Intelligent Network for Proactive Detection of COVID-19 Disease

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***Abstract*— This is a proposal for an automated detection and remote monitoring system made up of a centralized network of communicating portable electronic devices based on biomedical sensors operating in the IoT context in synergy with wireless sensor network technologies, telemedicine and artificial intelligence. This network will be deployed to monitor a population settling in a target area (cities, region, country, etc.). The goal of this system is the detection and early diagnosis of the disease in people infected with the COVID-19 virus, using a device (such as a bracelet or a chest strap). This device collects in real time all the necessary biomedical measurements of a person, including their location, freeing them from any hospitalization or use of complex and expensive equipment. These informations are then transmitted, via a wireless connection, to a regional or national control center which takes care of its storage in a specialized database. This center executes a decision-making algorithm using artificial intelligence and fuzzy inference engine to detect accurately each possible abnormal change in the supervised biomedical signs reflecting risk factor or indicating the appearance of symptoms characterizing COVID-19 disease. In the positive case, the control system triggers a warning alarm concerning this infected person and requests intervention of the competent authorities to take the necessary measures and actions. Computer simulations with Matlab software tool have been conducted to evaluate the performance of the proposed system. Study findings show that the designed device is suitable for application in COVID-19 patient monitoring.**

Keywords— COVID-19 disease, monitoring, E-health, artificial intelligence, Embedded system, IoT, E-diagnosis, Decision algorithm, Fuzzy logic, Arduino, Wireless network

I. Introduction

This subject is in keeping with the critical and unparalleled circumstances facing the whole world and our country caused by the remarkable and rapid proliferation of COVID-19 declared as a pandemic of global scope by the World Organization for Health (WHO). The latter urged government authorities to take preventive directives, measures and recommendations aimed at fighting this pandemic. However, these procedures remain limited to fight effectively against this fatal disease especially given the long time taken for radiological and biological analyzes to confirm a suspected case. In this regard, some researchers have proposed techniques for monitoring infected people based on their geolocation maps extracted from the mobile networks to which their smartphones are connected. This is done in order not to share with these patients any locations they have visited, the objects they have touched and the paths they have taken. Other researchers have proposed applications on smartphones using Bluetooth wireless technology to ensure social separation between infected and uninfected people. Indeed, the Moroccan authorities have developed a free application «Wiqaytna», to be downloaded from Google play or Apple store, makes it possible to follow contacts of people positive for the coronavirus in order to fight effectively against the spread of the virus [1], [2]. In fact, the notifications sent by «Wiqaytna» will allow rapid treatment of the infected person. This will help avoid complications and thus relieve the health system, but also limit contamination and therefore, reduce the circulation of the virus. It saves lives. Moreover, some researchers have leaned towards development of Artificial Intelligence audio smartphone application to aid in the early detection of COVID-19 from an accurate discrimination between coughs of a potentially infected patient, and a normal cough. This allows reducing the time required for diagnosis of COVID-19. Furthermore, other researchers have used Deep Learning techniques to classify suspected cases based on COVID-19 X-Ray and CT Chest Images Dataset.

However, the first drawback of these techniques is that they are based on the assumption that the person being monitored has a smartphone terminal connected to the internet and activating the GPS service. In addition, the second disadvantage is that the technique will only focus on the location of this person when it will be declared by the health authorities as being infected by the virus and during this period the contamination risks increase greatly because this person remains out of control in front of an epidemic which spreads at a faster speed which follows an exponential law. Thirdly, note that infection with this disease is not always accompanied by dry cough because clinical medical studies have shown that there is a group of infected people who do not show symptoms of the disease. Figure 1 shows an estimation of coronavirus COVID-19 epidemic evaluation in Africa using SIR model. We observe that the trajectory of the COVID-19 pandemic begins with a phase of regular growth passing through a peak then ends with a final phase of gradual disappearance. Whereas, statistics of COVID-19 pandemic in

Morocco proves an alarming increase in the number of people infected by this disease.

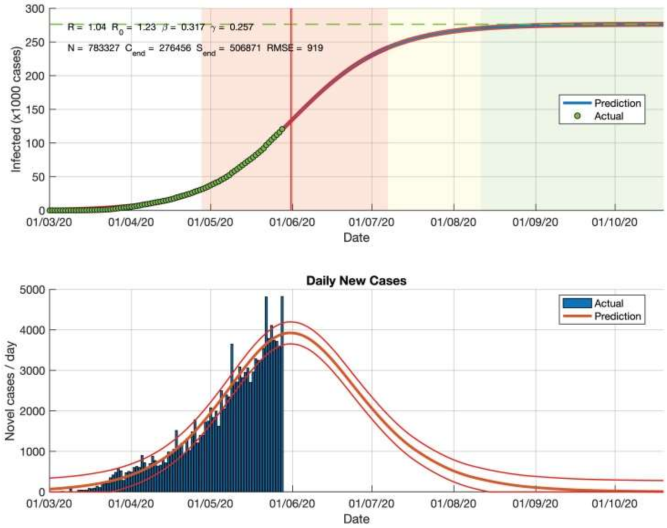

Fig. 1. Predicted and actual cases of COVID-19 based on the SIR model as of 28 May 2020 in Africa

Hence, there is an urgent need for a match between precautionary measures, examination, follow-up and the search for other techniques to allow the flattening of COVID-19 infection curve as shown in figure 2.

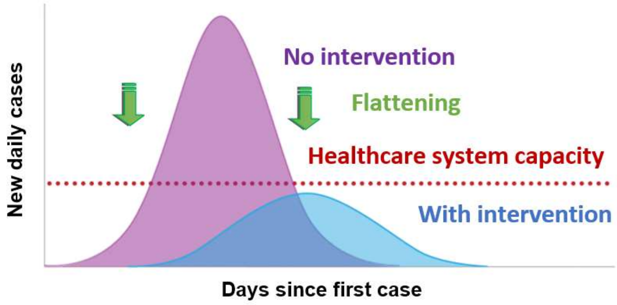

Fig. 2. Theoretical evolutions of an epidemic depending on the implementation, or not, of preventive measures

All in the absence of a medication or a vaccine that will permanently eliminate the virus which does not give us enough time to react when it contaminates our bodies. Certainly, this contribution is a challenge that responds to calls launched by governments, scientific organizations in order to propose and to develop solutions, tools and methods based on research work allowing not only to minimize any danger associated to this virus spread but also stop its span. The contribution of this proposal concerns the procedural side and not the therapeutic one, because it makes it possible to surround and reduce the rate of the virus spread.

II. PROPOSED MONITORING SYSTEM AND NETWORK

The contribution of this proposal concerns the procedural side and not the therapeutic one, because it makes it possible to surround and reduce the rate of the virus spread. The suggested supervision system is a remote-control system made up of a centralized network of communicating and portable electronic devices equipped with sensors. These sensors are IoT enabled in synergy with data mining and artificial intelligence applied in telemedicine (E-health). Figure 3 illustrates the monitoring and control system architecture.

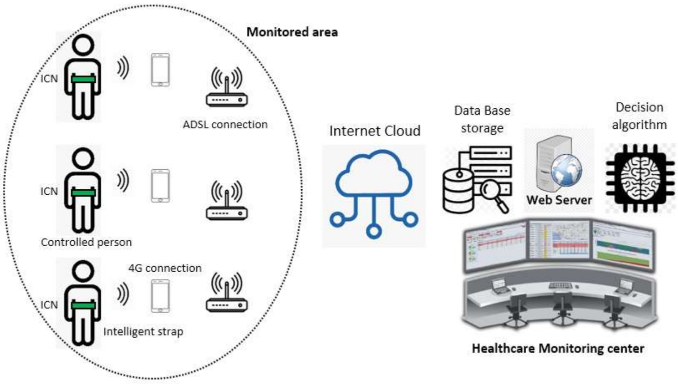

Fig. 3. Block diagram of the proposed monitoring system

This system consists mainly of the following parts:

1) Sensors for collecting the necessary biomedical measurements;
2) Processing unit board which is an Arduino board;
3) Wireless communication module;
4) Remote monitoring center containing a server which manages a database (Big Data) and an intelligent decision-making algorithm;
5) Power source: battery;

This network will be deployed to monitor a population settling in a target area (cities, regions, countries, etc.). The objective of this system lies in the detection and early diagnosis of the disease in people infected with the COVID-19 virus using a device presented (in the form of a bracelet or strap) which will be distributed by local authorities and which will imperatively be worn by every citizen over the age of 14 years old (by law such as the protective mask) throughout the period of health emergencies. The following figure describes the components of the system.

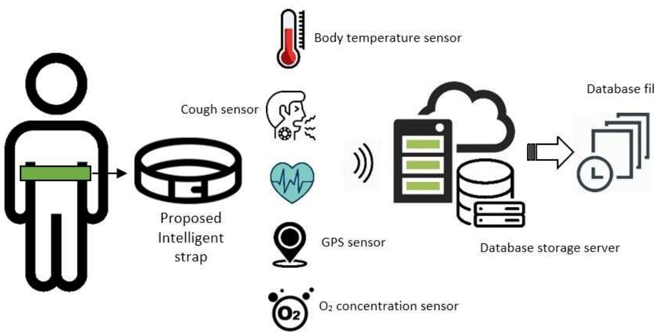

Fig. 4. Proposed healthcare control system architecture

The position of the electronic strap on the human chest is chosen carefully because this location offers a sampling of biomedical measurements with more precision compared to the other positions especially the sound acquisition by the mini microphone implemented on the Arduino Nano 33 BLE Sense board (which will be closer to the mouth which is the source of the cough) and the measurement of body temperature [3-6]. This healthcare application needs to acquire different types of sensor data [7]. This sensitive and valuable data must be collected in a precise and timely manner to avoid any possible loss in their transmission to the cloud database. Besides, the proposed system has other advantages. It is also used to remotely monitor the health state of the heart system of COVID-19 patients who follow the therapeutic protocol (Chloroquine, Azithromycin) knowing that these drugs cause sometimes undesirable side effects. This allows on the one hand, minimizing the infection risk for the medical staff who will be in direct contact with these patients. On the other hand, this system offers the possibility of following these patients to their homes if their condition is not serious or critical and does not require resuscitation or artificial respiration. This frees up their hospital spaces for others with higher priority. Faced with the situation of total saturation of hospitals, the use of this system constitutes a good alternative. In addition, this system remains an effective and usable telemedicine tool even after the period of COVID-19, because it facilitates (by adding a few features) the follow-up and medical control of patients (who are in far and difficult rural areas.) with chronic diseases such as diabetes, cardiovascular diseases, diseases of high blood pressure. This intelligent device collects in real time all necessary biomedical measurements of a person, including their location, freeing them from hospitalization and the use of complex and expensive equipment. Each person will be recognized by the device and surveillance system through their national identity card number (ICN). The device transmits these informations via a wireless connection (using a gateway or an access point: Wi-Fi router or smart terminal offering a 4G internet connection) to regional or national control center. This latter takes care, via a server (local, Big DATA or Cloud) using Wi-Fi module connected to internet, of the reception of all these data, their management and their display (periodic storage of these data in a specialized database as a daily files form). The data were sent to a PHP script with GET method which were then translated onto the Web Page as values, graphs and status conditions. The design diagram of this device is given in the following figure 5. In fact, the sensors are interconnected with an Arduino Nano 33 BLE Sense board combined to ESP8266 Wi-Fi module forming a miniature electronic circuit which facilitates wearing and portability of the suggested strap.

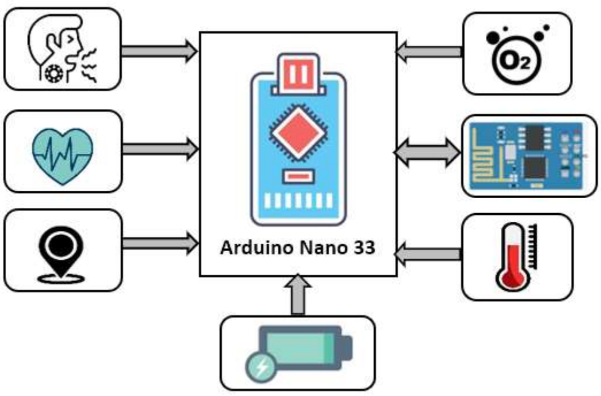

Fig. 5. Functional diagram of proposed strap

Furthermore, collected data is accessed either through internet using Web browser or either mobile application. Indeed, this device offers the possibility of connecting a smartphone to display collected data on its screen as shown in figure 6.

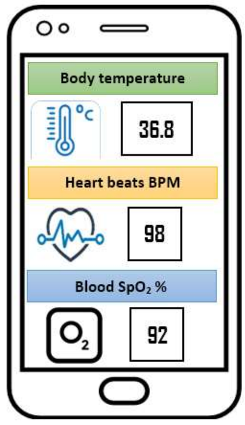

Fig. 6. Screen of mobile application

In addition, the supervision center displays the collected and saved measurements for each person on an interface as evolution curves form. It also processes them by running a decision-making algorithm using artificial intelligence (artificial neural networks, machine learning algorithms for real-time classification, and fuzzy inference engine for decision-making) to detect and recognizes in a precise manner each possible abnormal change in the supervised quantities reflecting risk factors or indicating the appearance of symptoms characterizing the COVID-19 disease. In this case, the control system triggers a warning alarm concerning this person and requests the intervention of the competent authorities to take the necessary measures and intervention actions (examination of the patient at home using the SaO_2 sensor for confirmation of his state of illness at the basis of which he will be hospitalized). The sensors used by the proposed device are comply with the medical diagnosis of COVID-19 disease symptoms which were determined by WHO [8-14]. The electronic device to be designed consists of the following units: Arduino Nano 33 BLE Sense, Body temperature sensor (Taidacent MAX30205MTA [4]), GPS location sensor, Heart rate variability sensor (MAX30102 pulse oximeter and heart-rate sensor), Radio frequency communication module (Wi-Fi module ESP8266-ESP-01) and Cough sensor which is made by a cough detection system on Arduino Nano BLE Sense using TinyML to sense the presence of coughing in real-time audio. To build accurately a cough training model, we have employed Impulse Edge platform using Machine Learning [5].

III. FUZZY DECISION ALGORITHM FOR COVID-19 DIAGNOSIS

In healthcare monitoring, we must consider the relationship between its input signals and its status indications. In most diseases, which have predictable symptoms or specific signs during their development, detection and interpretation, only by simple sensors are required. Contrariwise, the classification and diagnosis of the state of such illness and the determination of the severity evolution of its possible symptoms from its input signals are not an easy task, because they are affected by many factors. In front of this situation, the recourse to the computerized systems using artificial intelligence that mimicking human intelligence is necessary. They can indicate the precise health state of the patient by putting different probabilities of radical causes resulting observed symptoms. They allowing also making diagnoses and taking swift and consistent decisions. However, this requires a certain amount of knowledge and expertise on the relationship between the patient health condition and its illness symptoms. The application of fuzzy logic offers a very significant flexibility in making decision compared to other methods. This logic allows reasoning from inaccurate input data to generate output results approximately or gradually uncertain [17], [18]. The use of this technique in our proposed diagnosis approach decision-making of COVID-19 detection is justified by the difficulty to make an explicit mathematical model or an analytical formulation of the decision especially when a large number of inputs are used. So, it is possible to use an empirical model based on rules derived from human expertise in telemedicine and cardiology which can be incorporated. Determinant informations can be exploited using fuzzy inference systems FIS to increase confidence and accuracy of diagnosis results. The proposed diagnosis approach combines two techniques: intelligent cough detection and fuzzy classification of biomedical measurements. It contains multiple steps that must be executed to reach the final decision of diagnosis as shown in figure 7.

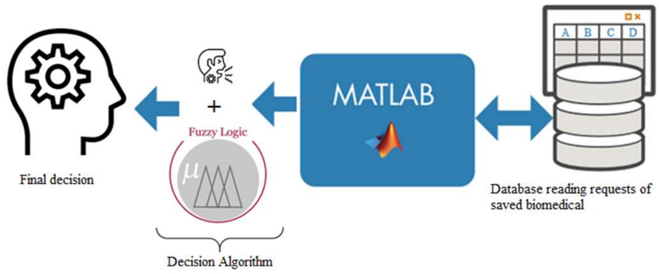

Fig. 7. Steps of final diagnosis decision

Initially, collecting, acquisition and storage of the different sensor signals is carried out. Afterward, intelligent cough detection is applied to recognize the percentage of cough quantification. From the stored data in the cloud database and by connecting MySQL database to Matlab using Database toolbox, knowledge is retrieved by matching the symptoms and their severity against the antecedent part of fuzzy rules.

IV. FUZZY INFERENCE SYSTEM

To evaluate the performance satisfaction of the proposed medical diagnosis system, intelligent decision algorithm has been simulated with Matlab Fuzzy Logic toolbox. The employed FIS uses four inputs and generates a single output each having three different membership levels. The input variables considered are cough percentage, blood oxygen (SpO_2), body temperature, heart rate. Membership values are assigned to the linguistic variables such as symptoms. Whereas, the output variable Risk-alarm shows the percentage of risk for the COVID-19 disease detection following to the measured values of input parameters reflecting COVID-19 symptoms quantification. On figure 8, a detailed architecture description of this system is presented with Matlab software.

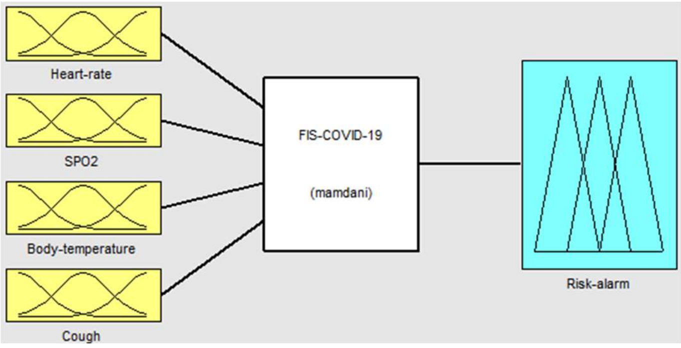

Fig. 8. Fuzzy inference system architecture

Moreover, in table I, the parameters and the methods used in this fuzzy inference system are illustrated. The selection of the trapezoidal membership functions for the fuzzy input variables is made by respecting the medicine expert doctors' instructions based on their statistical studies realized practically. This choice is also justified by the adaptation of these functions to the real numerical values needed in diagnosis, in addition to their simplicity and their calculation rapidity of the membership value.

TABLE I. FIS PARAMETERS

Parameter	Value
Fuzzy rules type	Mamdani
Input number	4
Output number	1
Rules number	63
AND Method	Min
OR Method	Max
Implication Method	Min
Aggregation Method	Max
Defuzzification Method	Centroïde

Figure 9, illustrates one input membership functions of the health parameters: Heart rate.

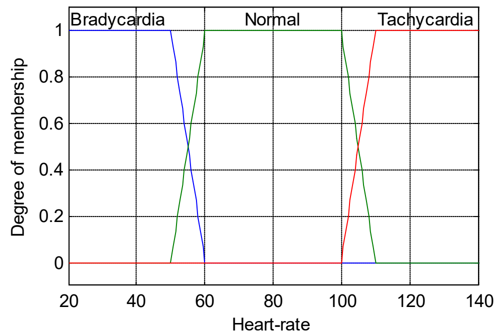

Fig. 9. Membership functions of the input1 fuzzy set

The selection of the following membership functions positions and theirs overlaps must respect certain rules to avoid indeterminate or dead zones and to avert problems of the controller instability or the flattening of the decision

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surface.

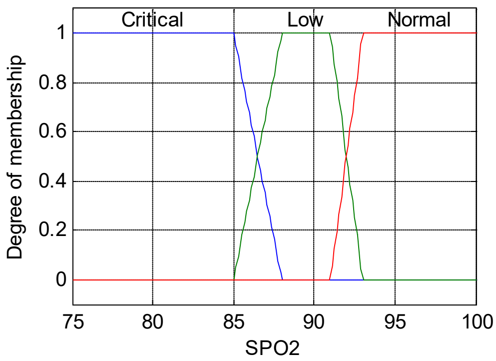

Fig. 10. Membership functions of the input2 fuzzy set

Hypoxemia can present due to impaired respiratory functions caused by COVID-19 viral load. Some patients do not necessarily have impaired oxygenation functions at the onset of infection but may manifest rapid deterioration in oxygenation over time. Therefore, continual monitoring of oxygen saturation is recommended. Oxygen therapy is not necessary for patients with oxygen saturation (SpO_2) of more than 93% or for patients without obvious symptoms of respiratory distress. However, when oxygen saturation (SpO_2) drops below 88%, this gives an indication of pulmonary respiratory failure [15], [16]. The membership functions for body temperature are shown in Figure 11.

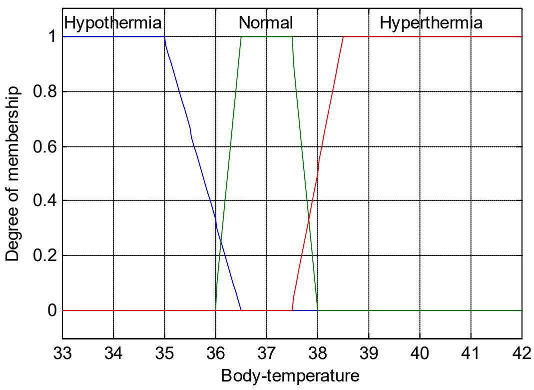

Fig. 11. Membership functions of the input3 fuzzy set

The initial presentation of the fever in COVID-19 in the first week, during the viral phase of this illness, is likely a manifestation of the body's immune response to the viral replication to augment immunity. However, if the viral infection does not resolve in due course, the disease process is complicated by the viral triggered state of dysregulated inflammation described as cytokine storm heralded by unremitting fever. Body temperature remains a relevant indicator of changes in COVID-19 viral load in a patient's body. Normal body temperature is 37°C but it may vary during the daytime, so a range between 36.5°C and 37.5°C is considered as normal body temperature. Figure 12 presents the membership functions of patient's cough.

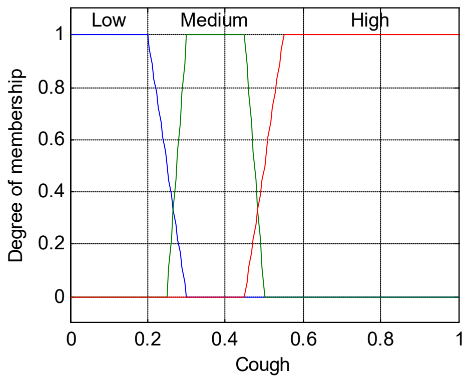

Fig. 12. Membership functions of the input4 fuzzy set

Coughing is a defining symptom of COVID-19. It is also a factor that determines transmission risk because the patient can spread infectious droplets to people around him, usually 5-10 days after being infected.

V. FUZZY RULES AND SYSTEM OUTPUT

In this smart system, more than sixty fuzzy rules IF-THEN relating to symptoms of COVID-19 disease are formed. The rules are formulated using Matlab Fuzzy Toolbox editor. In fact, the output from the FIS is used to detect if the risk detection of COVID-19 is Low, Medium or High with, a well-quantified percentage, based on the submitted input parameters values. Depending on this fuzzy output, the actions and alerts are generated to alert the competent authorities and medical specialist by the obligation to intervene to examine each suspected case. The fuzzy expert system computes the probabilities and determines output value in terms of percentage of the risk alarm. Decisions are described through the output membership functions that are illustrated in the figure 13. These functions determine whether the alert will be engendered, or normal monitoring is sufficient.

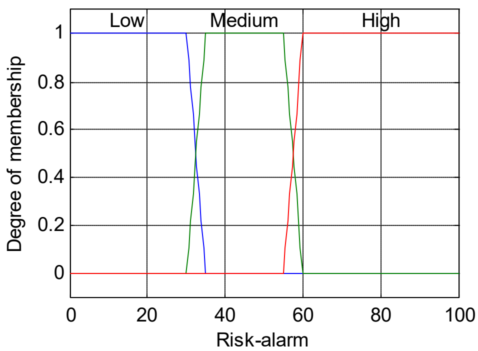

Fig. 13. Membership functions of the output fuzzy set

The used IF-THEN rules are presented in the Figure 14. They can analyze all possible situations and generate accordingly the accurate output.

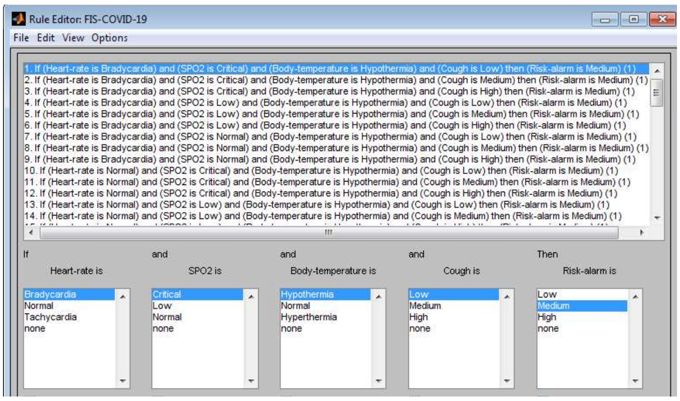

Fig. 14. COVID-19 FIS IF-THEN rules

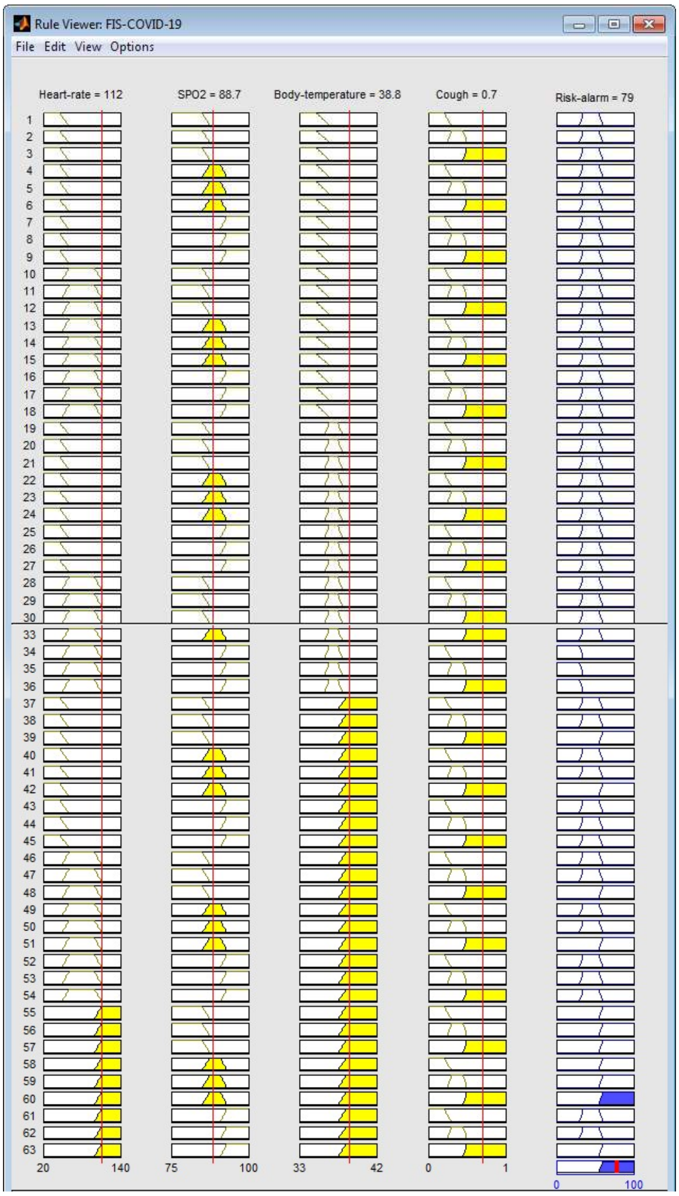

Fig. 15. Risk-alarm output determination

In addition, to explain how these rules have been constituted and how does a rule work and execute, a set of samples rules is presented in Figure 15. Rule 51 is described below. When temperature sensor reads a Hyperthermia body temperature, and MAX30102 sensor reads both Tachycardia and Low SPO_2 and cough sensor detect High cough level, it is indicated that the patient is contaminated by COVID-19 with a High level of Risk alarm equal to 79%. To produce the Risk alarm, the FIS system pass through defuzzification phase using fuzzy centroid or gravity center technique and Mamdani method. In fact, final decision, which is the FIS output, is equal to the gravity center abscissa of the resulting membership function surface. This later characterizes the fuzzy set formed after the aggregation of all conclusions. Therefore, the resulting membership function of the output variable is converted into digital quantity. In Figure 16 and 17, the surface decisions is illustrated. It depends on each variable used in the employed FIS. It is observed that these decisions are in discontinuities, non-linear, flexible and reflect human expertise in medical diagnosis.

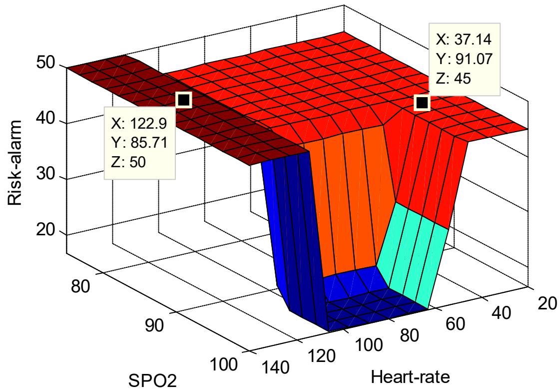

Fig. 16. SPO_2 and Heart rate versus Risk-alarm output

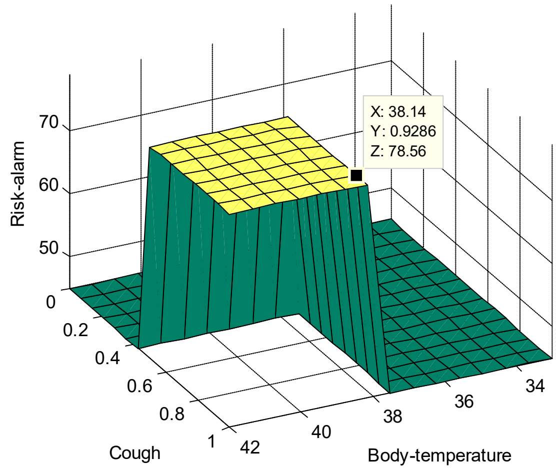

Fig. 17. Cough and Body temperature versus Risk-alarm output

In the event that the system generates a high-level alarm concerning a person infected with COVID-19, this system will search and identify, according to the GPS location coordinates saved in the cloud database, all the contact persons or all the people who are located close (within a radius of 5m) of this infected detected person. The system then sends alerts to medical staff of the obligation to submit these people to a clinical examination and analysis. Table II summarizes the meaning of each Risk-alarm level, the operating mode of the monitoring staff and the procedure that has been associated facing the generation of each alarm level.

TABLE II. ACTIONS ACCORDING TO THE RISK LEVEL

Risk alarm level	Range	Associated Action
Low (Yellow)	[0, 35[%	- The operational is normal - No dangerous case detected and no alarm is activated
Medium (Orange)	[30, 60[%	- Notification that patient disease symptoms exceeds the tolerance limits - Monitor closely this suspicious case - Triggering a warning alarm related to this case - Requirement of medical consultation
High (Red)	[55, 100[%	- Patient's symptoms develop into worrisome symptoms - System predicts an emergency condition and alerts doctors for an immediate intervention - Suspicious must be exanimated and should be confined and follow the associated treatment protocol

This intelligent supervision system offers other functionalities using Bluetooth, Big Data and Data mining techniques. In fact, it allows maintains distance by detecting people near of less than 1.5m using Bluetooth technology with which the Nano BLE Sense card is equipped. drawing automatically an accurate epidemiological map, following the statistics directly by regions, cities and streets and classifying them into three groups: A high-risk geographical group that is likely to know a large increase in infected cases, which will require the authorities to take strict measures. A geographical group that exists in an unstable epidemiological situation with a fluctuating trend in daily-infected cases, which requires the authorities to maintain partial containment measures. A geographical group that is in a stable epidemiological situation with the possibility of comprehensive control over the spread of the virus if self-protection measures, distancing and barriers are preserved.

VI. CONCLUSION

This research deals with the problem of COVID-19 disease detection and monitoring. An intelligent algorithm for its accurate diagnosis has been studied to avoid this issue. The proposed solution approach is based on different technologies. Effectively, the suggested diagnosis approach correctly treats the problem with satisfactory performance. In addition, the proposed system constitutes an effort toward the design of an intelligent, flexible and integrated fuzzy logic based home healthcare system. Simulation results proves the COVID-19 detection accuracy and the knowledge extraction feasibility. Furthermore, it is concluded from the obtained outcomes that the proposed remote diagnosis task has been accomplished successfully in real-time. This promotes the experimental validation and evaluation of the system of the performance in a university hospital center with COVID-19 patients. As perspectives, we proposed to extend this work to establish a comparative study towards other types of fuzzy inference engine : Tsukamoto, Takagi-Sugeno and ANFIS for an accurate diagnosis of COVID-19.

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