How to Cite:
Sharma, R., Jain, S. K., Kumar, S., & Sami, P. (2022). A study for the diagnosis of asthma disease using fuzzy logic based system. *International Journal of Health Sciences*, *6*(S1), 12156–12165.
https://doi.org/10.53730/ijhs.v6nS1.8041

A study for the diagnosis of asthma disease using fuzzy logic based system

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***Abstract*---**There are numerous expert systems that have been designed to diagnose the severity of Asthma, infect asthma is a chronic lung disorder of with the number of suffers is still estimated only. It has previously been estimated that prevalence of asthma in India is about 30 million patients with prevalence in children, young and adult. Results of various studies shows that asthma is usually under-diagnosed in developing countries. Asthma is a chronic lung disease that blocks the airways that carries air from the lungs. This blockage in the airways causes inflammations which make the patient susceptible to irritations and allergies. The purpose of this work is to design a fuzzy rule based expert system to alleviate this hazard by diagnosing asthma at initial stage. This system has 6 input parameters "FEVI test", "Age", "Allergy Rhinitis", "Environment Factor (Pollution)", "PEF test", "Medical Factor (chronic infection)"and one output parameter which is based on the final result of system and that is defuzzified in order to provide the assessment of the possibility of asthma.

***Keywords*---** asthma, allergy rhinitis, fuzzy logic.

Introduction

Whenever we talk about the asthma, it is a chronic disease with three signs; chronic inflammation, hyper-responsiveness, and reversible air flow obstruction due to people negligence of their common symptoms like cold, cough, wheeze,

Manuscript submitted: 27 March 2022, Manuscript revised: 9 April 2022, Accepted for publication: 18 May 2022

chest tightness and shortness of breath. Symptoms can range from mild to severe. A medical condition that makes breathing difficult by causing the air passage to become narrow. In India, at the first stages of the disease by patient, a survey shows that 25% of asthmatic children are not aware. The inability to perform spirometry in young children, is the lack of spirometry test.

A part from several medical scientists who are working for this disease, some other experts are also working in this direction. **Zarandi et al (2012)** stated that the asthma is a chronic lung disorder of which the number of sufferers estimated to be between 1.4-27.1% of the population indifferent areas of the world. Results of various studies shows that asthma is usually under-diagnosed, especially in developing countries, because of limited access to medical specialist and laboratory data. The purpose of this work was to design a fuzzy rule-based expert system to alleviate this hazard by diagnosing asthma at initial stages. A knowledge representation of this system is provided from a high level, based on patient perception, and organized into two different structures called Type A and Type B. Type A is composed of six modules with symptoms, allergic rhinitis, genetic factors, symptom hyper-responsiveness, medical factors and environmental factors. Type B is composed of 8 modules with symptoms, allergic rhinitis, genetic factors, response to short-term drug use, bronchodilator tests, challenge tests, PEF tests and exhaled nitric oxide.

Krishna Anand et al (2013)designed and implemented a fuzzy expert system for detecting and estimating the level of asthma and chronic obstructive pulmonary disease, further **Arani et al (2019).** Also worked in this direction to diagnose this, and a structure of a fuzzy expert system has been offered. This is done in order to help general physicians and the patients make decision and also differentiate among chronic bronchitis, tuberculosis, asthma, embolism, lung cancer.

Sundarman et al (2019) also worked on the diagnosis of asthma during the early stages as it plays a primary role in providing effective medical treatment. Different opinions are also given by different doctors for a patient having the same set of symptoms. This opinion was based on the type or degree of the disorder. There can be scenarios where the same doctor may diagnose differently for two different patients having similar symptoms. Hence, it can be concluded that the thought process of a doctor is fuzzy in nature. In any medical field, accuracy of diagnosis is extremely important as it concerns the life of a patient. Besides, with increase in number of hospitals and staff, the amount of measured data is extremely huge. Further some mistakes have tended to creep during recording of measurements, and these mistakes include carelessness, inaccurate measurements and failure in recording take place from time to time. Taking these points into consideration, the focus of the work has shifted to providing an improvement in the accuracy levels of detection.

As per **Sharif et al (2019),** the Emergency Department (ED) of a hospital is an important unit that deals with time-sensitive and life-threatening medical cases. Rapid treatment and accuracy in diagnosis are considered the main characteristics of excellent operational processes in ED. However, in reality, long waiting time and uncertainty in the diagnosis has affected the quality of ED services. Nonetheless, these problems can be improved by utilising computing technologies that assist medical professionals to make fast and accurate decisions. This work investigates the issues of under-treatment and uncertainty condition of acute asthma cases in ED. A novel approach, known as the fuzzy logic principle is employed to determine the severity of acute asthma. The fuzzy set theory, known as Fuzzy Rule-based Expert System for Asthma Severity (FRESAS) determination is embedded into the expert system (ES) to assess the severity of asthma among patients in ED. This fuzzy methodology effectively manages the fuzziness of the patient's information data, and determines the subjective judgment of medical practitioners' level on eight criteria assessed in severity determination. Knowledge acquisition and representation, fuzzification, fuzzy inference engine, and defuzzification are the processes tested by the FRESAS development that incorporates expert advice. The system evaluation is performed by using datasets that were extracted from the ED clerking notes from one of the hospitals in Northern Peninsular Malaysia. System evaluation demonstrates that this proposed system performs efficiently in determining the severity of acute asthma.

Now on the basis of above information the purpose of this work is to deal with asthma under diagnosis by designing a Fuzzy Expert System (FES). The designed FES gives patient with respiratory symptoms and the ability to check their disease for asthma. It helps the physician to diagnose at initial stage.This work describes a fuzzy inference system with 6 inputs, 1 output, used for diagnose of asthma. The diagnose is based on mainly six input variables: *i) Age, ii) FEV1 test, iii) Allergy rhinitis, iv) Environment factor, v) PEF test, andvi) Chronic infection*. The system output which gives the severity of the asthma divided into four stages.

The knowledge acquisition process is represented as semantic networks which are made of nodes providing the conditions of asthma (cause nodes) and nodes representing the effects of asthma (effect nodes). Model 1 is represented as high level. The cause nodes include atopy, airway hyper-reactivity, genetic factor and lung disorder. A symptom node is characterized by symptom type, pattern and intensity. Model 1 represents a modification which represents cause and effect nodes from high level. Major factors are allergic rhinitis, genetic factors, environmental factors, and medical factors, and effective nodes include lung functions, the effects of short-term drug and symptoms characterized by symptom appearance, symptom hyper- responsiveness, symptom intensity and symptom pattern. The conditions of these production rules are variables in defined modules, and their consequences are the degree of asthma possibility. This possibility is calculated using local experience knowledge and global knowledge.

The domain of the degree of asthma possibility in all the modules expect the lung function test to be considered, which is subdivided into fuzzy intervals categories represented as linguistic variables.Trapezoidal membership functions are used for representing fuzzy sets because of computational efficiency. Production rules in this module were using a combination of symptom appearance, pattern, intensity, antecedents, and degree of possibility of asthma which is based on stages of this disease (mild, mild-moderate, moderate and severe).

Fuzzy Inference System

It is the process of formulating the membership from a given input to an output using fuzzy logic. The system will be used to map the values of each input and output variable into a [0,1] interval with the use of trapezoidal membership functions. The process of fuzzy inference system involves membership function, fuzzy logic operators and *if-then* rules for making decisions. In the fuzzy logic, there are five parts of the fuzzy inference process. The first step is to take inputs and determine the degree to which they belong to each of the appropriate fuzzy sets *via* membership functions. Further apply fuzzy operator to obtain one number that represents the result of the antecedent for that rule. This number will be applied to the output functions. The model will consist of different rules which are used to generate different results which are then aggregate to just one fuzzified output.

Data Collection

All the data is to be collected during the present study of asthma patient. The consequences of this under diagnosing such as increasing severity of asthma create restriction on the physical, emotional aspects of patient lives and finally increase the mobility or mortality rate to evaluate the final result obtained by these modules of asthmatic or non-asthmatic patients with respiratory symptoms were considered and referred to Dr. Nitish Gupta (an International Pulmonologist in Agra)practiced at Dhiraj Hospital Vadodara and diagnosed asthmatic patients who were recently tested in "Scientific Pathology Centre" Delhi gate, Agra.The performance of this system is calculated by considering all modules of the knowledge base including symptoms.

Membership Functions for Input and Output Functions

Input Functions: For each input variable the membership function is defined as follows:
AGE: Asthma creates a much greater risk for older adults because they are more likely to develop respiratory failure as a result of the asthma. The author found that aged compared to younger asthma patient had significantly worse asthma than adults, called asthma attack control. Children have smaller airways than adults, which makes asthma serious for them. The membership function for the input variable is:

$$\mu_c(x) = \begin{Bmatrix} 1, x \leq 20 \\ \frac{25-x}{5}, 20 \leq x \leq 25 \\ 0, x \geq 25 \end{Bmatrix} \qquad \mu_y(x) = \begin{Bmatrix} \frac{x-20}{5}, 20 \leq x \leq 25 \\ 1, 25 \leq x \leq 40 \\ \frac{45-x}{5}, 40 \leq x \leq 45 \end{Bmatrix}$$

$$\mu_A(x) = \begin{Bmatrix} \frac{x-40}{5}, 40 \leq x \leq 45 \\ 1, 45 \leq x \leq 60 \\ \frac{65-x}{5}, 60 \leq x \leq 65 \end{Bmatrix} \qquad \mu_c(x) = \begin{Bmatrix} 0, x \leq 60 \\ \frac{x-60}{5}, 60 \leq x \leq 65 \\ 1, x \geq 65 \end{Bmatrix}$$

FEV 1 TEST: FEV1 is the maximal amount of air you can forcefully exhale in one second. It is measured during spirometry test. Both asthma and COPD are characterized by air flow obstruction it is defined as reduced FEVI1.The membership function for the input variable is*(if the decrease in FEV1 then the degree of possibility of asthma is high:*

$$\mu_N(x) = \begin{Bmatrix} 1, x \geq 90 \\ \frac{x-80}{10}, 90 \leq x \leq 80 \\ 0, x \leq 80 \end{Bmatrix} \quad \mu_M(x) = \begin{Bmatrix} \frac{90-x}{10}, 90 \leq x \leq 80 \\ 1, 80 \leq x \leq 70 \\ \frac{x-60}{10}, 70 \leq x \leq 60 \end{Bmatrix}$$

$$\mu_H(x) = \begin{Bmatrix} \frac{70-x}{10}, 70 \leq x \leq 60 \\ 1, 60 \leq x \leq 50 \\ \frac{x-40}{10}, 50 \leq x \leq 40 \end{Bmatrix} \quad \mu_{VH}(x) = \begin{Bmatrix} 0, x \geq 50 \\ \frac{50-x}{10}, 50 \leq x \leq 40 \\ 1, x \leq 40 \end{Bmatrix}$$

Allergy Rhinitis: An allergic response causing itchy, watery eyes, sneezing and other similar symptoms. Allergic rhinitis occurs seasonally or year-round diagnosis involves examination of nasal passage. The membership function for the input variable is (*if the patient has allergy and the allergy rhinitis is moderate to severe and the diagnosing of allergy is yes and the type of rhinitis is persistent then the degree of possibility of asthma is very high):*

$$\mu_N(x) = \begin{Bmatrix} 1, x \leq 250 \\ \frac{350-x}{100}, 250 \leq x \leq 350 \\ 0, x \geq 350 \end{Bmatrix} \mu_M(x) = \begin{Bmatrix} \frac{x-250}{100}, 250 \leq x \leq 350 \\ 1, 350 \leq x \leq 500 \\ \frac{600-x}{100}, 500 \leq x \leq 600 \end{Bmatrix}$$

$$\mu_H(x) = \begin{Bmatrix} \frac{x-500}{100}, 500 \leq x \leq 600 \\ 1, 600 \leq x \leq 750 \\ \frac{850-x}{100}, 750 \leq x \leq 850 \end{Bmatrix} \quad \mu_{VH}(x) = \begin{Bmatrix} 0, x \geq 750 \\ \frac{850-x}{100}, 750 \leq x \leq 850 \\ 1, x \geq 850 \end{Bmatrix}$$

Environment factor (pollution): Air pollution exposure is thought to potentially cause asthma in children by impacting the developing lung and immune system. The membership function for the input variable is (*if the patient has been exposed to passive smoking during infancy and the mother smoked during pregnancy and air pollution is high and smoking is high then the degree of asthma is high):*

$$\mu_L(x) = \begin{Bmatrix} 0, x \geq 30 \\ \frac{50-x}{20}, 30 \leq x \leq 50 \\ 1, x \geq 50 \end{Bmatrix} \quad \mu_N(x) = \begin{Bmatrix} \frac{x-30}{20}, 30 \leq x \leq 50 \\ 1, 50 \leq x \leq 70 \\ \frac{90-x}{20}, 70 \leq x \leq 90 \end{Bmatrix}$$

$$\mu_H(x) = \begin{Bmatrix} \frac{x-70}{20}, 70 \leq x \leq 90 \\ 1, 90 \leq x \leq 110 \\ \frac{130-x}{20}, 110 \leq x \leq 130 \end{Bmatrix} \quad \mu_{VH}(x) = \begin{Bmatrix} 0, x \leq 110 \\ \frac{x-110}{20}, 110 \leq x \leq 130 \\ 1, x \leq 130 \end{Bmatrix}$$

PEF TEST: The sub-module PEF test contains the antecedent of Peak Expiratory Follow (PEF) as antecedent and possibility of asthma is consequence. A peak flow meter is a handheld device that measures how well air moves out of your lungs. The membership function for the input variable is **(***if improvements is in PEF $\geq$ 20 and $\leq$ 30 after inhalation of a bronchodilator then the degree of possibility of asthma is high):*

$$\mu_{VL}(x) = \begin{Bmatrix} 1, x \le 5 \\ \frac{15-X}{10}, 5 \le x \le 15 \\ 0, x \ge 15 \end{Bmatrix} \qquad \mu_L(x) = \begin{Bmatrix} \frac{x-5}{10}, 5 \le x \le 15 \\ 1, 15 \le x \le 20 \\ \frac{30-x}{10}, 20 \le x \le 30 \end{Bmatrix}$$

$$\mu_M(x) = \begin{Bmatrix} \frac{x-20}{10}, 20 \le x \le 30 \\ 1, 30 \le x \le 35 \\ \frac{45-x}{10}, 35 \le x \le 45 \end{Bmatrix} \qquad \mu_H(x) = \begin{Bmatrix} 0, x \le 35 \\ \frac{x-35}{10}, 35 \le x \le 45 \\ 1, x \ge 45 \end{Bmatrix}$$

Medical factor (lung disorder)

Asthma and chronic obstructive pulmonary disease (COPD) are lung disease. Both causes swelling in your airways may produce extra mucus. This can make hard to breathe and trigger coughing, a whistling sound (wheezing) when you breathe our and shortness of breath.The membership function for the input variable is (*if the patient has emotional coughing/ dyspnoea/ wheezing and the existence of eczema is positive then the degree of possibility of asthma is medium/ high):*

$$\mu_L(x) = \begin{Bmatrix} 1, x \le 10 \\ \frac{20-x}{10}, 10 \le x \le 20 \\ 0, x \ge 20 \end{Bmatrix} \qquad \mu_M(x) = \begin{Bmatrix} \frac{x-10}{10}, 10 \le x \le 20 \\ 1, 20 \le x \le 30 \\ \frac{40-x}{10}, 30 \le x \le 40 \end{Bmatrix}$$

$$\mu_H(x) = \begin{Bmatrix} \frac{x-30}{10}, 30 \le x \le 40 \\ 1, 40 \le x \le 50 \\ \frac{60-x}{10}, 50 \le x \le 60 \end{Bmatrix} \qquad \mu_{VH}(x) = \begin{Bmatrix} 0, x \ge 50 \\ \frac{x-50}{10}, 50 \le x \le 60 \\ 1, x \ge 60 \end{Bmatrix}$$

Output Function

The domain of the degree of asthma possibility in all modules production rule were generated using a combination of symptoms, the type of outputs isdepending on the model and performance measure. The membership function of the linguistic values related to the given inputs and the possibility of asthmais defined as follow:

$$\mu_{Mi}(x) = \begin{Bmatrix} \frac{x-10}{10}, 0 \le x \le 10 \\ 1, 10 \le x \le 25 \\ \frac{35-x}{10}, 25 \le x \le 35 \end{Bmatrix} \qquad \mu_M(x) = \begin{Bmatrix} \frac{x-25}{10}, 25 \le x \le 35 \\ 1, 35 \le x \le 50 \\ \frac{60-x}{10}, 50 \le x \le 60 \end{Bmatrix}$$

$$\mu_{HM}(x) = \begin{Bmatrix} \frac{x-50}{10}, 50 \le x \le 60 \\ 1, 60 \le x \le 75 \\ \frac{85-x}{10}, 75 \le x \le 85 \end{Bmatrix} \qquad \mu_S(x) = \begin{Bmatrix} \frac{x-75}{10}, 75 \le x \le 85 \\ \\ 1, x \ge 85 \end{Bmatrix}$$

Example of the rule of the module

This module is applied to the process of diagnosing in this system, if the data for the lung function test available. Using the results of the laboratory data, the system presents the final result of diagnosing (a patient with respiratory symptoms has asthma or not), otherwise confirmation of the obtained results of the system need confirmation by the physician.Rules of this module are presented in the form of single input single output.

This table represents these linguistic variables and values, and associated fuzzy intervals related to variables of the inputs (*if the increase in FEV1 test after using a bronchodilator test then the degree of possibility of asthma in medium).*

Bronchodilator Test	Linguistic Variable	Linguistic Valus
INPUT	FEV 1 Test	Normal
		Medium
		High
		Very High
	PEF Test	Very Low
		Low
		Medium
		High
	ALLERGY Test	Normal
		Medium
		High
		Very High
OUTPUT	POSSIBILITY OF ASTHMA	Mild
		Moderate
		Highly Moderate
		Severe

Case study

Ms Megha Trivedi, 24 years old girl, was presented with complaints of Asthma disease, admitted on 10-07-2018 at Dhiraj Hospital Vadodara, Gujarat.Now consider the performance of the diagnosis system for asthma as an example. For the purpose of illustration, in case of asthma diagnose, we use six inputs *i.e.Age* (x_1)*, FEVI test* (x_2)*, Allergy rhinitis* (x_3)*, Environments factor* (x_4)*, PEF test* (x_5)*, Medical factor* (x_6). The input values of person are as:$x_1=42$, $x_2=66$, $x_3=700$, $x_4=98$, $x_5=36$, $x_6=40$

Fuzzification of the crisp values of inputs:Through the use of membership functions defined for each fuzzy set for each linguistic variable, the degree of membership of a crisp values in each fuzzy set are determined as:

$\mu_C(x_1) = 0$ $\mu_N(x_2) = 0$ $\mu_N(x_3) = 0$ $\mu_Y(x_1) = 0.6$ $\mu_M(x_2) = 0.6$ $\mu_M(x_3) = 0$
$\mu_O(x_1) = 0.4$ $\mu_H(x_2) = 0.4$ $\mu_H(x_3) = 1$ $\mu_{VO}(x_1) = 0.4$ $\mu_{VH}(x_2) = 0$ $\mu_{VH}(x_3) = 0$
$\mu_L(x_4) = 0$ $\mu_{VL}(x_5) = 0$ $\mu_L(x_6) = 0$ $\mu_M(x_4) = 0$ $\mu_L(x_5) = 0$ $\mu_M(x_6) = 0$
$\mu_H(x_4) = 1$ $\mu_M(x_5) = 0.9$ $\mu_H(x_6) = 1$ $\mu_{VH}(x_4) = 0$ $\mu_H(x_5) = 0.1$ $\mu_{VH}(x_6) = 0$

Fuzzy Rule Database

Fuzzy rules and fuzzy inference systems are extremely important and the quality of the system very much depends on them. These rules are defined as "*if-then*" rules. These inputs based on the value of the fuzzy membership function.Values for the example, under consideration, the following rules are applied:

rule 1: *if x_1 is young, x_2 is medium, x_3 is high, x_4 is high, x_5 is medium, x_6 is high then y is having asthma of moderate stage 2.*

rule 2: *if x_1 is young, x_2 is medium, x_3 is high, x_4 is high, x_5 is high, x_6 is high then y is having asthma of mild moderate stage 3.*

rule 3: *if x_1 is young, x_2 is high, x_3 is high, x_4 is high, x_5 is high, x_6 is high then y is having asthma of severe stage 4.*

rule 4: *if x_1 is young, x_2 is high, x_3 is high, x_4 is high, x_5 is medium, x_6 is high then y is having asthma of highly moderate stage 3.*

rule 5: *if x_1 is old, x_2 is medium, x_3 is high, x_4 is high, x_5 is high, x_6 is high then y is having asthma of highly moderate stage 3.*

rule 6: *if x_1 is old, x_2 is medium, x_3 is high, x_4 is high, x_5 is medium, x_6 is high then y is having asthma of moderate stage 2.*

rule 7: *if x_1 is old, x_2 is high, x_3 is high, x_4 is high, x_5 is medium, x_6 is high then y is having asthma of mild moderate stage 3.*

rule 8: *if x_1 is old, x_2 is high, x_3 is high, x_4 is high, x_5 is high, x_6 is high then y is having asthma of severe stage 4.*

Execute the Inference System

We use the "Root Sum Squares" (RSS) method to combine the effects of all applicable rules.

MILD= $\sqrt{\sum_{i \in Mi} (\mu_{Ri})^2} = 0$

MODERATE= $\sqrt{\sum_{i \in Mo} (\mu_{Ri})^2} = 0.72$

HIGHLY MODERATE= $\sqrt{\sum_{i \in HM} (\mu_{Ri})^2} = 0.58$

SEVERE= $\sqrt{\sum_{i \in S} (\mu_{Ri})^2} = 0.14$

Deffuzification: The last phase in the fuzzy expert is the defuzzification of the linguistic value of the output linguistic variable in to crisp values.

Output= $\frac{\sum x_i \mu_i}{\sum \mu_i} = 57.36$

Results: The crisp output is 57.36%. The crisp output belongs to the case based reasoning and discriminative analysis for diagnosing asthma (presenting the result of a prediction rate (57.36%) to evaluate asthmatic patients). The possibility of having asthma disease in stage of highly moderate.

Accuracy of Classification Methods in Diagnosing Asthma

In order to increase the accuracy of this evaluation, especially for calculating specify, the testing of non-asthmatic patients with lung disease having a high differential diagnosis of asthma is performed. This table summarizes the types of lung disease of non-asthmatic patients who participated in this study.

To enhance system validity, this system is proposed to patients to be checked by it. The criteria of ease of use, clarity of question, clarity of explanations and clarity of results are considered by physicians and patients, and have been improved to make it more efficient in diagnosing asthma.

Table 1
Results of diagnosing system for asthmatic and non-asthmatic patients

Number of Patients	Diagnosis of physician	Final diagnosis of physician
Patient 1	Allergy	Asthma
Patient 2	Cold	Asthma
Patient 3	Sinusitis	Asthma
Patient 4	Pneumonia unspecified	Pneumonia unspecified
Patient 5	Allergy	Allergy rhinitis

Method of Control

It is designed without a module of the lung function test and a response to short term drugs, in order to be applicable to patient with respiratory symptoms. The final result of this system is obtained by considering the Mamdani fuzzy inference mechanism. Fuzzy outputs of this system module is performed. The method of centroid is used for output defuzzification. The defuzzification offuzzy sets obtained by aggregating outputs modules of symptoms including allergic rhinitis, genetic factors and symptoms.This system is tested based on methods of system verification and validation. In order to increase the accuracy of this evaluation for calculating specificity the testing of non-asthmatic patients with lung disease having high differential diagnosis of asthma.

Discussion and Conclusion

Regarding the high prevalence of asthma and its consequence of mortality and morbidity, some intelligence systems have been developed to manage asthma disease. This system based on purpose of application to hospitals or primary care settings classified into these categories:

- Diagnosing or contributing to diagnosing.
- Control management and training, such as presenting a web-based asthma tool for enhancing information and awareness of asthmatic patients.
- Prediction, such as predicting the number of pediatric asthma admission, using neural network in a hospital.

The above model is a fuzzy rule-based system for analyzing the obtained results of spirometry tests, which showing the result of system evaluation by physicians. It is an expert system for the interpretation of serial peak expiratory patterns follows measurements in occupational asthma and it is presenting a sensitivity of 79% and a specificity of 97%. Further it is a computer-aided intelligent diagnostic system for bronchial asthma and that is presenting a result of 95% accuracy.

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