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A Fuzzy Expert System Model for the Determination of Coronavirus Disease Risk

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***Abstract* – Coronavirus disease, also known as COVID-19, is a novel disease that has defied the understanding of medical practitioners globally. It is very infectious and there is no known cure or vaccine. The disease which originated from Wuhan city, Hubei province, China is responsible for over 800,000 deaths globally and over 23 million confirmed infections. Infected individuals are identified by the symptoms they exhibit. Early detection is required to contain the virus and prevent fatalities. However, there is grossly limited testing kits in many countries and under-reporting of confirmed cases, thereby increasing the likelihood and threat of rapid spread of the disease. This study proposes a fuzzy expert system diagnostic model to aid early determination of infection risk using major clinical characteristics and symptoms. Relevant research findings were used to determine the fuzzy membership functions to handle the imprecision evident in this domain, as some of the symptoms are pointers to other diseases. The model was simulated with MATLAB and sample data tested. Results show that the system will be a handy decision support tool for early evaluation of people's COVID-19 health status.**

Keywords—coronavirus, COVID-19, fuzzy, expert system

I. INTRODUCTION

COVID-19 is a strain of corona virus diseases that is very infectious and has defied the understanding of medical practitioners worldwide. As a novel disease, experts globally are still studying to understand and curtail its rapid spread. The first officially documented case of the disease was on 30th December, 2019 in Wuhan city, Hubei province, China [1][2]. Wuhan city hosts a popular Huanan seafood and animal market where it is suspected that infected bats could have transmitted it to humans through intermediate hosts [3]. The Centre for Disease Control and Prevention [4] notified the public that COVID-19, which was initially named Wuhan CoV, was the cause of an outbreak of pneumonia in the Chinese city of Wuhan [2].

COVID-19 shares some similarities with two previous outbreaks in 2002 and 2012 respectively, that is, the Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV) and Middle East Respiratory Syndrome Coronavirus (MERS-CoV) [2][3]. As is the case of the current coronavirus pandemic, the past cases occurred during winter season and was suspected to have been transmitted to humans from live animals. The work of [2] showed that sequences of the new coronavirus genomes were quite similar to SARS-CoV and MERS-CoV. They noted that, while both previously known cases of coronavirus showed significant genetic distance from Wuhan CoV, MERS-CoV was more distant than SARS-CoV. Researchers are on the quest for the exact etiology of COVID-19 and to identify the causal pathogen [5].

Transmission from person-to-person became more evident when countries started isolation and testing of travellers by the airport. Research [6] shows that confirmed cases that had travelled from China to other nations were hitherto not detected, leading to global spread. When some persons were tested positive, other co-travellers were identified and encouraged to stay in self-isolation; some of them also turned out to be positive during the isolation period. Experts have, therefore, advised countries to enforce travel restrictions to limit the spread of the virus [1][3][6]. However, in their findings, [6] reported that travel restrictions would only be effective when combined with changes of individual behaviours and 'public health interventions'. There is evidence that travel limitations, especially through the airport, can help mitigate the spread of the disease [3][6].

There is no known cure for this disease, but it can be managed using different methods [3]. Early detection, quarantine of confirmed cases, sensitization of the citizenry, maintaining social distances, travel restrictions, changes in behaviour, adopting proper hygiene, frequent washing of hands with soap and water, or the use of alcohol-based hand sanitizers, and the use of face mask has been recommended by experts to curtail the spread of COVID-19 [1][3][6]. The research shows that the virus can be contacted from contaminated surface and transferred to the mouth or eyes or by inhaling droplets.

Although the about 58 million inhabitants of Hubei province of China have recovered from the ravaging virus, other countries are still terrified and battling to curtail the coronavirus disease. There are over five million confirmed cases of coronavirus disease in 216 countries with over 800,000 deaths recorded as at 23rd August 2020 [7]. Americas and European continents are mostly hit with Americas alone having over 12 million confirmed cases. Africa has almost 1 million confirmed cases with infections rising geometrically every day. Since the first confirmed case in Nigeria on the 27th February 2020, there has been about 997 deaths from about 51,905 infected [8]. It is noteworthy that these figures change often on a daily basis, and many cases are unreported.

Singhal [3] cautions that limited testing kits and lack of effective monitoring of the population could lead to under-reporting of COVID-19 cases. Out of about 200 million Nigerians, less than 400,000 samples have been tested [8]. It is noteworthy that Governments may play down the number

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of confirmed cases to avoid stirring tension and fear among the populace. In Africa, and Nigeria in particular, the gross inadequacy of testing kits, civil disobedience to government directive to maintain social distancing, as well as the complicity of security outfits in enforcing these directives are suspected factors that has resulted in the sporadic increase of confirmed cases of coronavirus disease in countries like Nigeria. Hospitals and health workers are overwhelmed, economies of nations are heading for a collapse as unemployment looms high due to the stay-at-home order. Educational institutions are closed and students are forced to abruptly suspend their education or school from home. Most countries declared a lockdown, where everyone is to stay at home and avoid social gatherings so as to curtail the spread of the virus. This study proposes a fuzzy expert system for the early detection of COVID-19 due to the very contagious nature of the disease, gross dearth of testing kits, absence of recognised treatment, and confusable nature of the symptoms. Fuzzy logic handles uncertainty and reliably supports medical expert in disease prognosis.

The rest of the paper are organised as follows. Section II provides a theoretical framework for the study; Section III discusses some related works in literature. Section IV discusses the material and methods deployed in the study. Section V discusses results obtained from simulations performed and Section VI concludes with some findings from the study.

II. THEORETICAL BACKGROUND

Globally, there are frantic efforts to understand this new strain of coronavirus. Infected individuals have exhibited various symptoms. There are asymptomatic patients who are infected with the virus but do not exhibit any symptoms. Hence, experts have advised that people who come in contact with confirmed cases should proceed on self-isolation for a period of 2 to 14 days [4][5]. It is believed that symptoms of the disease should become evident, if present.

The symptoms observed in confirmed COVID-19 cases include; fever, cough, difficulty in breathing, sore throat, headache, fatigue, and sputum production. In severe cases of the disease, patients experience pain or pressure in their chest, dyspnoea, diarrhoea, haemoptysis, lymphopenia, or confusion [3][4][9]. Severe cases progressed into pneumonia, and multi organ dysfunction [3].

Notably, some other factors can increase the possibility and fatality of infection. Such factors, which need to be considered for enhanced diagnosis, include pre-existing health issues or comorbidities leading to compromised immune system, rate of virus mutation, and age of the individual [2]. Fatality rate is higher among elderly persons of 75 years and above as well as those with other immune compromising conditions such as lung infections, Acute Respiratory Distress Syndrome (ARDS), diabetes and cardiovascular diseases [3][4].

Prevention is the only remedy to this pandemic, as there is currently no globally approved treatment protocol [1]. Singhal [3] identified reasons why prevention may be difficult to include; transmissibility of the disease from asymptomatic patients, confusable clinical features, as well as the rather long period before the manifestation of the disease, amongst others. Medical experts, as well as individuals, can use an expert system as a decision support to determine if the individual under consideration might be infected. Early detection of the disease will help recovery and reduce fatality.

Several of the clinical features of COVID-19 are confusable with other diseases especially respiratory diseases, conjunctivitis and pneumonia [1][3]. This uncertainty in clinical features is tackled in this study using fuzzy logic.

III. LITERATURE REVIEW

An expert system is designed to solve problems like a human who is skilled in a specific area. The knowledge, experience, and problem-solving procedure of the domain expert is encoded into the system. An expert system may consider the knowledge of several experts and their approach to resolving issues. A fuzzy expert system has shown to be effective in solving real world problems that may have incomplete information, uncertainty, and imprecision [10][11][12][13][14][15].

A fuzzy expert system was developed in [15] to diagnose a type of skin disease known as Psoriasis. The study applied symptoms of the disease to define its membership function (MF) and used fuzzy rules to classify levels of infections. A system to predict levels of depression risks using fuzzy logic was developed by [11]. The prediction was based on medical experts' recommended parameters using fuzzy rules for inferencing.

Fuzzy logic has integrated well with other Artificial Intelligence techniques. A hybridization of Fuzzy logic and Artificial Neural Network (ANN) was used to develop a case-based expert system in diagnosing depression [16]. The study has its fuzzy MF determined based on learned information. Also, a hybrid system, comprising Fuzzy logic and Genetic algorithm, was designed for diagnosing hormonal imbalance [17]. The system tackled imprecision in medical cases where certain symptoms of one disease is also applicable in another medical condition.

Besides the medical field, fuzzy logic has also produced acceptable results in other domains [14][18][19].

IV. MATERIALS AND METHOD

The fuzzy system components include the fuzzifier, the inference engine, and the defuzzifier as shown in Fig. 1. This system is discussed hereunder.

A. Fuzzification

User input to the system is in crisp form. The fuzzification process converts these inputs into fuzzy representation based on the MF defined for the fuzzy set, which associates a degree of membership of the elements to the fuzzy set. The resultant numeric values must be between 0 and 1. The most commonly used fuzzy MFs in fuzzy systems include triangular, trapezoidal, and gaussian. The expert defines the MF that best suits the dataset [18]. The triangular MF is mostly used due to its simplicity in implementation and the desirable results it produces [16][19][20]. The general form of the triangular MF shown in (1) is defined by Fig. 2.

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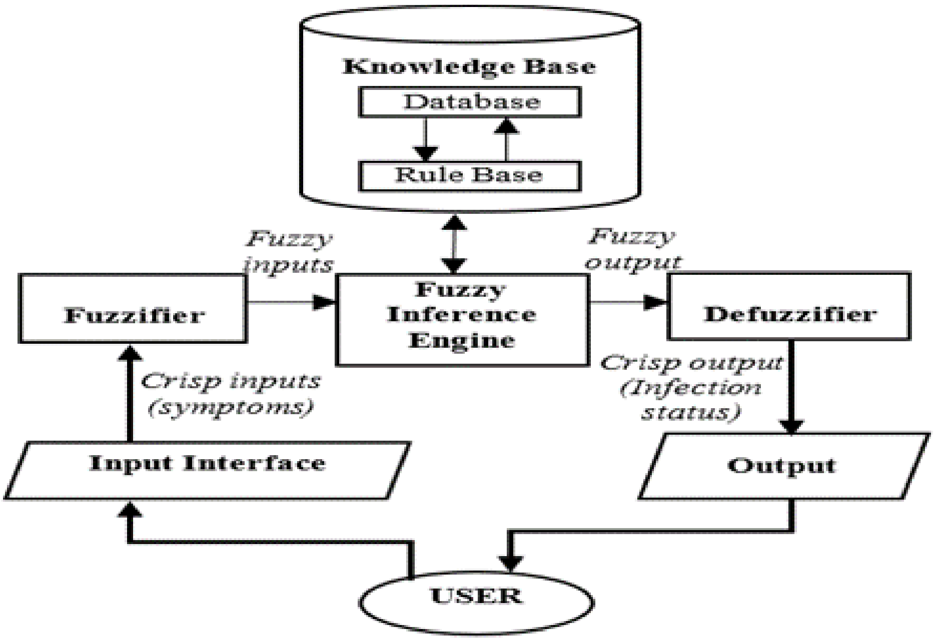

Fig. 1. Architecture of the Fuzzy Expert System

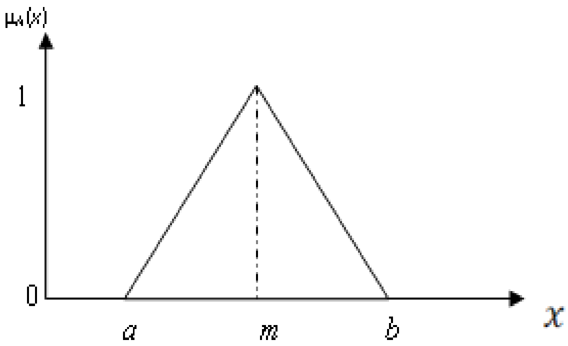

Fig. 2. Triangular Membership Function

$$\mu_A x = \begin{cases} 0 & if\ x \leq a \\ \frac{x-a}{m-a} & if\ a < x \leq m \\ \frac{b-x}{b-m} & if\ m < x < b \\ 0 & if\ x \geq b \end{cases} \qquad (1)$$

B. Fuzzy Inference Engine

The fuzzy outputs from the fuzzifier is fed into the fuzzy inference engine, which applies the predefined rules in the knowledge base to the fuzzy data. It is possible for several rules to be fired at the same time, requiring the inference engine to calculate the fuzzy output. We adopt the max method for inferencing. The inference engine consisted of a reasoning algorithm driven by fuzzy rules based on Mamdani's Inference method. Built-in methods supported by MATLAB are maximum (max), probabilistic OR (probor), and sum of the rule outputs [21].

C. Knowledge base

The knowledge base is the component that comprises the database and the rule base. The database contains knowledge from medical domain experts. In this case, the prevalent symptoms and clinical features of COVID-19 are stored in the database. The rule base defines the applicable rules in determining the consequents for various conditions/antecedents. These IF-THEN fuzzy rules are stated by domain experts in the form:

IF *antecedent(s)* THEN *consequent(s)*

Notably, the rule(s) that meets the stated antecedent gets fired. It is possible for more than one rule to be fired depending on their firing strength [12].

D. Defuzzification

Defuzzifier handles the conversion of the fuzzy output from the inference engine to a crisp value which is required by most real-life applications. Commonly used methods of defuzzification include Center-of-Gravity (CoG), mean-of-maxima, and max-criterions. The CoG, also called centroid, is widely used [17][22] since it calculates average and it is considered more accurate in representing fuzzy sets irrespective of the shape [20]. Equation 2 shows the formula for calculating the defuzzification process for discrete domain as used by [11].

$$\mathrm{CoG}(a_i) = \frac{\sum_{i=1}^{n} \mu_{a_i}(x)\, x_i}{\sum_{i=1}^{n} \mu_{a_i}(x)} \qquad (2)$$

Given x_i as the centre of the MF and μ_{a_i} as the membership value for $i = 1, 2, \ldots n$.

E. Research Experiment

Linguistic variables often used by domain experts to describe diseases such as COVID-19 was used for this research. The degree of membership of each linguistic term for the symptoms is presented in (3).

$$Symptoms(x) = \begin{cases} Absent & if\ x \leq 0.1 \\ Mild & if\ 0.1\ \leq x\ < 0.3 \\ Moderate & if\ 0.3 \leq x\ \leq 0.6 \\ Severe & if\ x > 0.6 \end{cases} \quad (3)$$

Other parameters that aid accurate diagnosis of the disease include the age of the patient and travel history within the last 14 days, hence their inclusion in this expert system. Recent studies have shown that elderly persons with a mean age above 54 years dominated the cases of infected individuals [23][24]. Also, travel history to infected communities, regions, or countries indicated a red-flag for medical experts when attending to patients [6]. The linguistic variables for age and travel history are shown in Table 1 and the trapezoidal MFs for representing their degree of membership are shown in Fig. 3 and 4 respectively.

Table 1: Clinical characteristics for COVID-19 diagnosis

S/N	Clinical Characteristics	Linguistic Variables	Value Range
1.	Age (years)	Very Young	$x\ \leq 12$
		Young	$12\ < x\ < 30$
		Adult	$30\ \leq x\ \leq 50$
		Elder	$x\ > 50$
2.	Travel History (to areas affected by COVID-19 within the past 14 days.)	Never	$x\ < 1$
		Rarely	$1\ < x\ \leq 5$
		Frequently	$x\ > 5$

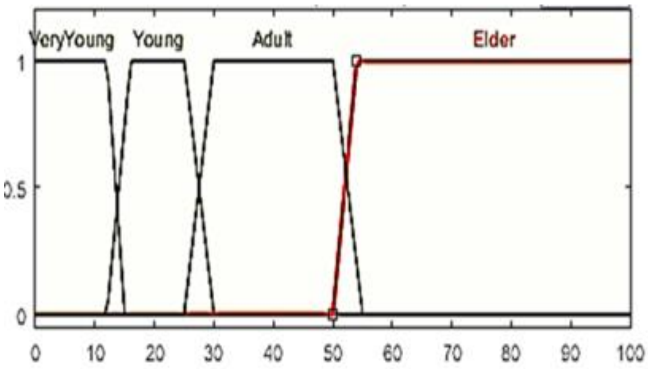

Fig. 3. Input Trapezoidal Membership Function for Age

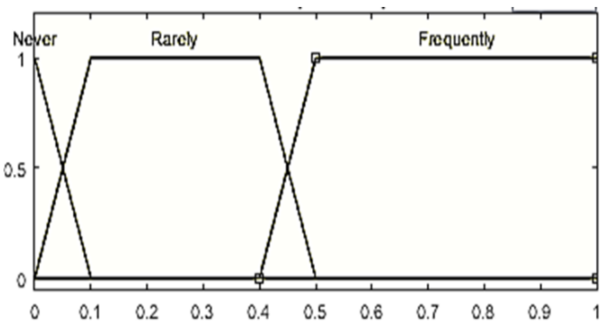

Fig. 4. Input Trapezoidal Membership Function for Travel History

F. Fuzzy Rules

The MATLAB Rule editor given in Fig. 5 helps to add, change and delete the rules in. The rules were developed based on advice from medical Doctors and from literature. While some of the symptoms may indicate other diseases, this fuzzy expert system handles this uncertainty.

Research by [23] report that 90% of patients exhibited more than one symptom. The presence of some symptoms such as pneumonia, fever, and cough have been reported as indicators of severe cases [9][23]. The case of patients worsens if there is presence of immune-compromising comorbidities. Comorbidities, which is the presence of more than one disease/condition affecting an individual, was observed in almost all patients with severe cases of coronavirus disease. Mortality rate was higher among such patients, because of their low immunity. COVID-19 could cause complications such as ARDS and acute myocardial injury [25]. It is reported that the age of a person could determine the incubation period before the symptoms become obvious [25]. The fuzzy rules applied in this design is derived from research and medical Doctors and is based on Mamdani's inference mechanism.

V. RESULT AND DISCUSSION

This study considers research findings from experts managing COVID-19 patients. In selecting the shape of the output MF, this study is guided by reports from independent experiments [9][23][24][26]. While the choice of MF is often subjectively determined by experts, this research adopts the integrated/combined weighting method [27] in ranking the symptoms from medical experts as shown in Table 2. The integrated weighting approach considers the subjective judgement of medical experts while applying objective mathematical models based on available information.

The clinical characteristics, which comprises of major identified symptoms of coronavirus disease, are ranked according to the mean value of confirmed cases for each feature. Thereafter, weight is assigned, where the highest-ranking feature corresponds with the highest weight. The rank sum [27] is calculated with (4), and normalised to give the output MF points as shown in Fig. 6.

$$Rank\ Sum = \frac{n - p_i + 1}{\sum_{i=1}^{n} n - p_i + 1} \quad (4)$$

where p_i indicates the rank of clinical features for i = 1, 2, 3, .. n

The studies used for this research had various sample sizes of patients they examined, but all had the representative percentage of the symptoms in common. Hence, Table 2 is populated with percentages of infected patients for each study as indicated.

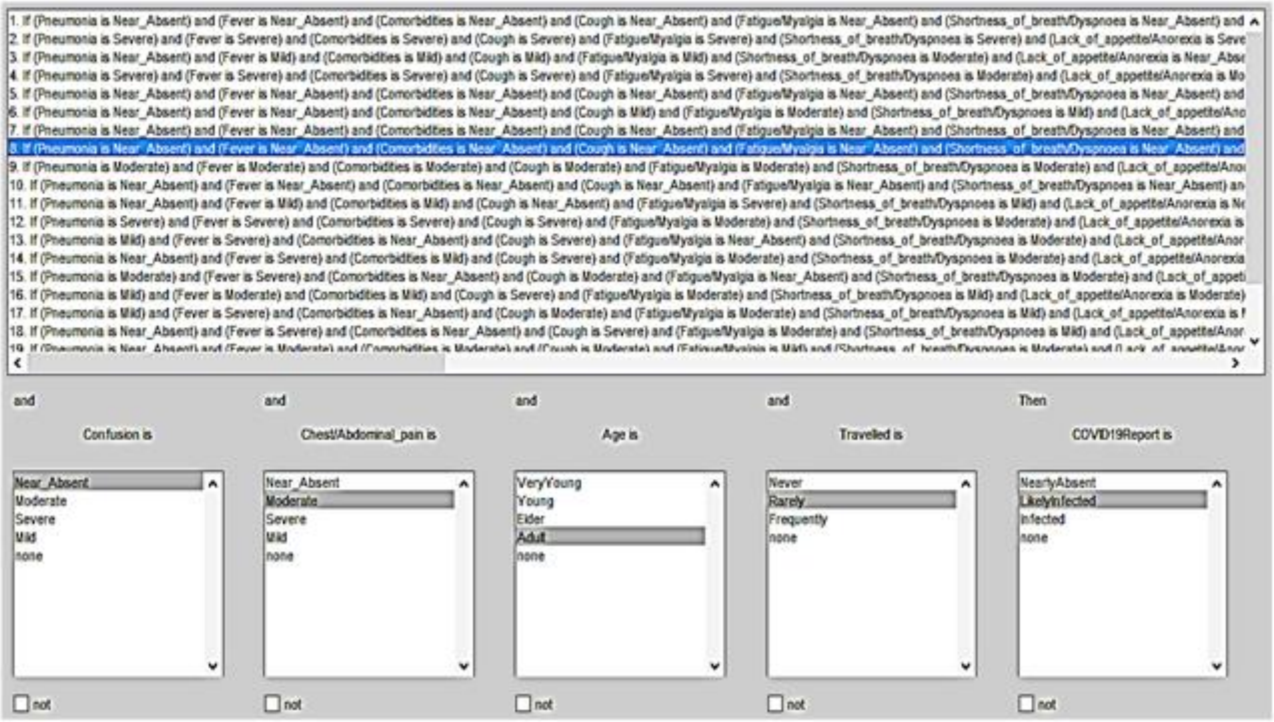

Fig. 5. MATLAB Rule Editor

Table 2: COVID-19 Clinical Characteristics and Output MF

Clinical Characteristics and Symptoms	Reported Studies (%)				Mean	Rank	Weight	Rank Sum	Output MF
	Chen et al (2020)	Mao et al (2020)	Wang et al (2020)	Huang et al (2020)					
Pneumonia	100.00	-	-	100.00	100.00	1	14	0.13	**1.30**
Fever	83.00	61.70	98.60	98.00	85.33	2	13	0.12	**1.20**
Comorbidities (Hypertension, Diabetes, Cardiac, Malignancy, or ARDS)	66.00	92.50	78.20	88.00	81.18	3	12	0.11	**1.10**
Cough	82.00	50.00	59.40	76.00	66.85	4	11	0.10	**1.00**
Fatigue/Muscle Ache/Myalgia	11.00	-	69.60	44.00	41.53	5	10	0.10	**1.00**
Shortness of breath (Dyspnoea)	31.00	-	31.20	55.00	39.07	6	9	0.09	**0.90**
Lack of appetite (Anorexia)	-	31.80	39.90	-	35.85	7	8	0.08	**0.80**
Expectoration/Sputum production/ Rhinorrhoea	4.00	-	26.80	28.00	19.60	8	7	0.07	**0.70**
Dizziness	-	16.80	9.40	-	13.10	9	6	0.06	**0.60**
Sore throat (Pharyngalgia)	5.00	14.50	17.40	-	12.30	10	5	0.05	**0.50**
Headache	8.00	13.10	6.50	8.00	8.90	11	4	0.04	**0.40**
Diarrhoea	2.00	19.20	10.10	3.00	8.58	12	3	0.03	**0.30**
Confusion	9.00	7.50	-	-	8.25	13	2	0.02	**0.20**
Chest/Abdominal pain	2.00	4.70	2.20	-	2.97	14	1	0.01	**0.10**
							105	1.00	

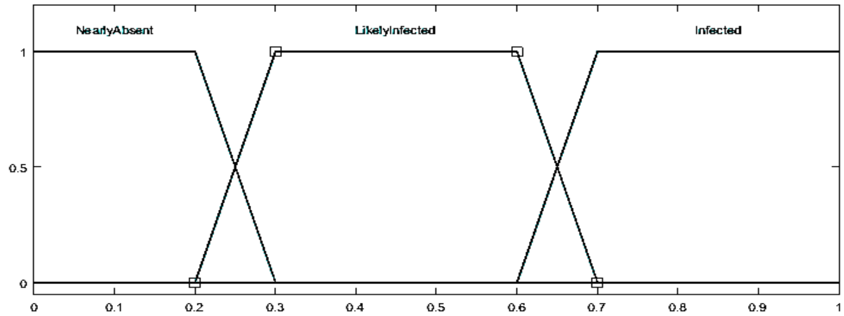

Fig. 6. Output Trapezoidal Membership Function for COVID-19 Diagnosis

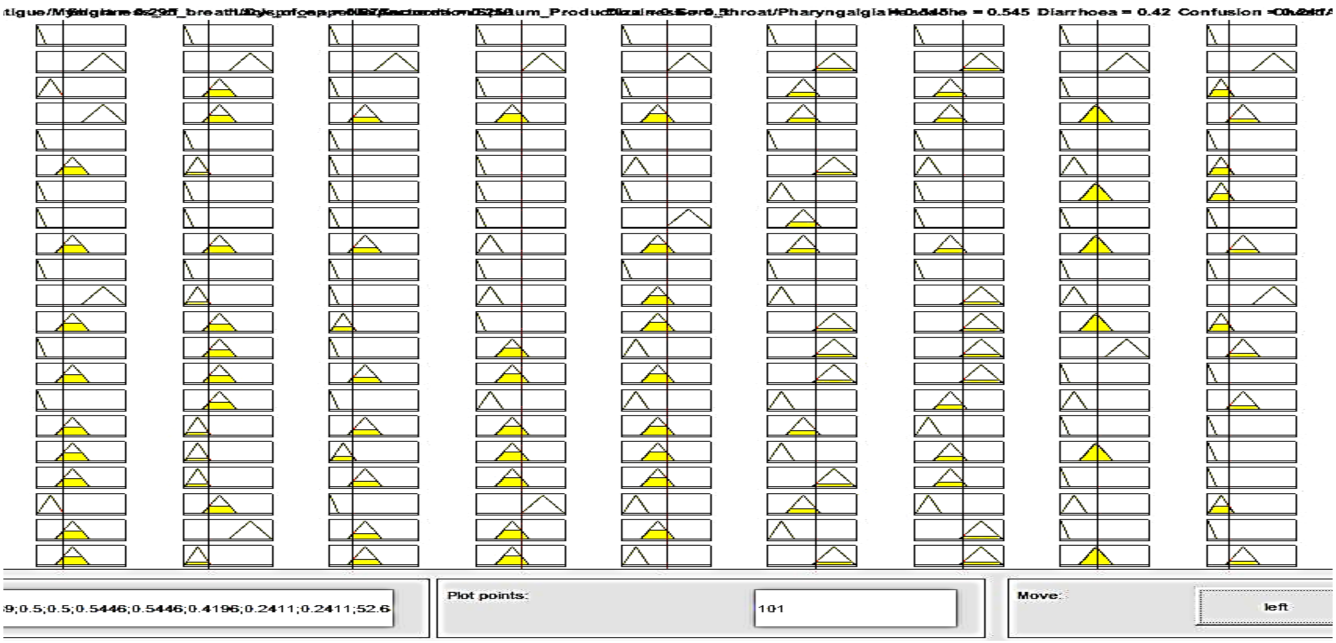

Fig. 7. MATLAB simulation of FES model

The fuzzy expert system was developed and simulated using Fuzzy Logic Toolbox (FLT) in Matrix Laboratory (MATLAB) R2015a. MATLAB provides a graphical user interface and coding window for designing robust applications, data visualisation, and design simulation. MATLAB is the mostly used tool for developing fuzzy inference systems [28]. The FES is designed to determine the risk of COVID-19 by using the fuzzy rule viewer as shown in Fig. 7. It consists of 16 inputs and one output. The inputs consist of clinical symptoms in Table 2, age, and travel history, while the output is the risk of COVID-19 (%). Linguistic variables; *Absent*, *Mild*, *Moderate* and *Severe* are used for the input while *Nearly Absent*, *Likely Infected*, and *Infected* are used for the output.

VI. CONCLUSION

The developed FES is appropriate as a decision support tool to assist COVID-19 physicians and other health workers provide early evaluation of individuals' COVID-19 health status. This is because FES can simulate an expert Doctor's behaviour in order to determine the risk level of the disease. For future work, using more periodic clinical sample data would enhance the diagnostic ability of the system as it will validate the results of the risk factors for COVID-19 patients.

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