Personal Home Healthcare System for the Cardiac Patient of Smart City Using Fuzzy Logic

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***Abstract*—Home based health care system is increasing trend in smart cities. The timely availability of information about health status of chronic heart disease patients can play a significant role in decision making about diagnosis and needed treatment in real time. Fuzzy logic has proved to be the remarkable tool for building intelligent decision making systems based on the healthcare practioners's knowledge and observations. This paper proposes a fuzzy logic based home healthcare system for the chronic heart disease patients (in stable conditions) for out-of-hospital follow-up and monitoring. The proposed system can provide an innovative, timely resource and a supplement for the existing healthcare systems helping practioners's to treat efficiently to cardiac patients who lived alone at their homes. Additionally our model is anticipated to be cost effective, smarter and result oriented with compare to other prevailing traditional methods. An analysis of structure and evaluation of the system performance is presented along with the potential applicability in real world system development.**

***Index Terms*—heart, fuzzy logic, home healthcare, Internet of things**

I. Introduction

The quality of life of residents is an important objective of smart cities [1], and the daily mobile health-care service becomes more and more important for the solitary people, such as the disabled and elderly people [2]. Chronic diseases such as cardiovascular and cerebrovascular diseases [3] Influence the health of the people living alone in daily life, such as cardiovascular and cerebrovascular diseases affect [4], so that the corresponding motor, sensory and cognitive functions have been lost or compromised, and real-time remote monitoring service is required.

The cardiovascular disease is the foremost cause of death in the United States (US) and Europe since 1900. More than ten million people are affected in Europe, one million in the US, and twenty two million people in the world [5]-[7]. The number is expected to be triple by 2020. The ratio is 17% in South Korea and 39% in United Kingdom (UK) [8]-[9]. The healthcare expenditure in the US is expected to increase from $2.9 trillion in 2009 to $4 trillion in 2015 [10]. The future health crisis attracts the researchers, industrialists, and economists towards optimal and rapid health solutions.

The need for home health care is being driven by several factors [11] including demographic trends; the needs of patient in-home health-care, and changes in health care towards the more cost–effective approaches, such as managed care and other risk sharing systems. Chronic heart disease patients who are in stable condition, belonging to one of four specific risk groups: Arterial hypertensions, malignant arrhythmias, heart failure and post infarction rehabilitation Cardiac disease patient compulsory require their continuous health monitoring. One method to provide home health-care is to use communication technology, *e.g.,* providing an emergency care and health monitoring at home.

Internet of Things (IoT) [12] will be the most sought soon after enabling technology from the domain of Intelligent City. Therefore, distant health-care monitoring services, aided with IoT, tend to be valuable. A remote health monitoring system mainly is made up of portable, wearable and battery pack powered sensing unit that's assigned with the task of sensing a variety of physical parameters of the human body. This unit boasts the responsibility regarding transmit the sensed data for the remote environment with regard to storage and diagnosis in the patient.

II. Related Work

There are various researched works that give attention to providing remote health services by using portable sensors along with communication technologies. A remote health monitoring system using a physician apparatus that interactively monitors the patient's health by asking the sufferer questions and getting answers to those people question, is displayed in [13]. A technique of monitoring patients within their own homes using electronic devices and wireless technological is discussed inside [14]. A centralized checking station that receives data from remote patients using mobile phone lines and allows medical procedures to be administered. Remotely is identified in [15]. A research in [16] targets optimizing battery inside remote health checking system that works by using smartphone. A system architecture presented with [17] performs real-time research of sensor's

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information, provides real-time feedback for the user, and forwards the actual user's information to your telemedicine server.

Our proposed system mainly focuses on the patients with chronic heart disease who are in stable conditions. The major objective of the system is to provide the 24/7 health monitoring. We design the model that efficiently utilized the wearable battery powered sensors unit and fuzzy scheme to diagnosis the health parameter for the chronic cardiac diseases.

Reminder of the paper is organized as follows, Section III and IV presents the Internet of Things for Healthcare and the data collections from the sensors. Section V discussed the Model of Fuzzy Expert System, and section VI presents the fuzzy scheme for the proposed system and its implementation and section VII Inference mechanism and system output. Finally, section VIII concludes the paper and the future work.

III. Internet of Things for Healthcare

The IoT is a new era of intelligence computing and it's providing a privilege to communicate around the world. The objective of IoT is anything, anyone, any place, any service and any network. IoT enabled objects to communicate with each other, access information over the Internet, and interact with users creating smart, pervasive and always connected environments.

IoT enabled remote health monitoring system has enormous advantages over the traditional health monitoring system. Health sensing components have become very compact and portable, allowing patients to wear them round the clock for monitoring. The virtual patient has the exact physiological conditions as the real patient. A doctor can monitor a patient only a few times a day but critical health issues can occur at any moment. Therefore, 24/7 monitoring of health data is necessary. As IoT enabled patients can be accessed over the Internet and by other machines, the health condition of a patient can be monitored uninterruptedly, allowing critical illness to be detected at the right time so that proper actions can be taken. Faster and voluminous and error free collection of data becomes possible with implementation of IOT, which can never be achieved by manual methods. In this section, a health monitoring system based on IoT is described.

We have proposed a sensor-cloud framework in [18] and some of the challenges are discussed with particular focus on health-care application. This framework lays the foundation of the IoT enabled health-care monitoring system. Here, a system design is presented in Fig. 1 that is used for the healthcare management. Our system comprises two parts: (a) local and (2) remote. Firstly, the local part deals with collection of information from the sensors connected to a patient, and the remote part enables storing and distributing the data to remote service seekers like emergency service providers, doctors, and insurance providers. Arduino-based data aggregator (Arduino is an open source electronics prototyping platform) [19], is used to collect the sensor-data before sending to the data processing unit. It also processes the collected raw data to generate meaningful information's that can be understood by specialists and doctors. Then, it displays the processed information and sends it to the remote servers.

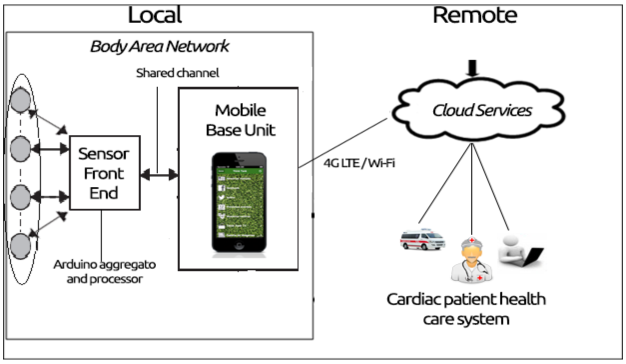

Figure 1. Architecture of health-care System

The above health-care monitoring system comprises several sensors connected to a person. Different kind of Sensors which have been used in the health-care system are shown in Fig. 2. Furthermore, many supplementary sensors can be integrated to this remote monitoring system as recommended by specialized doctors. The data is uploaded to cloud through multi-hop wireless communication from the data aggregator and may be accessed and visualized by care-givers. Additionally, the data may be used to detect anomalies and generate alerts.

Figure 2. Health monitoring sensors

IV. Data Collection from Sensors

Health-care applications need to acquire different types of sensor-data. The sensors-data need to be collected in precise and timely manner [20]. When health sensor-data are forwarded to the data aggregator node, more sensing data may be accumulated along the route. Thus, a huge traffic may be generated during data collection. Handling such a large amount of data while and minimum data loss is challenging. Improper handling may result in unbalanced and inefficient energy dissipation. In most cases, the data is forwarded or collected through multiple hops either in a request-reply manner or in continuous streams. Furthermore, it has also been observed in the back-end system [21]. Huge amount of data may lead to burdened payload which results in packet fragmentations and due to packet fragmentation, the latency for data collection becomes longer. To tackle the above issues, an event driven knowledge collection technique is proposed.

Continuous data collection from the sensors is not required in event-driven approach [23]. Usually, data gathered on occurred fusion center makes the decision. In this scheme, instead of implementing fusion centers, case detection and choice mechanisms are executed by the sensor nodes. Events are defined by means of some threshold values of the parameters. Assume, three sensor parameters I_1, I_2 and I_3 are defined for any health-care system M.

$$M = \{I1, I2, I3\}$$

In the event the values of the parameters rely on each other along with I^{1st}, I^{2nd} and I^{3rd} include the threshold values of I_1, I_2 along with I_3 respectively, and then the info gathering function can be explained as

$$f(M_g) = \begin{cases} f(\mathrm{i}_1) & \mathit{if}\ \mathrm{i}_1 < \mathrm{i}_{1\mathrm{th}} \\ f(\mathrm{i}_1, \mathrm{i}_2) & \mathit{if}\ \mathrm{i}_1 \geq \mathrm{i}_{1\mathrm{th}}\ \&\ \mathrm{i}_2 < \mathrm{i}_{2\mathrm{th}} \\ f(\mathrm{i}_1, \mathrm{i}_2, \mathrm{i}_3) & \mathit{otherwise} \end{cases}$$

This particular event-driven data collecting will indeed minimize the application of communication resource as well as reduce overhead to a large extent. It can make sense of the health data if we mention state on the particular parameters. Thus, in our system, we use fuzzy rules rather than the threshold parameters.

V. Model of Fuzzy Expert System for the Cardiac Disease Medical Diagnosis

The modeling of any fuzzy expert system normally contains the following steps: (i) selection of relevant input and output parameters, (ii) selection of proper membership functions, fuzzy operators, reasoning mechanisms, (iii) choosing of specific type of fuzzy inference system, and (iv) formulation of rule base. The Fig. 3 signifies the model of a proposed generic fuzzy expert system and showing the flow of data through the system. Primarily it consists of GUI, knowledge acquisition, knowledge base and inference engine modules.

User can refer and select the relevant clinical parameters and symptoms from the knowledge base to converge to the inference. The knowledge acquisition module allows user to seek the inputs as well as to build the new domain knowledge. The input variables are fuzzified whereby the membership functions defined on the input variables are applied to their actual values, to determine the degree of truth for each rule antecedent.

Finally, defuzzification is applied to convert the fuzzy output set to a crisp output. The basic fuzzy inference system can take either fuzzy inputs or crisp inputs, but the outputs it produces are always fuzzy sets. The defuzzification task extracts the crisp output that best represents the fuzzy set. With crisp inputs and outputs, a fuzzy inference system implements a nonlinear mapping from its input space to output space through a number of fuzzy ‘if-then’ rules. Fig. 4 represents the elements and hierarchy of fuzzy expert system.

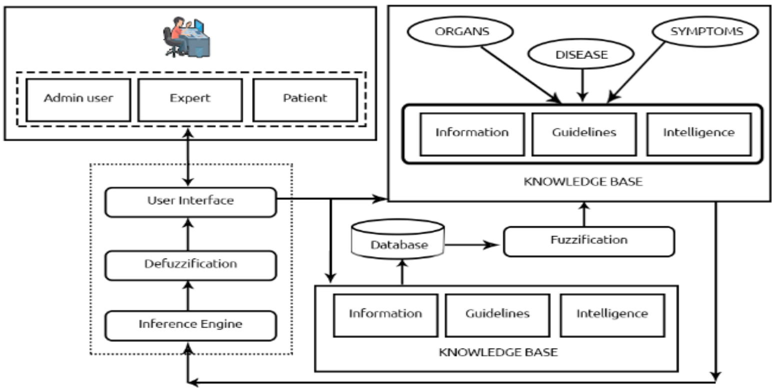

Figure 3. Model of proposed fuzzy expert system

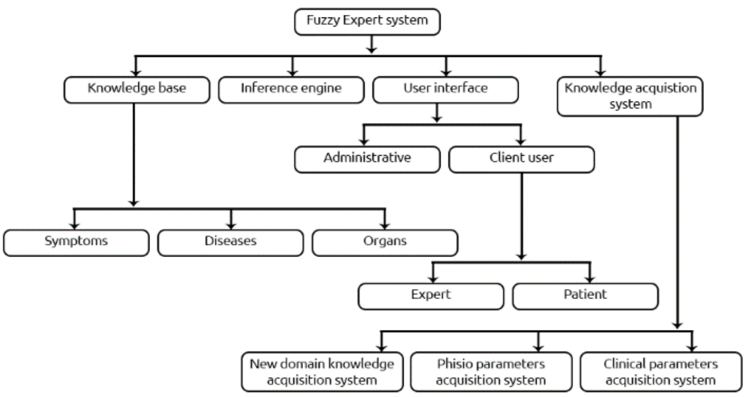

Figure 4. Hierarchy elements of fuzzy expert system

VI. FUZZY SCHEME FOR CARDIAC DISEASE DIAGNOSIS

The MatLab fuzzy logic toolbox was used to simulate the medical diagnosis application. The input variables considered are blood pressure, blood oxygen, body temperature, ECG, heart rate, respiration rate *etc*. Membership values are assigned to the linguistic variables such as symptoms low, medium, high and very high. The patient data is stored in a database and knowledge is retrieved from the knowledge base by matching the symptoms and their severity against the antecedent part of fuzzy rules. In knowledge base to make the decision as the disease name or the risk of the disease. The fuzzy decision value is defuzzified by the defuzzification component of the designed system to finally arrive at a crisp decision for the disease diagnosis.

Our proposed system contains various sensors, which measure some physical properties of a human body. Diagnosis is performed by studying several parameters of a human body known as symptoms and several symptoms are verified one after another before obtaining a final conclusion about a particular disease. This fuzzy assisted scheme uses these rules of diagnosis and follows the steps of diagnosis to take the decision regarding which sensor is required to be activated and when it is required to be activated. The system activates few sensors which record some basic parameters of the human body. The crisp values received from the sensors are transformed to fuzzy sets like 'normal', 'above normal', 'low' *etc*., using pre-defined knowledge base (rules defined by specialized doctors). These fuzzy variables become the input to the decision making program which detects the true condition of the patient like weak heart condition, shock, respiratory problem *etc*. According to these outputs, actions and events like alerting doctors and/or activating more sensors for further monitoring the patient are started. In our implementation, we have used e-Health sensor kit [22] from Libelium. These sensors are IoT enabled. If some abnormal conditions are detected then the device alerts doctors who are remotely located.

The fuzzy assisted technique may be employed in wide area of health applications. As a test case, we have tried to implement fuzzy assisted detection of heart condition in a step by step manner, just as it is diagnosed in the real world. Severe heart conditions like myocardial infarction, ischemic heart disease *etc* have the symptoms like sweating, low peripheral body temperature, tachycardia (high heart-rate), and normal respiration rate *etc*. We have followed data from Table I to VI for preparing the knowledge base and rules. Thus patient status may be investigated in real-time.

Initially, the data from all the sensors are retrieved and the data aggregator decides which particular data should be sent depending upon the condition of the patient. All data are fed into the fuzzifier. Fuzzifier is used to detect whether the parameters are normal, low or high (fuzzy sets) on the basis of some predefined membership functions.

At first, temperature and GSR sensor-data are checked. These two help in determining the physical condition of the patient, i.e. whether the patient is in shock or not. If shock is detected, the data from heart rate sensor and respiratory sensor are checked to detect the specific cause of the shock. The output from the fuzzy system is used to detect if the heart condition is bad, critical or normal. Depending on these fuzzy output, the actions and alerts like starting the ECG, alerting heart specialist *etc*. are generated. Some of the input membership functions of the health parameters are shown in Fig. 5 to 10. Also, output membership function is shown in Fig. 11.

The average heart rate ranges from 60 to 100 beats per minute. Here, the heart rate parameter range is divided into three fuzzy sets, namely, 'low', 'medium' and 'high'. Table I and Fig. 5 present the fuzzy sets of heart rate.

TABLE I. RANGE OF VALUE AND FUZZY SETS OF HEART RATE

Input	Range	Fuzzy Sets	Diagnosis
Heart rate	< 100	Low	Bradycardia
	90 – 150	Medium	Normal
	140 >	High	Tachycardia

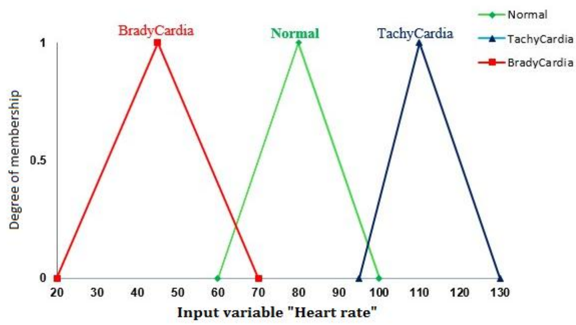

Figure 5. Membership function of heart rate

A human being has a normal respiration rate between 9 and 23 breaths per minute. A respiration rate below 9 is considered as low and a respiration rate above 25 is considered high. The membership function and the respiration rates are shown in the Fig. 6 and Table II respectively.

TABLE II. RANGE OF VALUE AND FUZZY SETS OF RESPIRATION RATE

Input	Range	Fuzzy Sets	Diagnosis
Respiration rate	0 – 12	Low	Hypopnea
	12 – 25	Medium	Normal
	26 – 60	High	Tachypnea

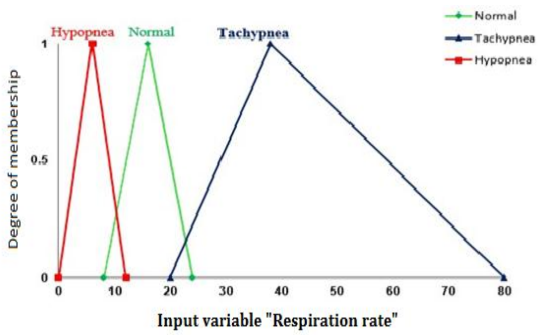

Figure 6. Membership function of respiration rate

The blood oxygen sensor reads the percentage of oxygen in the blood. Normal range is 93 and above. Percentage of oxygen between 87 and 92 is taken as low and below 86 is considered as critical. It is shown in Fig. 7 and Table III.

TABLE III. RANGE OF VALUES AND FUZZY SETS OF BLOOD OXYGEN

Input	Range	Fuzzy Sets	Diagnosis
Blood oxygen	87% to 92%	Low	LowSPO2
	93% to 100%	Medium	NormalSPO2
	75% to 86%	High	CriticalSPO2

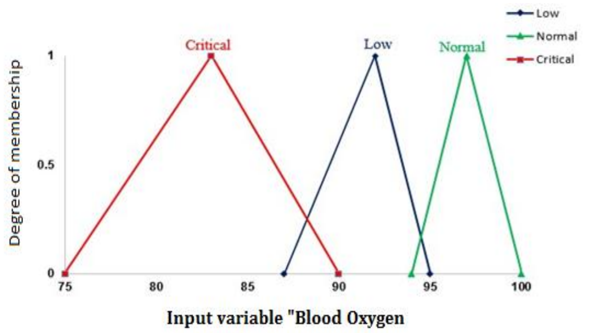

Figure 7. Membership function of blood oxygen

The blood pressure is one of the most significant parameter in the heart disease. Here, the blood pressure input parameter range is divided into four fuzzy sets, namely, ‘low’, ‘medium’, ‘high’, and ‘very high’. These are represented in Fig. 8 and Table IV. A value of systolic pressure 90-119 and diastolic pressure 60-79 is considered to be normal. The systolic range 120-139 and diastolic range 80-89 is considered as per-hypertension. Systolic pressure 140-159, diastolic 90-99 and systolic 160-179 diastolic 100-109 are considered hypertension respectively. The systolic pressure of > 180 and diastolic pressure of > 110 is considered as hypertensive crisis.

TABLE IV. RANGE OF VALUES AND FUZZY SETS OF BLOOD PRESSURE

Input	Fuzzy Sets		Diagnosis
	Systolic (mmHg)	Diastolic (mmHg)	
Blood Pressure	< 90	< 60	Hypotension
	90 – 119	60 – 79	Desired
	120 – 139	80 – 89	Prehypertension
	140 – 159	90 – 99	Stage 1 Hypertension
	160 – 179	100 –110	Stage 2 Hypertension
	>180	>100	Hypertensive Crisis

TABLE V. RANGE OF VALUES AND FUZZY SETS OF BODY TEMPERATURE

Input	Range	Fuzzy Sets	Diagnosis
Body Temperature	<35.0˚C (95˚F)	Below Normal	Hypothermia
	36.0 -37.5˚C (97.7-99.5˚F)	Normal	Normal
	>37.5 -38.3˚C (99.5-100.5˚F)	High	Fever or Hyperthermia
	>40.0 -41.5˚C (104.5-106.7˚F)	Very High	Hyperpyrexia

The membership criteria for body temperature are shown in Fig. 9 and Table V. 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.

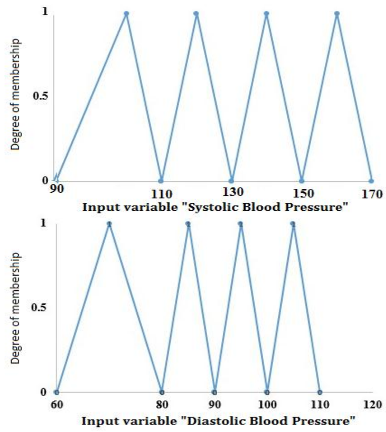

Figure 8. Membership function of Systolic and diastolic blood pressure

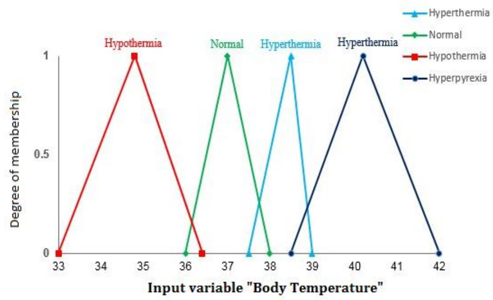

Figure 9. Membership function of body temperature

Electrocardiogram (ECG) is a test that measures the electrical activity of the heart. It uses ultrasound to evaluate the heart muscle, heart valves, and risk for the heart disease. ECG parameter range is divided into three fuzzy sets, namely, ‘Normal’, ‘ST-T Normal’ and ‘Hypertrophy’. The range of values and respective fuzzy sets of ECG is shown in Table VI and Fig. 10 respectively.

TABLE VI. RANGE OF VALUES AND FUZZY SETS OF ECG

Input	Range	Fuzzy Sets
Electrocardiogram	[–0.5, 0.4]	Normal
	[0.25, 1.8]	ST – T
	[1.4, 2.8]	Abnormal Hypertrophy

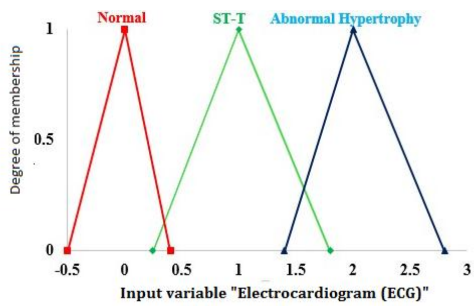

Figure 10. Membership function of ECG

VII. INFERENCE MECHANISM AND SYSTEM OUTPUT

In this system, more than one thousand fuzzy rules pertaining to the heart disease are formed. The output shows the presence or absence of risk for the heart disease subjected to given the values of input parameters. The rules are formulated using Matlab rule editor. The rules consist of antecedent and consequent parts. All the rules fire to some extent in the antecedent part of the fuzzy system. In the inference process, the truth value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. The fuzzy expert system computes the probabilities and determines output value in terms of percentage of the risk of heart disease from zero percent to hundred percent. Decisions are described through the output membership functions that are mention in the Fig. 14. These functions determines whether the alert will be generated or normal monitoring is sufficient

A set of samples rules is presented in Fig. 12. To clarify how the rules have been constituted, Rule 3 in Fig. 12 is described below. When temperature sensor reads peripheral body temperature is low, and SCL sensor reads high (patient is sweating), it is indicated that the patient is in shock. Shock may arise from fear or heart problems or psychological issues. As one of the symptoms of heart attack is severe shock of the patient, our system activates the heart rate monitor when the above two conditions are true. When shock is followed by tachycardia (high heart rate), ECG is started and doctors are alerted as the system predicts an emergency condition.

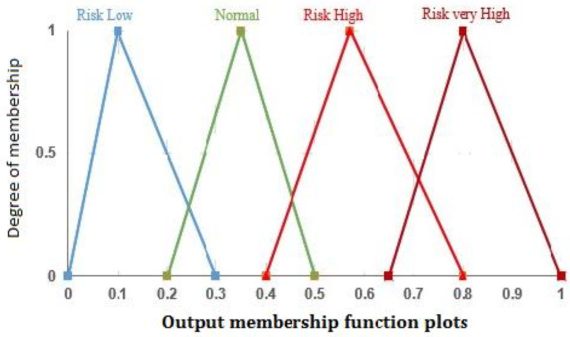

Figure 11. Output state membership function

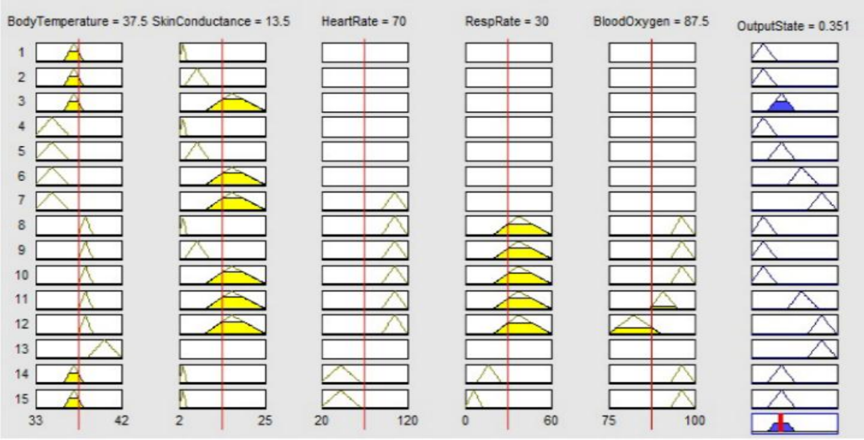

Figure 12. Output membership function graph

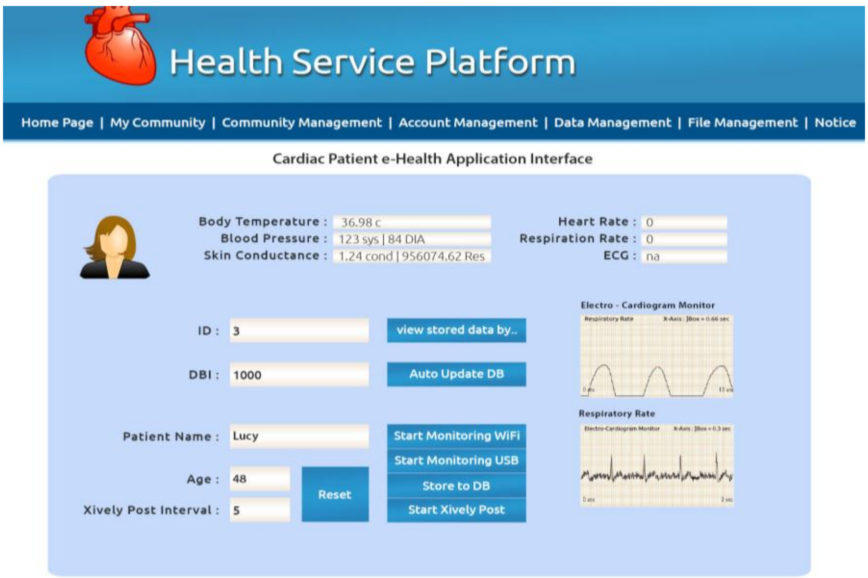

Figure 13. Visualization of patient health status

Fig. 13 shows the fuzzy assisted health data visualization in real-time. The fuzzy system is programmed on the Arduino board which is used as a data aggregator unit in the healthcare monitoring system. The data aggregator only transmits sensor-data according to the fuzzy rules.

Thus unnecessary transmission of all sensor-data is avoided. Only required data will be transmitted and alert will be generated in case of emergency health condition. Moreover, ECG is resource demanding as it requires high sampling rate. So, preventing it from working unnecessarily.

VIII. Conclusion

Given the nature of Cardiac patient's disease, the physical conditions information is necessary for determine the required actions to be taken by the health practioners's. Upon timely and accurate information availability can ensure efficient intervention. Benefiting from using of fuzzy techniques such health monitoring system can be used to overcome the traditional limitations of ambiguit and less efficient monitoring system. In our proposed healthcare model, we have attempted to fulfil the gap. Proposed system model is a fuzzy logic based home healthcare system for cardiac patients. Step by step diagnosis and detection of physiological stages of patient body is promising way to avoid unnecessary data collection. This way saving valuable energy of a portable monitoring device can be achieved. The generation of accuracy of knowledge can enhance performance of whole system. The proposed system constitutes an effort toward the design of an intelligent, flexible and integrated fuzzy logic based home healthcare system.

Our hypothesized system can be augmented further practical research and possible better enhancements could be introduced when applied in adopted in real world situation.

Acknowledgement

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