stiffness versus Drainage

CONCLUSION

Rule Based Fuzzy Model for Osteomyelitis Severity Prediction that deals with the imprecision and vagueness in medical diagnosis was designed with six input variables and one output variable. The model was developed using trapezoidal membership function for the input variables and triangular membership function for the output variable. It will assist in fast and early diagnosis of the Osteomyelitis disease; thereby reducing loss of function rate especially where there are limited numbers of qualified orthopedic consultants.

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