FUZZY LOGIC BASED PATIENTS' MONITORING SYSTEM

by

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Abstract

The ever increasing health care costs are becoming a major concern to both, individuals and authorities. This has tempted researchers to seek alternative models to the traditional and costly hospital-based monitoring and caring approach. One such an approach is the utilization of mobile units that allow for the remote observation and diagnosis of patients in their homes. Advances in VLSI circuits, single-chip embedded-system computing platforms, mobile telecommunications, and web services have provided valuable opportunities to enhance the design and performance of mobile patient's health monitoring platforms. In particular, Radio Frequency Identification (RFID) technology has emerged as one of the possible valuable solutions that can be utilized in future healthcare systems. RFID tags integrated with built-in vital signs sensors such as Body Temperature (TEMP), Blood Pressure (BP), Heart Rate (HR), Blood Sugar Level (BS) and Oxygen Saturation in Blood (SPO2) are useful in identifying and recording the state of a patient. In this work, we proposes the design, implementation, and testing of a mobile RFID-based health care system. The system consists of a wireless mobile vital signs data acquisition unit and a fuzzy-logic–based-software algorithm to monitors and assess patients' conditions on 24/7 bases. A set of fuzzy rules are developed to diagnose the monitored patient's status based on the received vital signs namely; TEMP, BP, HR, BS, and SPO2. The fuzzy algorithm will output an early warning of any patient's abnormality status. The system was implemented and tested at Rashid Center for Diabetes and Research (RCDR) hosted in Khalifa Hospital, Ajman, UAE using a representative sample of 26 patients. System performance is compared with the medically accepted standard, namely, the Modified Early Warning System (MEWS) that is currently widely used in practice. The proposed system has proven that it outperforms the MEWS system in many cases, and hence an indication of the usefulness of this fuzzy-based approach.

Search Terms: Mobile patient monitoring, RFID, Fuzzy-logic, MEWS

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Chapter 1

Background and Literature Review

1.1. Introduction

Aging and growing population have become a serious concern in developed countries due to the rising in medical care costs and increasing demands for health services. The rate of growth in aging population has witnessed a continuous rise over the last few decades. The number of older persons has tripled over the last 50 years; and it will further triple again over the next 50 years [1]. Figure 1 shows a comparison between the growth rates of older populations to total population; we can notice the increase in the older population rate.

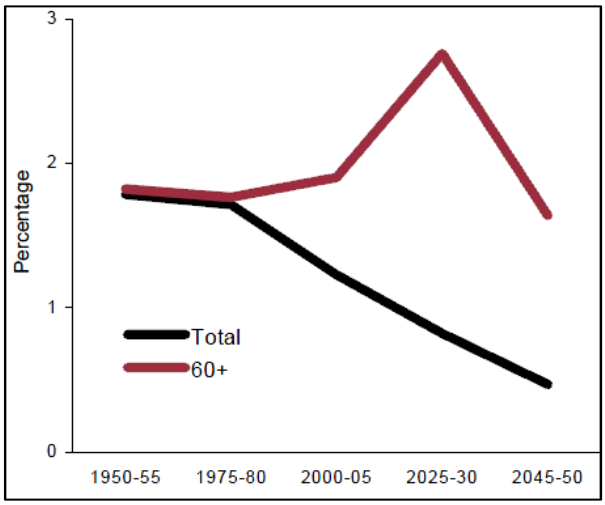


Figure 1: Average annual growth rate of total population and population aged 60 or over [1]

The integration of computing platforms and wireless communications technologies in healthcare systems has enhanced the quality of health care for millions of people around the globe. It has helped to better manage the medical supplies, medical diagnoses, patient record administration and health care services. However, following indoor patients' status is still consuming more of the nursing staff time and physically occupied the limited hospitals' beds as well as adding more cost and consumed more resources.

As patients' health care records are becoming integral part of the health care, it started to have an impact on health care safety, cost, and quality. The technology to develop, transmit, store and manage patient's health data is rapidly advancing. The advances in health information system will help to provide patients and care takers with electronic access to the records from anywhere anytime. Realizing these benefits requires an underlying

infrastructure that can support the use of patient-centered electronic health information; that goes beyond the limitations of a specific provider, health plan or delivery system [2]. Hospitals tend to have numerous and independent medical information systems that support departments, clinical wards, surgeries, and laboratories. For example, radiology may have its own application system that is separated from the database maintained by the hospital's main information system. The critical issue is the ability to integrate the patient's medical records and image files so that different healthcare providers can share and communicate patients' vital signs and health data for immediate and accurate diagnosis and treatment.

1.2. General Problem and Organization of Thesis

Monitoring patients in hospitals or in any health care delivery organizations restricts patients from being mobile or having the sense of freedom to walk or move around the hospital bed. Patients requires continuous monitoring, and if any critical case occurs, nurses alarm the in-call doctors by informing them, and the doctors might respond late causing a less quality care. A better and efficient monitoring system is needed to provide high quality patients care from anywhere at any time.

Also, hospitals and medical centers mainly used to have abundant and independent medical information systems that support many care delivery organizations. The main consideration is the ability to integrate the patient's medical records and files so that different healthcare organizations and providers can share and communicate patients' current status and health data for immediate and accurate diagnosis and treatment.

In this research, a mobile RFID intelligent patient monitoring and diagnose system is developed to support mobile health care applications and clinical decision support. It also includes a medical records system that profiles the patients and generates an Electronic Health Records (EHR) for them. A fuzzy logic base algorithm is developed. The patient's medical records and the fuzzy logic base system are used to issue warnings and send alarm messages to caretaker in-case of any abnormality. The system can be used to monitor in-door and out-door patients, especially those with chronic diseases.

The organization of the thesis goes as follows: This chapter, which is Chapter 1. It describes the most relevant mobility approaches available in the literature for Wireless Patient Monitoring system, and evaluates the types of wireless network technologies suited for remote monitoring systems. In addition to that, there are six other chapters:

Chapter 2 discusses the overall system design. It includes functional and non-functional requirements of the system and describes the Hardware architecture of the system.

Chapter 3 Describes the Software architecture of the system.

Chapter 4 discusses the implementation of the proposed system. It includes the evaluation of the sensors used in our system, along with the evaluation and validation of the system's fuzzy logic rule and the integrated system itself.

Chapter 5 concludes the thesis and highlights future research.

1.3. Existing Patient Monitoring and Diagnosis Systems

Patient monitoring system is a system that consists of various devices that are used to monitor the patients status such as the heart ECG signal and alerts the health care takers if there is an abnormity [3]. These systems are needed in situations where the patient is in a life threatening condition or critical physiological state or has chronic diseases such as diabetes [4] [5] and high blood pressure [6] [7].Such systems are emerging due to the increased healthcare needs of an aging population, new wireless technologies, better video and monitoring technologies, decreasing healthcare resources and proven cost-effectiveness. It's not new in health care; it started in 1625 with the measuring of body temperature and blood pressure. New technologies have been developed after World War 2 and a vast amount of different types of monitoring can be developed [8]. Many existing wired and wireless patients' monitoring systems are available in the market today. However wireless technologies are gaining ground due to its mobility, size, durability, cost and ease of installation. The following is a literature survey to some of the most recent and poplar systems.

Many wireless patients' monitoring systems are reported in the literature [9 - 37]. Some of these systems are based on short range communication protocols such as Bluetooth [9 - 14], Zigbee [15 - 21], WiFi [22 - 24] and RFID [25 - 35]. Other systems combined short range with long range protocols such as GPRS and WiMax [36 -37].

1.3.1. Bluetooth-Based Solutions:

A Bluetooth with integrated Zigbee based system was developed to record and transmit a patient electrocardiogram, pulse and body weight [9] as shown in Figure 2. The system consists of 3 wireless sensors for cardiovascular monitoring ECG, Pulse and Body

Weight. The data is collected from these sensors via single 16 bit RISC Microcontroller to process the data and frame it and forward it to a ZigBee base wireless gateway. The Zigbee gateway Forward the packets via a Bluetooth transceiver to a personal computer for further data analysis and archiving. The designed gateway is large sized, the security of the wireless sensor network is not considered and the connection range is short.

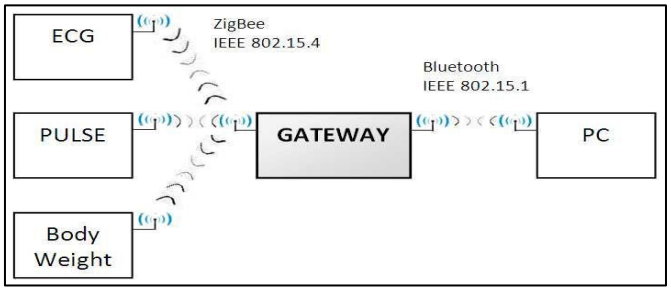


Figure 2: Proposed Bluetooth with integrated Zigbee based health monitoring system [9]

Another wireless system was design to monitor Psychiatric Patients vital signs namely SPO2, heart rate, skin temperature and respiratory rate using four different sensors [10]. The system consists of a two wearable Data acquisition units and a central monitoring station (CMS). One of the data acquisition units measures the SPO2 level and transmits it via Bluetooth to the CMS. The other one measures the heart rate, skin temperature and respiratory rate and repot it to the server using Bluetooth. A software package was developed to process the received raw data from the wireless acquisition units. The extracted signals are displayed graphically to help physicians diagnose the status of their patients. The system was tested in a laboratory setting on healthy volunteers. The system is big in size and the PC is isolated and not connected to the internet.

In [11], a Bluetooth-enabled ECG Monitoring System was developed as shown in Figure 3. This system consists of a mobile data acquisition unit (DAQ) and a server. The DAQ unit consists of ECG sensor, processing module and a transceiver. The ECG signal is read using 2-lead ECG sensor from a patient. The processing module (PM) consists of a signal conditioning circuit, an analogue-to-digital converter (ADC) and a microcontroller. The PM acquires process and frame the ECG signal. The framed ECG signal then transmitted to the server via a Bluetooth module for further analysis. At the server side, the ECG signal is extracted and displayed on the PC monitor to be analyzed and diagnosed by the physician. The system didn't include a database to store patient's personal information, health status and history. It's worth mentioning that the DAQ unit consists of three different modules. Also it monitors one patient at a time.

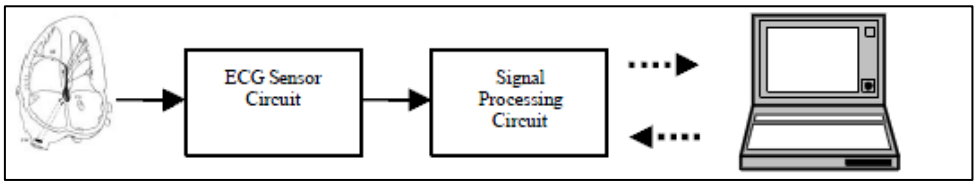


Figure 3: Block Diagram of the Bluetooth-enabled ECG Monitoring System [11]

In Seoul National University, a group of researchers have designed and developed a System for Ubiquitous Health Monitoring in the Bedroom via a Bluetooth Network and Wireless LAN [12] to measure ECG, body weight, body movement and detect snoring of a patient. The ECG signal is measured using a conductive textile electrode attached to the bed sheet. The patient body weight and movement during sleep are measured and monitored using four compression type load cells that have been attached to the legs of the bed. Finally, patient snoring during sleep is detected using electret condenser microphone and a RMS-to-DC converter. For data processing and transfer, a small data processing unit has been developed. It consists of three parts: power supply, microcontroller and Bluetooth module. The Bluetooth network has been used for the purpose of transferring data from the sensor to the Bluetooth access point and a WLAN has also been used from the Bluetooth server to the Home server and a PDA has been installed in each room for WLAN. The system limits the patients to be sleeping on bed while they are monitored.

Another example of Bluetooth based wireless patient monitoring system was designed and developed as a master thesis at the University of Mälardalen, Sweden [13]. The thesis proposed the design of a small wireless sensor system to make the patient more mobile without losing the reliability of the ECG sensor. It developed a small prototype embedded ECG sensor that transmit the signal to a personal digital assistant (PDA) using a Bluetooth module. The prototype is well suited for patient monitoring were a low noise and power efficient system has been created to be powered by a cellular phone battery. In this system the use of Bluetooth has limited the ECG-sensor system to 10 meter range and 750 kbps data rate.

In [14], Bai and Yang develop a design that utilizes a portable Bluetooth blood sugar measuring device for timed measurements of the blood sugar, a remote site server equipped with appropriate software and an input inquisition device. The system architecture is shown in the below figure (Figure 4). The system test results showed that this design creates a management system that can help the diabetic's patient control his/her diet. The development

of the remote server end, the local user software end and the biochemical blood sugar tester incorporated with wireless technology in the entire system are in line with the original feature settings, and through repeated execution tests the fluency of the entire system has verified its feasibility and the possibilities of future commercialization.

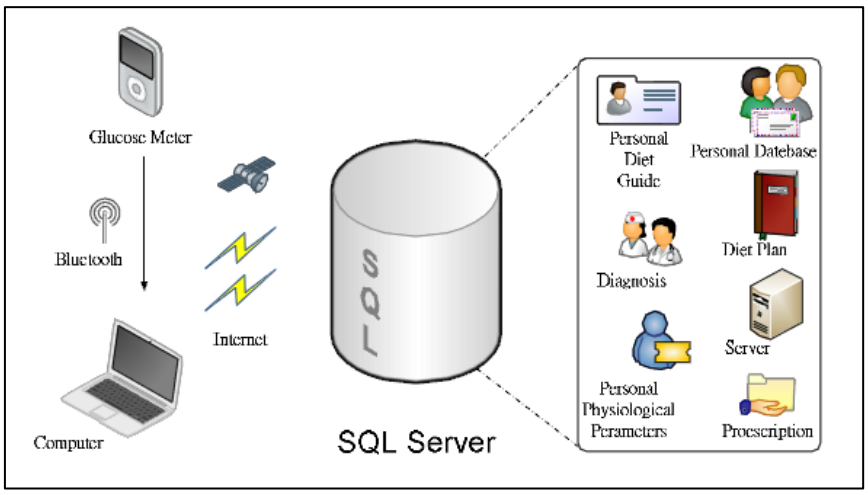


Figure 4: System architecture [14]

1.3.2. Zigbee-Based Solutions:

ZigBee is an Assistive Technology that can be used anywhere in the world. It is designed with simplicity in mind, making it easy for people to use and allowing them to maintain their independence and mobility. It is also extremely efficient in its use of power, and as a result, capable of running on common batteries for years. It was developed for monitoring and control applications in short ranges. In [15], the authors have developed a Zigbee Network-based Multi-channel Heart Rate Monitoring System for Exercising Rehabilitation Patients, so that it gives physical therapist early warning in real time if necessary as shown in Figure 5. The whole system consists of the patient's side device (PSD) and a central monitoring system (CMS). The PSD was designed to be wearable and consume minimum electrical power and has its own identification number. The CMS can monitor multiple numbers of patients simultaneously and generate a warning signal if necessary, and they are linked via Zigbee network. The maximum distance between the PSD and the CMS was about 1500m which is really great. Nevertheless the system is limited to monitor one vital signal per node. A similar system was presented in [16].

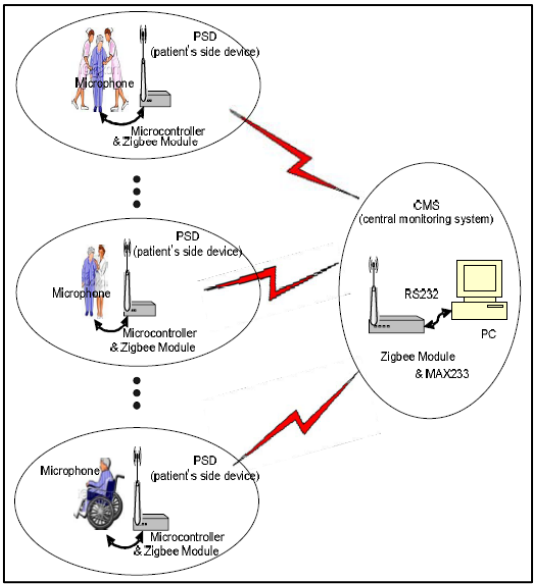


Figure 5: Zigbee Network-based Multi-channel Heart Rate Monitoring System [15]

Another Zigbee Based patient monitoring system was presented in [17], they developed a wireless blood pressure monitoring system which provides a useful tool for users to measure and manage their daily blood pressure values. The wireless blood pressure monitor can measure the blood pressure and heart rate and then store and forward the measured information to the management unit through the ZigBee wireless transmission. So in their system they used the Zigbee module as communication devices.

In [18], the authors have presented a new tested architecture that allows physiological signs measurements to be impeccably integrated into a friendly user Interface or a Healthcare Information System. They kept their hardware design generic and they defined a software interface for different types of medical devices. The medical devices can share the wireless resources with wireless ECG (Electrocardiogram) and Pulse-Oximeter sensors. They achieved a range of 20m within the confines of the laboratory which would equate to the maximum distance between an end device and a router in the hospital. The results showed that a Wireless Sensor Network is a suitable means for capturing data from a medical device. They have discussed how Zigbee meets their requirements in terms of data throughput, power and mobility.

And in [19], the Performance Analysis of ZigBee-based Body Sensor Networks was studied. The paper analyzed the effect of different back-off parameters on the performance of beaconless operation of ZigBee MAC protocol. It showed that ZigBee sensor network support small power consumption and node expansion compared to other network standards for WSN, but it has limited bandwidth and hard to support real time data transmission because of the adoption of CSMA-CA as its medium access control (MAC) protocol.

Advanced wireless sensor network (WSN) architecture for smart healthcare was developed [20] to monitor assisted and independent-living residents, and manages a continuous medical history while preserving resident comfort and privacy. The WSN system consists of different data acquisition units such as a Motion sensor that is interfaced to a MicaZ wireless sensor node used to detect motion and ambient light levels. A wearable wireless sensor body network with MicaZ motes embedded in a jacket. The sensors can monitor human actions and location using a 2-axis accelerometer and GPS. An Indoor temperature and luminosity sensor was connected to the wearable network via MicaZ to give the environmental conditions of the habitat and. In addition to that, a bed sensor that measures breathing rate, heart rate and agitation of a patient was connected to the bed. Also a Pulse-oximeter and EKG wearable sensors connected to MicaZ and Telos devices, and collect patient vital signs such as Heart rate (HR), heartbeat events, oxygen saturation (SpO2), and electrocardiogram (EKG). The MicaZ motes use a Zigbee module for communication. A software package was developed to process the received raw data from the sensors.

In [21], the authors implement a home self-healthcare monitoring system which can monitor respiration, blood sugar, urinary flow, and temperature. The obtained bio-signal by the each sensing unit is transmitted to a monitoring station using Zigbee wireless communication in real time at home on the personal computer**.** Figure 6 shows the system configuration. The test results were displayed on the monitor screen by the GUI. The present wireless biosignal acquisition system enables the patient to select an appropriate module, perform self-test, and check his/her health condition at home on a daily basis. The wireless data communication also provided great convenience and flexibility in practical as well as frequent self-test.

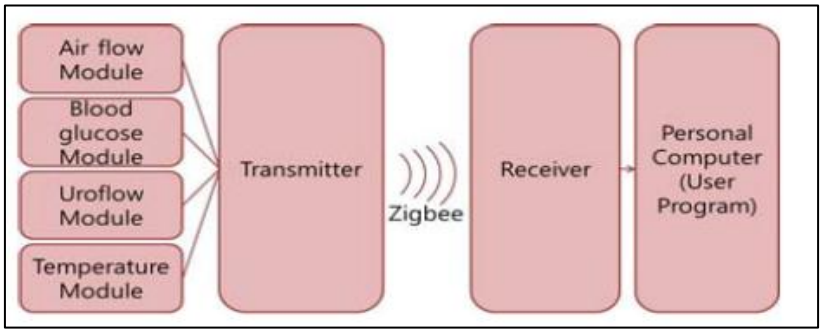


Figure 6: System Configuration [21]

1.3.3. WiFi-Based Solutions:

In [22], the Authors have developed a remote monitoring system for ECG signal. They implemented a portable monitors based on a PDA and digital acquisition cards. They outlined several scenarios (as shown in Figure 7) to apply this platform. The system provides remote monitoring of one or several patients wearing a portable device. The device is equipped with wireless connectivity based on different technologies such as Bluetooth, WIFI or UMTS.

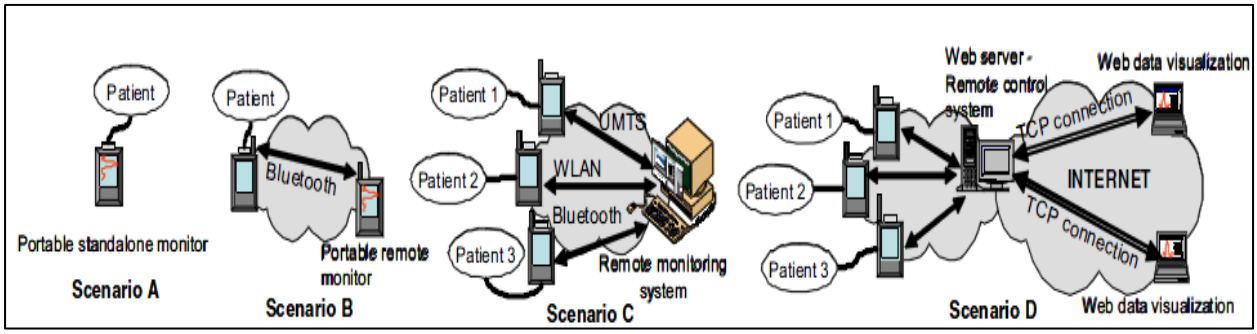


Figure 7: Application scenarios for the PDA based monitor [22]

While In [23], the author presented a system that consists of 4 subsystems namely; a portable ECG transceiver to check the status of patient and send the bio-signal with ZigBee/IEEE RF module, an IP video camera, a WiMAX transceiver that sends ECG signals and pans video camera of the patient to the Doctor using WiMAX technology and a Personal monitor to analyze data and view panning video camera of patient. The patient is attached to an ECG sensor, and when there is any abnormality in the signals, the sensor will send the signals to IP video camera near patient in order to open for panning video camera of patient and being monitored by the physicians.

Another example was presented in [24] in a WiFi and Bluetooth based wireless patient monitoring system. A wireless portable multi-parameter device was designated to acquire physiological signals and transmit them to a local server using Bluetooth wireless technology. Four kinds of monitor units were designed to communicate via the WiFi to meet different medical monitoring requirements, including a local monitor unit, a control center, mobile devices, and a web page. With the combination of Bluetooth and WiFi networks, the proposed system highly promotes the mobility for both the patients and the medical personnel.

1.3.4. RFID-Based Solutions:

In [25], the authors have developed a RFID-based Mobile Intelligent Medical System that supports nursing and medical staff, reduces data entry error and redundancy, and integrate medical information from various monitoring devices for intelligent decision making. They used A Java-based expert system integrated with an RFID-enabled patient data collection module and a rule base is used to issue warnings and send diagnostic messages. The system network model demonstrates how to receive patient's identification and bio-information using RFID technology and mobile devices. The system consists of a patient identification and location broadcasting RFID application, an interface to patient vital sign instruments, a mobile nursing application, and a clinical decision support system. The system also includes functions for issuing and detecting alarms, integrating patient information, sending messages, operating RFID tags and readers, synchronizing mobile nursing data, operating the mobile software and user interface, monitoring the database and user authority, encrypting communications, and communicating with a system center server. The system could be improved by extending the signal based rules to a more comprehensive set of rules for emergency medical diagnostics and nursing care decision support.

One of the most popular ways for patient monitoring in hospitals is the use of a bar code printed wrist bands. And Due to the larger read range, the ability to store more information and the non-line-of sight operation, RFID tags can replace bar codes [26]. Body matched tags (suspended patch-type) have been proposed for real-time bio-monitoring and localization of patients [27]. An implantable RFID chip [28] has been reported for storing patient information and tracking location. In [29] an RFID tag that operates on human body was design for remote human monitoring. This tag can be placed on belts, collars or waist bands. The tag complex conjugate matched to Alien Higgs-2 microchip.

A wireless sensor system named the Health Tracker 2000 was developed [30] to monitor patient’s vital signs namely Heart rate, Blood Pressure, Respiration rate and Body temperature, and keep track of their location (using RFID Tags) to alarm their relatives and nurses during life threatening situations as shown in Figure 8. The system consists of wireless sensor networks, existing RFID (Radio Frequency Identification) and Vital Sign Monitoring technology.

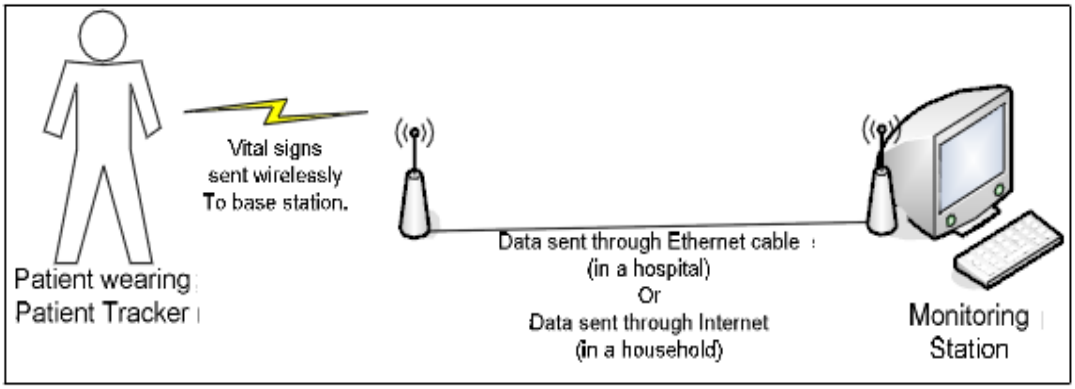


Figure 8: Health Tracker 2000 [30]

In [31], an intelligent Medicine Case System (iMec) was developed for assisting elderly patients' caretakers in medication monitoring. The system consists of the iMec which is a medicine case that can confirm the dosage of medication by using an internal camera using simple image processing. The ubiquitous sensors placed on the house furniture and appliance of the patient house and used to confirm the timing of medication, and the iMec server that is used to upload the adequacy about dosage and timing in it. The iMec System can measure the movement by using RFID tags and readers. The System used a simple fuzzy inference method to estimates the present behavior of the patient and evaluates the adequacy about the timing by using simple If-Then rules. They developed a RFID version iMec system by placing a high-power RFID reader in the medicine case. The reader can recognize RFID tags in the storage space because its scanning range is about 30cm. The system consists of a presence sensor for detecting the recipient in front of the case, a compact speaker for warning the recipient, a compact computer, and a wireless communication device (SunSPOT, Sun Microsystems) for receiving sensing data. They placed 11 RFID readers in the refrigerator, on the cupboard and on the kitchen unit of the patient's house. And they used 4 kinds of RFID tags for different purposes. The system costs too much.

Another wireless system was design to allow remote monitoring of patients in an elderly health care facility. The system makes it possible for old patients to receive treatment according to protective medical protocol. The communication between the agents and the smart wearable devices is conducted with wireless technologies: Wi-Fi, ZigBee, NFC, while radio-frequency identification (RFID) is used for identification [32].

In [33], the authors proposed a design using a guiding system, Radio Frequency Identification (RFID), IEEE 802.15.1 short-range wireless transmission technology and the

Internet to fabricate a blood pressure measurement (BPM) which works in cooperation with a health management system. The design has many advantages, including being easy to use by the aged, low cost and wireless connectivity. It allows the early detection of high blood pressure and provides a doctor with a means for observing a patient's health over a long period. Figure 9 shows the operation environment of the design.

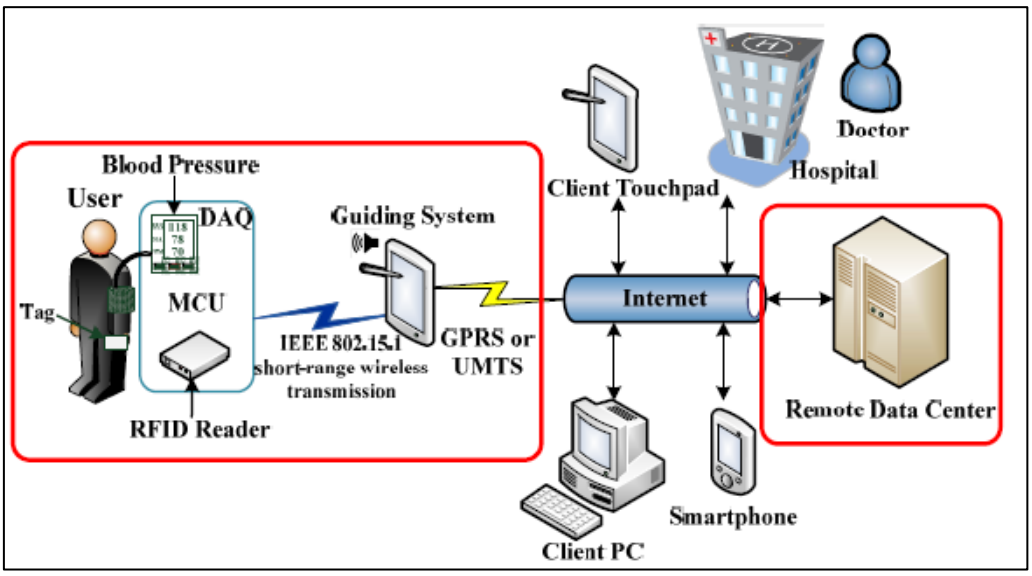


Figure 9: Operation Environment of the Design [33]

Another RFID Application was presented in [34]**.** The authors presented a sensor-enabled RFID system to monitor arm activity. They presented an approach that places sensors on patients and household objects. An accelerometer and the transmitter component of a radio-frequency proximity sensor are attached to objects; the receiver component is attached to the arm of interest. The receiver triggers an on-board RFID tag to signal proximity when that arm is within 23 cm of an instrumented object. In benchmark testing, this system detected perfectly which arm was used to move the target object on 200 trials. The measurement error was low (2.5%). The results support this system's reliability and validity in individuals with unimpaired movement; testing is now warranted in stroke patients. In [35]**,** the authors presented the design, implementation, and testing of a radio-frequency identification (RFID) system for healthcare applications. The constantly growing passive RFID technology at ultra-high frequencies (UHF), in conjunction with current state-of-the-art information and communication technologies (ICTs), was used for the system design. The end product was installed at an oncology hospital in Cyprus, where it was thoroughly evaluated by medical staff and hospital administrators. The authors three main objectives were to achieve an automatic and error-free patient identification of in-hospital patients using RFID-enabled cards or wristbands; Real-time location service (RTLS) for locating and

tracking medical assets and high-value equipment in the hospital ward; and quick and hassle-free drug inventory management through the use of inexpensive smart labels. A block diagram of the overall RFID system design, depicting the various hardware components used, is shown in Figure 10.

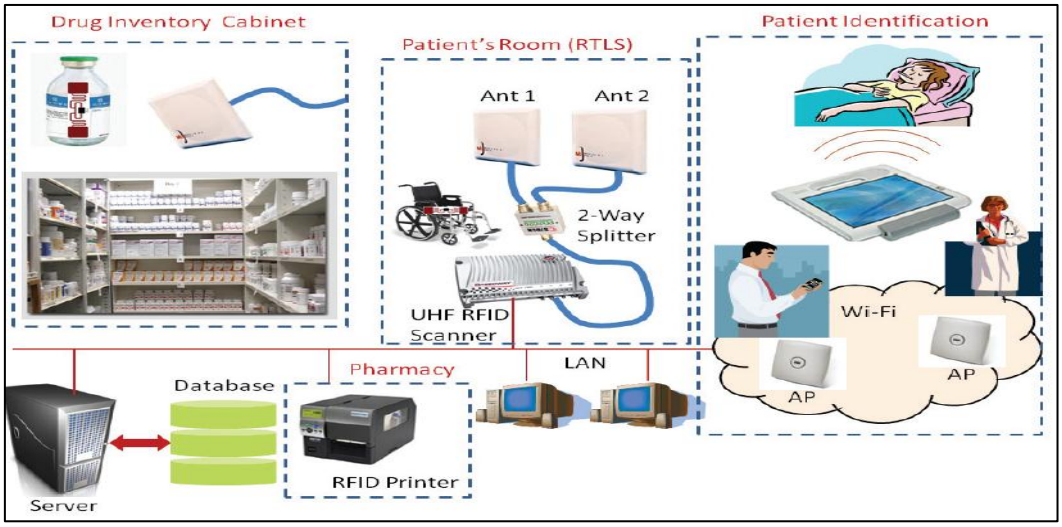


Figure 10: A block diagram of the RFID system's design, depicting the hardware components used [35]

1.3.5. GSM/GPRS-Based Solutions:

GSM and GPRS are standards for cellular telephone communications. The system resources required for the cellular technologies, GSM/GPRS, are too substantial to be even considered for this low-power project. In [36], the authors have developed a GSM mobile system to monitor brain function using a near-infrared light sensor as shown in Figure 11. The system is an example of a GSM application. Other example is in [37] SMS-based platform for cardiovascular tele-monitoring, which is a fully automatic platform to transmit, using the SMS service, medical data collected at home.

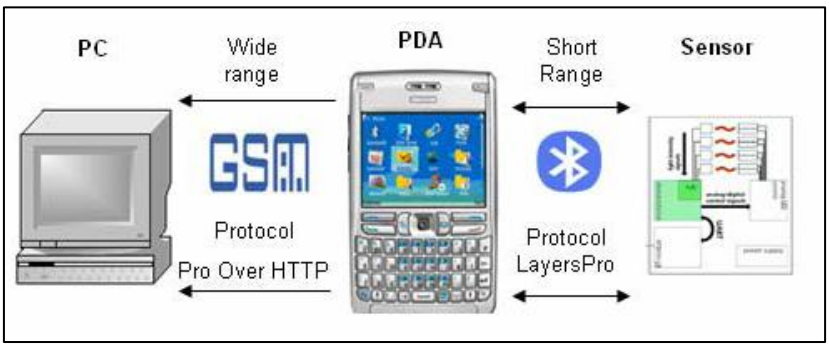


Figure 11: GSM mobile monitoring system [36]

As the e-health systems are evolving, a recent trend in electronic medical record is emerging and became necessity. Many electronic Health Records systems were reported and implemented. The EHR is the comprehensive electronic record of health-related information on a patient that is created and gathered cumulatively across more than one health care delivery organization. The record is managed and consulted by licensed clinicians and staff involved in the patient's health and care" [38]. An EHR system is described in Figure 12 [39] by Orion Health's software.

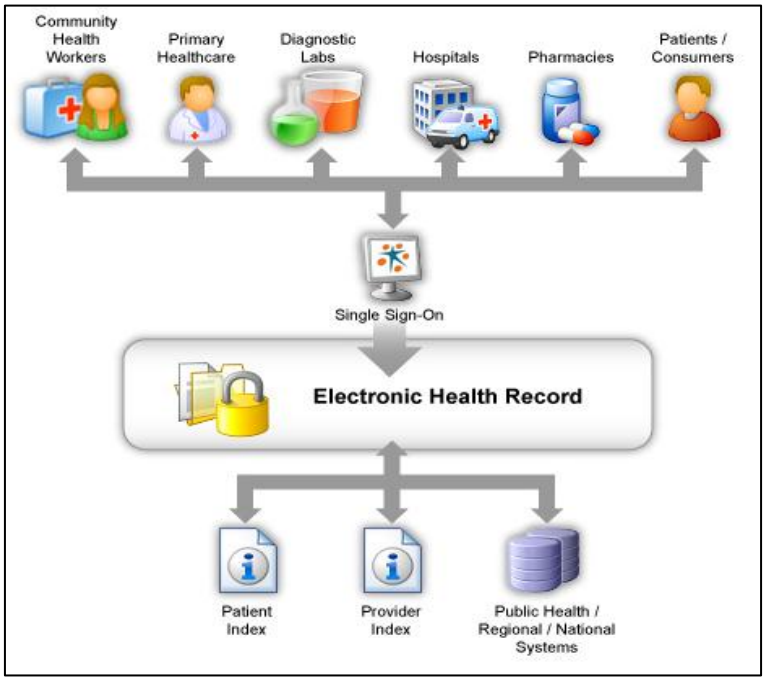


Figure 12: Orion Health's software EHR System [39]

The elements of an EHR include Health information and data, lab results, radiology reports, X-ray images, automated prescriptions, health educational material, online appointment scheduling and the number of patients a physician has treated. An Electronic Health Record EHR is smart enough to notify patients about their medicine interactions and help them make a diagnosis.

1.4. Fuzzy Logic Systems

"Fuzzy logic is a form of many-valued logic; it deals with reasoning that is fixed or approximate rather than fixed and exact. Fuzzy logic variables may have a truth value that ranges in degree between 0 and 1" [40] [41] [42]. It is simply a conclusion reached by a rule-based algorithm, "Fuzzy Logic", using linguistic variables that are utilized to form

membership functions (MFs) which may or may not have overlapping boundaries. The input to the rule-based may or may not have absolute values such as yes or no, 0 or 1; therefore the values can be varied between 0 and 1. The algorithm scans all the input/s values and generates output decision reflecting the status of the monitored object/s. i.e., the Fuzzy logic system is a simple, rule-based system that can be used to monitor biological parameters that could be difficult or impossible to model with simple linear mathematics.

Fuzzy logic-based algorithms have shown a potential to improve clinician performance by imitating human thought processes in complex circumstances and accurately executing repetitive tasks to which humans are ill-suited. Previous work on Fuzzy Logic has been implemented in the area of patients' care [43 - 47]. In [43], the author developed an artificial intelligence system using Fuzzy Logic. This system used an implanted blood glucose sensor [43]. The information from the sensor was used to adapt the rate of infusion of insulin to see whether it could cope with responses to common 'inputs' such as daily insulin, food and exercise. it was found the mean absolute percentage error between the predicted and actual blood glucose values was over 10%. Another study developed a clinically viable system that utilized an internal blood glucose monitoring system [44]. The system was able to monitor the glucose level and adjusts the insulin level using an expert fuzzy logic algorithm. In [45], the authors explored the use of an insulin pump and the application of fuzzy logic technology to act as an artificial pancreas in diabetes patient. The drawbacks highlighted so far include occasions when FL systems do not match standard human performance and this often relates to inadequate programming (it still requires an expert diabetologist to set the rules for how an expert system should behave). Fuzzy logic is very well suited for medical control systems because the parameters involved are mostly have wide range that may leads to different diagnose; for example one physician my consider a patient ill and the other considered him/her very ill. A tailored hardware and software system design can provide a high level of functionality and reliability. Such systems implementation uses multiple input sensors to monitor vital sings such as blood glucose levels. The collected data will be compared against each other to control the amount of insulin to supply. This redundancy makes the system less error prone [45]. Figure 13 depicts such system architecture.

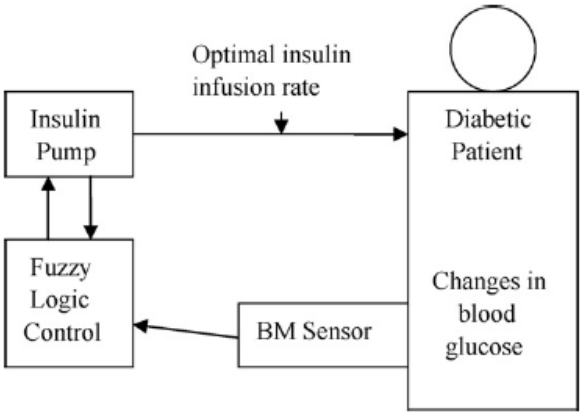


Figure 13: Demonstrates a closed loop feedback system, which continuously monitors the patient's blood glucose level and adjusts the infusion of insulin to an optimal rate [45]

Figure 14 shows another application of Blood glucose monitoring using Fuzzy logic [46]. The author described the use of fuzzy logic techniques to develop a decision support system that allows the optimization of postprandial glycaemia in type one diabetes patients. The process takes into account the kind of meal taken by patients, the pre-prandial glycaemia and the insulin resistance. The results were very encouraging. The system was able to suggest the appropriate change of insulin unites to be injected before a meal.

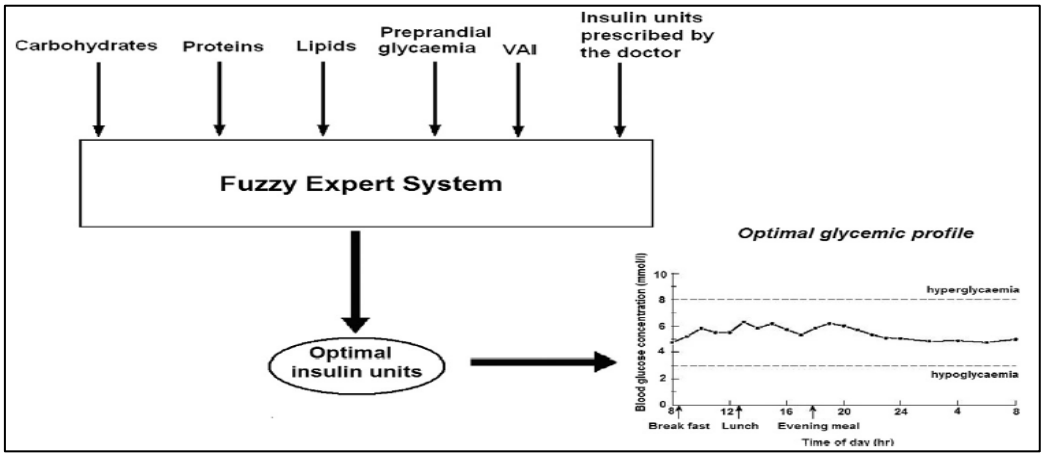


Figure 14: Input–output of the fuzzy expert system. The output of the fuzzy expert system assures an optimal glycemic profile [46]

Also, Fuzzy Logic was used for Heart Disease Diagnosis. In [47], Adeli and Nashat have presented the design of a Fuzzy Expert System for heart disease diagnosis. The reported system based on the V.A. Medical Center, Long Beach and Cleveland Clinic Foundation database. The system has 13 inputs including Chest Pain type, BP, BS, HR, Cholesterol, and one output that indicates of the patient is a heart disease patient. The system was designed

using Matlab software. Experimental results showed that this system did quite better than non-expert urologist and about 94 % as a well as the expert did.

The use of Fuzzy Logic was reported in other medical applications such as applying FL to Medical decision making in intensive care unit (ICU) [48]. The system used two inputs: The mean arterial blood pressure MAP and Hourly Urine Output (HUO). Theses inputs are used to determine how Intravenous Fluid Rate (IFR) should be adjusted each time measurements were made. In [49], a system that is capable to be used for medical diagnosis was developed. It uses the fuzzy logic design: fuzzifier, inference engine, rule base, and de-fuzzification giving the entries of five inputs: Protein, Red blood cells, Lymphocytes, Neutrophils and Eosinophil's, and generating three outputs: Normal, Hemorrhage and Brain Tumor. MATLAB simulation was utilized to formulate the rule-based engine. The simulation results are found in agreement with the design based calculated results. This research work proposes to develop a control system to enhance the efficiency to diagnose a disease related to human brain.

Another example, a Fuzzy Logic monitoring and diagnostic alarm system was developed to detect critical events during anesthesia administration [50]. In [51], a Master Thesis proposed a system that behaves like an un-biased expert that follow a process as the human expert and which searches the entire head and neck cancer patient database and prints out a patient record showing another patient's (a patient whose symptoms are most similar) treatment plan as the suggested starting point for generating the new plan. The system used case based reasoning that was applied using fuzzy IF THEN rules to search the patient database.

Chapter 2

Overall System Design

To design a reliable, scalable, secure, low cost, and low power consumption system, functional and nonfunctional requirements should be studied. This chapter defines the proposed system's functional and nonfunctional requirements. The overall design will be geared towards the satisfaction of these requirements.

2.1. System Hardware Requirements

Defining the system requirements helps designers to better select the components and optimizes resources. In this research, the system requirements establishes the features and services that a wireless monitoring system should provide and the constraints under which it must operate. The following section highlights the proposed system functional and non-functional requirements.

2.1.1. Functional Requirements

A functional requirement specifies what the system should do: "A requirement specifies a function that a system or component must be able to perform [52]." In a software engineering context, functional requirements describe the list of specific tasks or behaviors which a product must perform. The primary requirements in this project are to remotely collect a patient's vital signs that are measured by RFID based sensors, evaluate the patient health status using fuzzy logic algorithm, keep patient health history in electronics medical records and alerts the caretakers about the patient status. Also, a web-based tool that is capable of organizing and displaying collected sensor data is required. Other functional requirements include:

I. Arranging readers in a specific arrangement and localizing their positions to a fixed dataset,

II. Having the ability to collect readings from nodes in the wireless sensor network

III. Performing registration tasks, which include,

i. Registering staff

To be able to use the monitoring system, each staff member must have an account. Each staff member is given a username, password, and staff ID. Minimal personal information is required, such as first and last name, and telephone number.

ii. Registering patients:

Patients must be registered into the system and their information should be profiled and kept in a database. The patients' personal information should be recorded, given a patient ID, a temperature tag ID, a blood pressure tag ID, a SPO2 tag ID, and a blood sugar tag ID. They must also be assigned to a certain staff member.

iii. Deleting patients

Staff members should be able to profiling, charging and discharging patients

iv. Canceling staff member access

Unauthorized staff members should be denied access to the system.

v. Logging in

Only authorized staff members could log in, monitor, and track patients

IV. Collecting patients' vital signs

Reading patients' vital signs from RFIDs sensors happens through various means, including,

i. Reading data from temperature-measuring wristbands

We have wristbands with RFIDs connected to temperature sensors. We must have a reader that has multi-tag reading capabilities to be able to read multiple tags simultaneously.

ii. Reading data from blood pressure meters

The system must also read frames coming from an RFID tag connected to a blood pressure sensor.

iii. Reading data from blood sugar meters

The system must also read frames coming from an RFID tag connected to a blood sugar sensor.

iv. Reading data from SPO2 meters

The system must also read frames coming from an RFID tag connected to an SPO2 sensor.

V. Storing data

All data read is considered to be of high importance and required to assist in monitoring the patients. For that, data must be continuously stored in a database.

This data will be used in the system's fuzzy logic engine to monitor patients on a regular basis.

VI. Displaying data

i. Displaying patients' data

Medical personnel can view patients' personal information and data gathered. Data will be displayed in several formats according to the users' request. Users will be able to choose whether they want to view patients' gathered data using the web-based application or the desktop application and to specify the time period they want to monitor. Patient selection is done by entering a patient ID. Staff members can view patients' temperature, blood pressure, SPO2, heart rate and blood sugar.

ii. Displaying staff's data

Staff members must be able to view other staff members' personal information such as telephone numbers in case of emergencies. Staff member selection is done by selecting the staff member from a list with all staff members' names and staff IDs (SIDs).

VII. Alerting staff

Staff will be alerted through an SMS if any abnormality in the patients' data was detected. Using the fuzzy logic engine, we can know whether the patient status is normal, low risk, or high risk.

2.1.2. Non-Functional requirements

Non-functional requirements describe the limitations or constraints in the implementation of a product. The non-functional requirements that needed to be investigated in this project include:

- Accessibility

The distributed nature of transmission lines motivates the need to develop a web-based interface to deliver information to users. Such interfaces are accessible over the web, from any location without the need of installing

specialized software to view data, and are compatible with the majority of web browsers.

- Scalability

The use of a web-based tool to visualize the activity of the wireless sensor networks was an attempt to improve the scalability of the number of users who can access the system. Furthermore, the system is scalable to accommodate additional patients. A reader is capable of reading and processing 100 tags simultaneously. And multiple readers can be used in the system.

- Security requirements

To keep the system safe and secure, the user, whether a doctor or a nurse, must enter a valid username and password every time he/she wants to access the system. This measure is taken in order to protect doctor-patient confidentiality. None of the information can be updated without the proper security requirements. In general, information cannot be updated, as information is not entered by the nurses or doctors but sent by the RFID tags to the reader, and the reader to the clients.

- Software usability requirements

The system should be simple and easy to use, user-friendly. No or few doctors/nurses should find it hard to use the system.

- Safety

The system shouldn't interfere or collide with other systems in the same environment. Data should be backed up in case of an emergency.

- Operational requirements

Products should have an extended battery life, and resilience.

2.2. Overall System Architecture

Based on the above requirements, the proposed wireless monitoring system should consist of five major building modules:

- ✓ The Mobile Data Acquisition Unit Module
- ✓ The Mobile Communication Network Module
- ✓ The Hospital Server Module
- ✓ The Home Station Module
- ✓ The Clients Access Module

The mobile data acquisition unit module consists of sensor units worn by the patient. These sensor units monitor real-time vital signs including temperature, blood pressure, heart rate, SPO2, and blood sugar. The vital signs information then will be wirelessly transmitted wirelessly through wireless access points, using RFID technology, to a central monitoring computer for processing through the mobile communication network module. The proposed system architecture is scalable in both the number of patient's and number of monitoring areas covered. Each monitoring area can support multiple sensor units. Using this type of automated monitoring allows a minimal number of medical personnel to comprehensively address the needs of a large number of patients. A block diagram of the proposed system is shown in Figure 15 below.

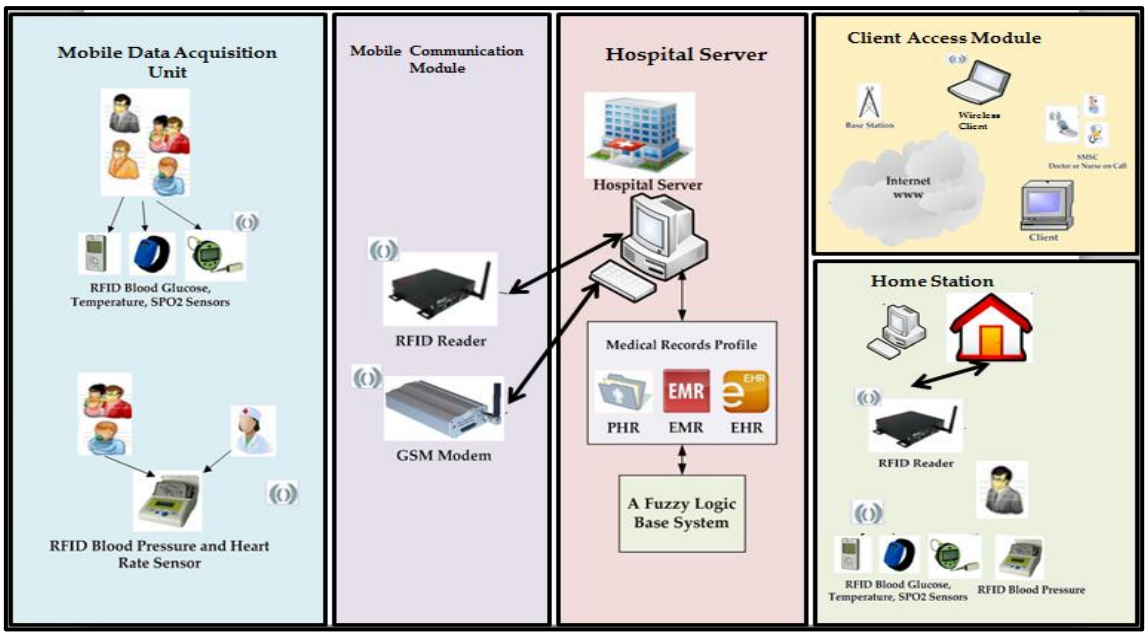


Figure 15: System architecture

The complete system for monitoring patients consists of data acquisition units i.e. sensors and readers which are described in this chapter, the GUI and web application, which

are further described in Chapter 3, and the fuzzy logic engine, which is further described in Chapter 3. The main hardware requirements of our system are described in Table 1.

Requirements	Model Number	Description
TEMPERATURE DETECTION WRISTBAND	AT245MFA	➢ Measures the patient's Temperature, and Send out a reading every 0.5 second when moving, and 4 seconds when not moving. ➢ Frequency: 2.40~2.48 GHz. ➢ Reading Distance: 20M~50M.
RFID BLOOD PRESSURE GAUGE	AT245MBP	➢ Measures the patient's Blood Pressure and Heart Rate, and Send out signal after measurement when power is ON. ➢ Frequency: 2.40~2.48 GHz. ➢ Reading Distance: 20M~50M.
RFID SPO2 GAUGE	AT245MTE	➢ Measures the patient's SPO2 and Heart Rate, and Send out a reading every 1 second when power on. ➢ Frequency: 2.40~2.48 GHz. ➢ Reading Distance: 20M~50M.
RFID BLOOD SUGAR GAUGE	AT245MSG	➢ Measures the patient's Blood sugar, and Send out signal after measurement (with power ON). ➢ Frequency: 2.40~2.48 GHz. ➢ Reading Distance: 20M~50M.
AR245M ACTIVE READER	AR245M	➢ Reads Data collected by sensors. ➢ Frequency: 2.4GHz-2.48GHz ISM Microwave. ➢ Identification: All-direction identification. ➢ Reading Distance: Max. 80M, open area, no interference, adjustable. ➢ It can read more than 100 cards simultaneously
TCP/IP		➢ Connects the reader to the desktop/ server using TCP/IP protocol.
SWITCH		➢ Connects more than one reader to the server.
SERVER		➢ Connects the reader to the PC station. ➢ Connect the data being read by the reader to a database
GSM MODEM		➢ Connects the GSM modem to the server and alerts the staff by sending an SMS.

Table 1: The main hardware requirements of the system

We next will outline the details of the architecture of a proposed remote-monitoring system. Followed by the description of the operation of the overall proposed system and each system component. A prototype implementation of an automated patient monitoring system will be described. The different aspects of the prototype system will be addressed, including overall system design and hardware implementation. Connectivity of the various units, and software implementation will be covered in the next chapter.

2.2.1. The Mobile Data Acquisition Unit Module

This mobile data acquisition unit module consists of the RFID based vital signs sensors. Vital sign measurement is the initial and the most important task in monitoring patients. The existing instruments are commonly equipped with cable-based sensors, which make them bulky, intrusive and inconvenient. These sensors may not be suitable for long-term monitoring of vital sign at home. To improve comfort and mobility of patients, wireless biomedical sensors are considered. They are normally small in size and have wireless communication capabilities. This chapter evaluates the sensors we used to measure vital signs of our patients.

Vital signs are very important in patient monitoring. In traditional medicine, health examination and monitoring was carried out by traditional manual medical devices, through which medical personnel examine a patient and make decisions based on their knowledge and experience. The development of electronics and digital signals processing techniques has made it possible to use small and wireless devices to examine patients. The system consists of the following RFID based vital signs sensors:

2.2.1.1. **Blood Pressure Sensor**

Typical blood pressure sensors used in clinical environments are designed to measure systolic and diastolic blood pressures utilizing the oscillometric technique. A blood pressure sensor is usually used along with a pump bulb and a standard adult size adjustable cuff (typically 25 to 40 cm) that can inflate and deflate automatically [53]. In addition, a wrist-worn blood pressure measuring device, which is portable and user-friendly, has already been utilized in current practice of patient monitoring. This type of device includes a memory storage that makes recording measurements easy, but they do not include communication capabilities for wireless patient monitoring systems. Some efforts have been made to design a wireless sensing device for remote monitoring of blood pressure. The proposed system includes BP measurements. The BP monitor measures SBP, DBP, and pulse rate of patients and sends the data wirelessly using RFID technology to an active RFID reader. Figure 16 shows a picture of how this blood pressure monitor can be used.

The blood pressure unit uses AA batteries to function. It is important to check if batteries have enough power to assure that the incorporated RFID tag is transmitting data. A nurse has to be around to manually measure the blood pressure of patients, but

the data is sent wirelessly to our system GUI and database. In this case, three different values are being measured and sent:

1. Pulse: this is the number of times the heart beats per minute. The average heart beat rate is 80 beats per minute.
2. Systolic Blood Pressure (SBP): this measure is the top number. It measures the pressure of the blood within the vessels as the patient's heart contracts. The average measure for systolic is 120.
3. Diastolic Blood Pressure (DBP): this measure is the bottom number. It is the pressure of the patient's blood between the heartbeats (when the heart is resting and then refilling). The average diastolic measure is 80.

A BP sensor will be transmitting patients' SBP and DBP levels and heart rates respectively wirelessly (through RFID tags to the reader). Table 2 shows the RFID tag attached to the BP sensor specification. It shows that the frequency range is from 2.4 to 2.48 GHz. The reading distance is from 20 to 50 meters, and so on. The wireless transmission of the data could be clearly understood after taking a look at the data frame structure and data fields in Figure 17.

Figure 16: RFID BP gauge.

RFID Tags Specification	
Frequency	2.4GHz – 2.48 GHz
Reading Distance	20M – 50M
Parameter	ID(FF 00 00 00 00), user data
Blood Pressure	20 ~ 280 mmHg, Accuracy±5mmHg
PULSE	40 ~ 195 BPM, Accuracy±3%

Table 2: RFID BP tag specification

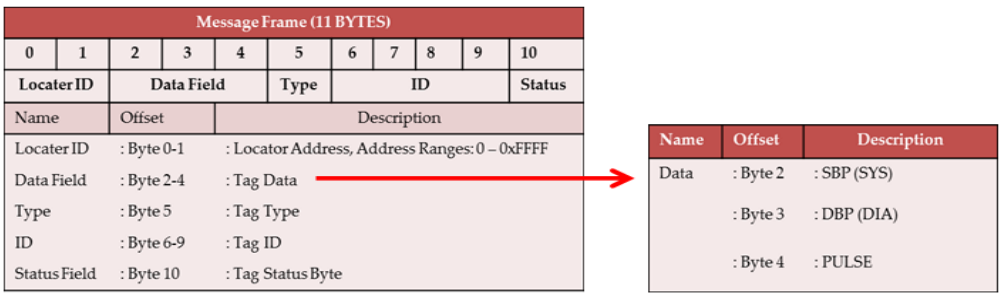


Figure 17: RFID BP data frame structure and data fields

2.2.1.2. Pulse OxiMeter (SPO2)

The pulse oximeter was invented for patient monitoring in the early 1970s. It can be used to examine two types of vital signs: heart rate and blood oxygen saturation (SPO2). These parameters yield critical information, particularly in emergencies when sudden changes in heart rate or reduction in blood oxygen saturation can indicate a need for an urgent medical intervention.

The pulse oximeter has advantages when used in wireless patient monitoring. The major advantage is that one sensor provides two types of vital signs at a time. Hence, it would offer more flexibility and convenience in wireless patient monitoring. An oximeter can be simply placed on a patient's finger for monitoring (as shown in Figure 18); professional skills are not required for placement compared to ECG sensors. Supported by the RFID wireless technology, pulse oximeter was utilized in our wireless patient monitoring system.

In addition to measuring the patients' blood pressure, our system also includes SPO2 measurement. The SPO2 unit uses AA batteries to function as the BP monitor. A nurse has to be around to manually measure the blood pressure of patients, but the data is sent wirelessly to the system's GUI and database. Using the SPO2 Unit, two different values are being measured and sent:

1. Pulse: this is the number of times the heart beats per minute. The average heart beat rate is 80 beats per minute.
2. SPO2: this measure the blood oxygen saturation percentage. The average measure for the SPO2 is 97.

An SPO2 sensor will be transmitting patients' SPO2 levels and heart rate respectively wirelessly (through an RFID Tags to the reader). Table 3 shows the RFID Tag attached to the SPO2 sensor specification. It shows that the frequency range is from 2.4 to 2.48 GHz. The reading distance is from 20 to 50 meters, and so on. The wireless transmission of the data could be clearly understood after taking a look at the data frame structure and data fields in Figure 19.

Figure 18: RFID SPO2 gauge.

RFID Tags Specification	
Frequency	2.4GHz – 2.48 GHz
Reading Distance	20M – 50M
Parameter	ID(1-255), user data
SPO2	35%-99%, Accuracy : ±2%
PULSE	30-250 BPM, Accuracy : ±2%

Table 3: SPO2 RFID Tag Specification

Message Frame (11 BYTES)										
0	1	2	3	4	5	6	7	8	9	10
Locater ID		Data Field			Type	ID				Status

Name	Offset	Description
Locater ID	: Byte 0-1	: Locator Address, Address Ranges: 0 – 0xFFFF
Data Field	: Byte 2-4	: Tag Data
Type	: Byte 5	: Tag Type
ID	: Byte 6-9	: Tag ID
Status Field	: Byte 10	: Tag Status Byte

Name	Offset	Description
Data	: Byte 2	: SPO2
	: Byte 3	: PULSE
	: Byte 4	: Reserved – Fill "00"

Figure 19: Data Frame Structure and Data Fields of the SPO2 Unit.

2.2.1.3. Body Temperature Sensor

Each patient in our system will be wearing a temperature-measuring wristband. This band has a sensor which measures the temperature of the body. Each tag has a built-in battery that is recharged using DC power. The battery lasts up to a week without charging. Information about the temperature is updated every 10 seconds. It has a temperature tolerance of ±0.2℃. The wristbands in our system are active RFID tags. Since they are active, they have an internal battery source, which means that after a lot of usage, they need to be charged in order for them to be supplied with power again. Figure 20 shows our system's wireless body temperature sensor.

Temperature Sensor will be transmitting patients' temperature wirelessly (through RFID tags to the reader). Table 4 shows the RFID tag attached to the temperature sensor specification. It shows that the frequency range is from 2.4 to 2.48 GHz. The reading distance is from 20 to 50 meters, and so on. The wireless transmission of the data could be clearly understood after taking a look at the data frame structure and data fields in

Figure 21. These are the data fields that transmitted from the wristbands. For the temperature, the integer and the decimal parts are being sent, as well as a 1 bit to indicate whether the temperature value is positive or negative.

Figure 20: RFID Temperature Tag

RFID Tags Specification	
Frequency	2.4GHz – 2.48 GHz
Reading Distance	20M – 50M
Parameter	ID(1-255), user data
Temperature Range	30 – 43 ℃
Working Environment	0 – 80 ℃

Table 4: The RFID Tag attached to the Temperature Sensor specification

Message Frame (11 BYTES)										
0	1	2	3	4	5	6	7	8	9	10
Locater ID		Data Field			Type	ID				Status

Name	Offset	Description
Locater ID	: Byte 0-1	: Locator Address, Address Ranges: 0 – 0xFFFF
Data Field	: Byte 2-4	: Tag Data
Type	: Byte 5	: Tag Type
ID	: Byte 6-9	: Tag ID
Status Field	: Byte 10	: Tag Status Byte

Name	Offset	Description
Data	: Byte 2	: 0xFF
	: Byte 3	: Integer Parts of Temperature
	: Byte 4	: Decimal Parts of Temperature MSB of Byte 4 is sign bit: 0: Positive vale 1: Negative value

Figure 21: Data frame structure and data fields of the Temperature Sensors.

2.2.1.4. Blood Sugar (Glucose) BS Monitor

Diabetes is a major, complex chronic metabolic disease, for which the health care is supposed to be a satisfactory daily diet and practicing regular habits, in addition to proper medication and qualified doctors. In our system, we have a mobile (RFID) blood sugar sensor. Patients can measure their blood sugar levels using the device shown in Figure 22, and then the data will be wirelessly transmitted to our GUI through an RFID Reader. Table 5 shows the RFID tag attached to the blood sugar sensor specification. It shows that the frequency range is from 2.4 to 2.48 GHz. The reading distance is from 20 to 50 meters, and so on. The wireless transmission of the data could be clearly understood after taking a look at

the data frame structure and data fields in Figure 23. These are the data fields transmitted from the BS Gauge.

Figure 22: RFID blood sugar BS gauge

RFID Tags Specification	
Frequency	2.4GHz – 2.48 GHz
Reading Distance	20M – 50M
Parameter	ID(1-255), user data
Description	Full function keypad design Large LCD display Only take 6 seconds for testing Minimum blood needed (0.7uL),

Table 5: Blood sugare BS RFID tag specification

Message Frame (11 BYTES)										
0	1	2	3	4	5	6	7	8	9	10
Locater ID		Data Field			Type	ID				Status

Name	Offset	Description
Locater ID	: Byte 0-1	: Locator Address, Address Ranges: 0 – 0xFFFF
Data Field	: Byte 2-4	: Tag Data
Type	: Byte 5	: Tag Type
ID	: Byte 6-9	: Tag ID
Status Field	: Byte 10	: Tag Status Byte

Name	Offset	Description
Data	: Byte 2	: Glucose
	: Byte 3	: Reserved – Fill "00"
	: Byte 4	: Reserved – Fill "00"

Figure 23: The Data Frame Structure and Data Fields in BS Gauge.

2.2.2. The Mobile Communication Network Module

The mobile communication network module consists of an RFID reader and a GSM modem. This module collects the vital signs data from the mobile data acquisition unit sensors and forwards it either to the home server or the hospital server via an RFID reader. The GSM modem sends alert messages to the on-call doctor.

2.2.2.1. RFID Reader

The reader is a device with an antenna that emits radio waves. When there is a tag in a range up to 20 meters in diameter, it would respond to the reader by sending back the data

stored in it. The reader also has an ID parameter which is made up of 8 bits. Therefore, we could have 256 different ID combinations. Its frequency ranges between 2.40 to 2.48 GHz. In order to connect the reader to the PC station, a TCP/IP connection is used. The reader needs to be connected to a DC power supply for it to start reading. The hyper terminal was used to configure the IP address and port for the reader. The IP address was set to 192.168.1.3, and it communicates to the PC using port 20700. The reader is shown in Figure 24.

Figure 24: The RFID reader

Accurate and timely measurements of vital signs re vitally important in wireless patient monitoring systems. Relevant sensors that were used to measure vital signs are discussed and evaluated in this section. These sensors can be used to measure patients' blood pressure, heart rate, oxygen saturation, body temperature, and blood sugar. In-order to achieve more precise measurements, multiple sensors could be places in appropriate positions for measuring vital signs in wireless patient monitoring.

2.2.2.2. GSM Modem

The modem will be connected to the server. The ambulance and staff will be informed via SMS if anything goes wrong with a patient in order to be able to help the patient as fast as possible.

A GSM modem, also known as a Global System for Mobile Communications, is a famous standard for digital mobile cellular services. It allows us to send and receive SMS through computers. In order to be able to do that, we need a program to which the GSM modem can

connect and “talk”. In our case, we decided to use Ozeki SMS server. It is a flexible and user-friendly application which allows its users to send and receive text messages via the computer. We also need a SIM card which is subscribed to a mobile operator (Etisalat in our case).

The GSM modem was connected using a serial port (RS232). All the options needed to make the modem work were configured in the Ozeki SMS application. As for the HyperTerminal, the following settings were used:

- Baud Rate: 9600
- Parity: None
- Stop Bits: 1
- Data Bits: 8
- COM1

2.2.2.3. Types of available communication:

2.2.2.3.1. Wired Communication:

Wired communication exists between the RFID reader and the server. There are two methods to connect the reader to the PC. Each method is briefly explained as follows:

- Serial connection:

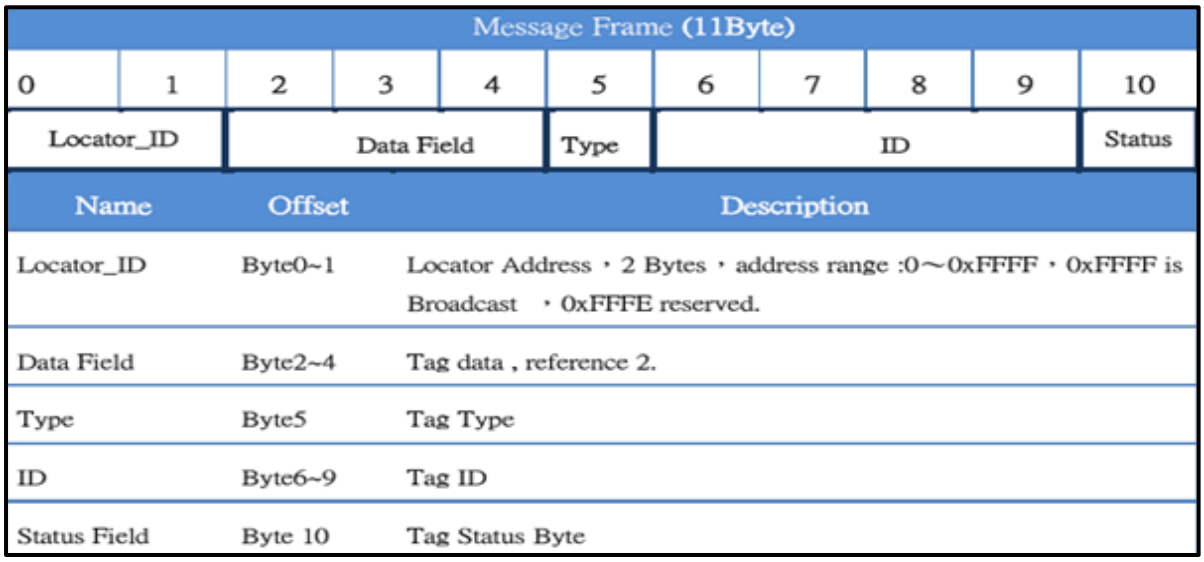
  An RS-232 wire can be used to connect the reader to the PC.

- LAN connection:

  Local Area Network covers a small geographical area. LAN follows the IEEE 802.3 Standard Ethernet technology that runs at 10kbps or 1,000 Mbps. An Ethernet cable is used with an RJ-45 connecter to connect the reader to the PC through the Ethernet ports.

2.2.2.3.2. Wireless Communication:

A blood pressure sensor, SPO2 sensor, blood sugar sensor and temperature wristband will be transmitting patients’ blood pressure levels, blood sugar levels, SPO2, heart rate and temperatures respectively wirelessly (through RFID tags to the reader). This could be clearly understood after taking a look at the data frame structure and data fields in the following figures (Figures 25 and 26).



Message Frame (11Byte)										
0	1	2	3	4	5	6	7	8	9	10
Locator_ID		Data Field			Type	ID				Status

Name	Offset	Description
Locator_ID	Byte0~1	Locator Address ‧ 2 Bytes ‧ address range :0～0xFFFF ‧ 0xFFFF is Broadcast ‧ 0xFFFE reserved.
Data Field	Byte2~4	Tag data , reference 2.
Type	Byte5	Tag Type
ID	Byte6~9	Tag ID
Status Field	Byte 10	Tag Status Byte

Figure 25: Active Tag Message Frame

Name	Offset	Description
Data	Byte2~4	No data , Fill with 0xFF.
Type	Byte5	0x59(Configuration Lock) ‧ 0x79(Configuration setting available)

Figure 26: Wristband Data Field

Name	Offset	Description
Data	Byte2	0xFF
	Byte3	Integer parts of temperature
	Byte4	Decimal Parts of temperature MSB of Byte[4] is Sign bit 0 : positive value 1 : negative value
		Example. Byte[3] Byte[4] temperature 0x20 0x00 32℃ 0x20 0x80 -32℃ 0x20 0x01 32.1℃ 0x20 0x81 -32.1℃

Figure 27: Data fields sent from the temperature sensor

These are the data fields transmitted from the wristbands. As an example, the data field for the temperature is shown in Figure 27. For the temperature, the integer and the

decimal parts are being sent, as well as a 1 bit to indicate whether the temperature value is positive or negative. The structure of the data frame being transmitted from the blood pressure sensor, blood sugar sensor, and SPO2 sensor will have different format.

2.2.3. Hospital Server

The hospital server is the high-end computer. The server hosts the EHR records, the fuzzy logic base system, and the system's database. This high-end server has a high speed and adequate storage capabilities. The details of the fuzzy logic engine and the system's database are described in Chapter 3.

2.2.4. Home Station

The home station consists of mobile RFID sensors, an RFID reader and a PC connected to the Internet. It consists of the following sensors:

- A temperature sensor
- A blood pressure sensor
- An SPO2 sensor
- A blood sugar sensor

The reader is connected to the PC using a TCP/IP cable. The sensors transmit vital signs measurements to the reader wirelessly. The data will be saved in the server database and updated on the website.

2.2.5. The Client Access Module

The client access module allows clients to login and view their contact information, appointments, and diagnoses online. This module can be used by insurance companies, doctors, clients, etc.

Chapter 3

Software Architecture

Figure 28 shows a high level view of the components that comprise the software architecture of the system. The Mobile Patient Monitoring System (MPMS) is comprised of five major components. The components collectively provide for the efficient and reliable operation of the complete system. These components are Data Acquisition Unit (DAQ) Application Programmable Interface (API), MySQL DataBase Manger, Fuzzy Logic Matlab code, Graphical User Interface (GUI), C# code, and a web application using C# and HTML code. The MPMS is comprised of all five pieces of the software operating together. After the system is built, experiments were carried out to validate the developed framework overall robustness, reliability, etc. The evaluation of the system was executed in an indoor office environment. The details of each software component are described in the next subsections.

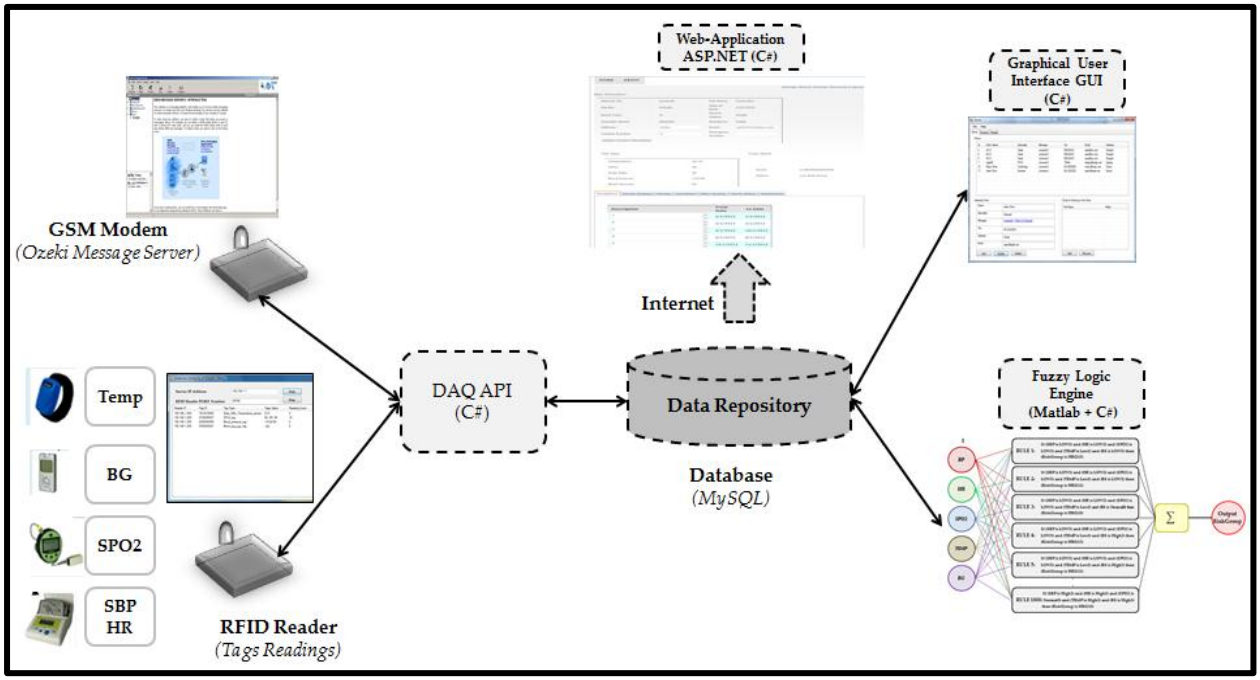


Figure 28: System Software Architecture

3.1.The Data Acquisition Unit (DAQ) Application Programmable Interface (API)

The DAQ API allows interacting with the reader in order to collect the data and display them on the API screen. It is the front-end control and monitoring interface used by system operators. It includes many different displays that allow operators to monitor patients' vital signs. The API was implemented based on the API that was provided by Summit.co (a program required to interact with the reader). Summit.co is the company that provided the RFID products. Extra functionalities to the code were added and adjusted to suit and fulfill the requirements of the system. The API was written in C#, and it allows operators to view real-time patient data. It has the following functionalities:

a) Finding a tag type,
b) Extracting temperature, blood pressure, SPO2, blood sugar and heart rate frames values received by an RFID Reader,
c) Finding corresponding patient from tag ID,
d) Rearranging the vital signs values to be compatible with the arranged database tables
e) Inserting the vital signs values in table, and
f) Triggering an alarm in case of any irregularities. Irregularities are discussed in a later section.

When the API is first launched, the monitoring screen is displayed. The monitoring screen displays real-time vital signs information for every patient in the system. A snapshot of the monitoring screen is shown in Figure 29.

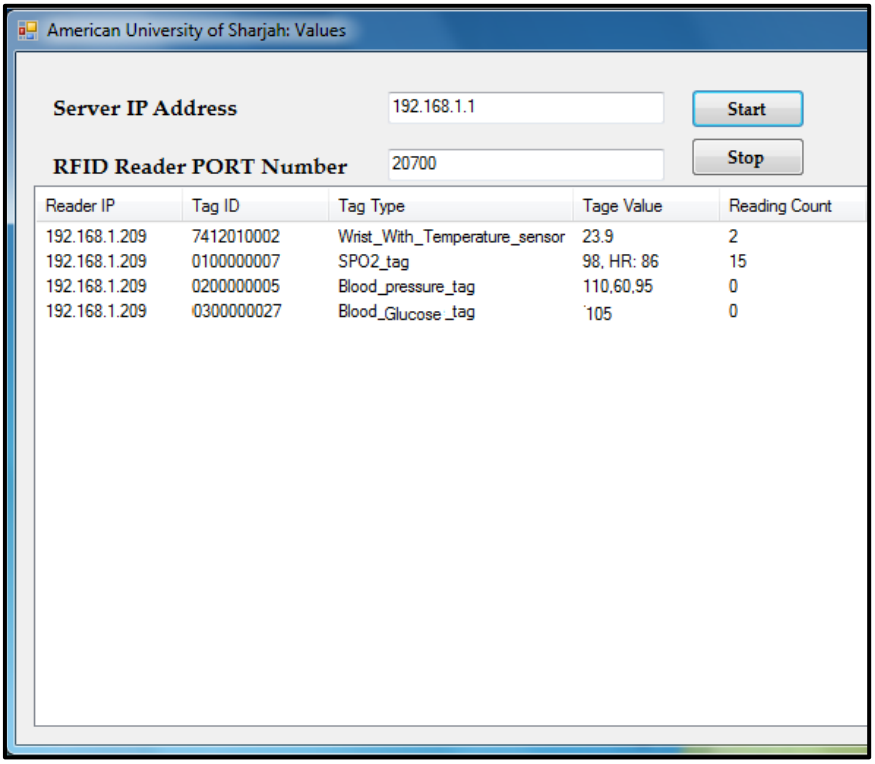


Figure 29: The Reader API Monitoring Screen

The monitoring screen includes the following fields:

- The transmitted monitoring signal of the Server IP Address field.
  - In this text field, the server IP address is entered.

- The port number of the monitoring RFID reader field.
  - In this text field, the reader port number is entered.

- Real-time patient display panel:

This panel displays the following real-time vital signs information for every patient registered in the system:

- Reader IP
  - It is the default gateway's number, and it indicates in which reader coverage area the patient is currently.

- Tag ID
  - It is uniquely assigned to each patient and recorded when the patient is added to the system.

- Tag Type
  - It indicates the type of the sensor the patient is wearing based on the tag ID. There are four kinds of sensors :
    - Temperature Sensor: Measures the temperature of the patient.
    - Blood pressure monitor: Measures the patient's BP and HR.
    - SPO2 Gauge: Measures the patient's SPO2 and HR.
    - Blood sugar monitor: Measures the patient's blood sugar Level (BS)

- Tag Value
  - It is a value retrieved from the sensor frame (after formatting and adjustments).

- Reading count
  - It indicates how many times the patient's vital signs information are updated.

By pressing the **Start** button of the system DAQ API, which is shown in Figure 2, the user can view real-time trending data for individual patients

3.1.1. API Flow Chart

The API is implemented using C#. The flow of events in within the API program and its data structure are shown in Figure 30**.**

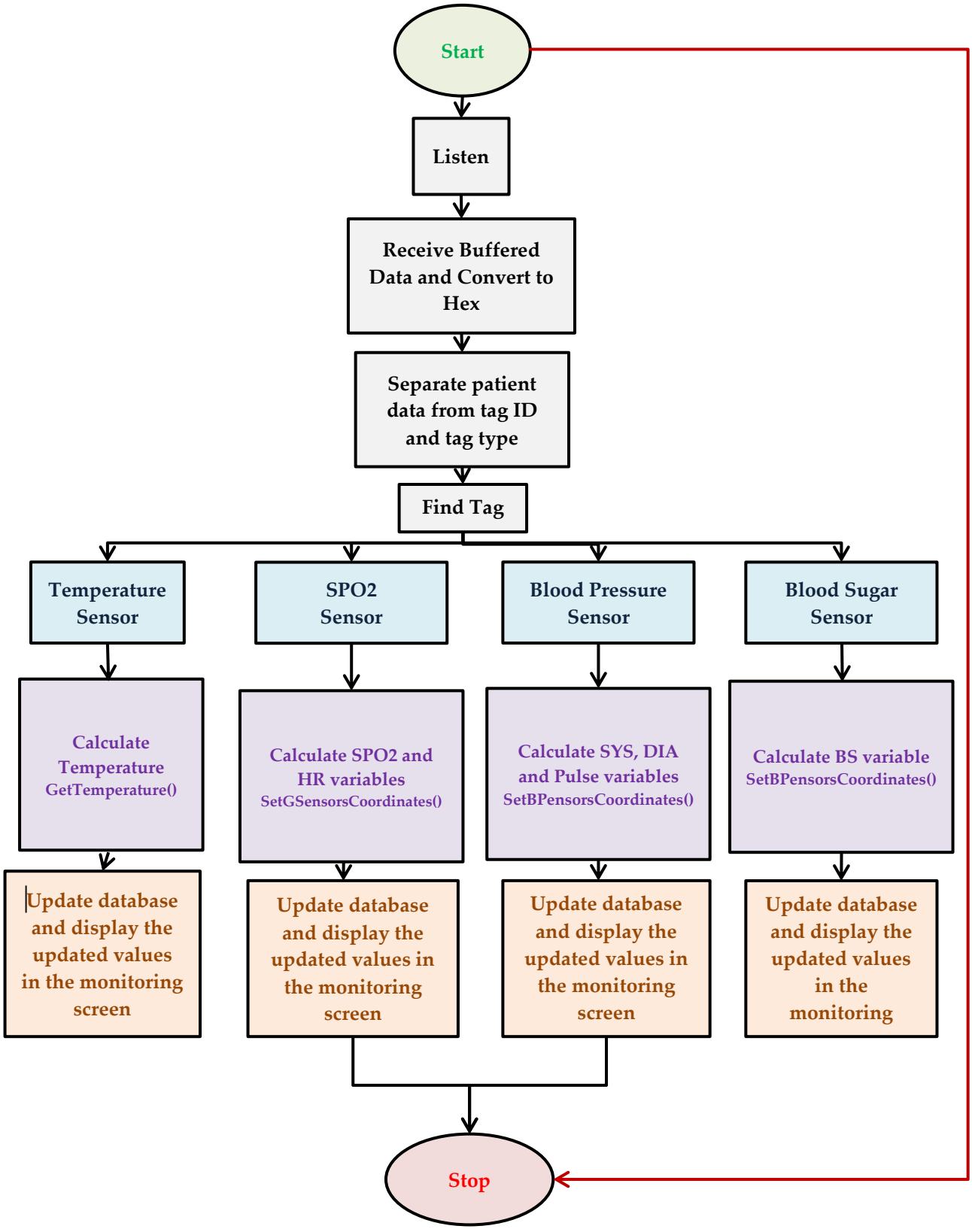


Figure 30: The sequence of the system's API events

3.1.2. API's Main Functions:

The implementation and Data Structure of the API required the usage of the following functions:

- DBConnect()

  This is a constructor that calls the Initialize ().function

- Initialize()

  This function is of void type. It initializes variables required for the database connection such as server, database name, database user ID, database password and the SQL query required for the connection to be made. It also creates a new connection.

- OpenConnection()

  As its name suggests, this function establishes the connection with the database. This function is of the Bool type.

- CloseConnection()

  This function closes the database connection. This function is of the Bool type.

- StopListen()

  This function is of void type and is used to stop the monitoring.

- ListenState()

  This function determines whether the monitoring is successful or not. The monitoring is done at 0.5 seconds.

- ReceiveData()

  This function covers a number of tasks. It,

  i. gets buffered data using the monitor's socket,

  ii. gets IP EndPoint of Reader Socket,

  iii. get Reader IP,

  iv. sends buffered data to be analyzed by calling the function BufferData_Analyze (Byte[] _byteBuffData)

v. gets a tag's name by calling the function GetChtName(TagFormatClass.TagType _tagType),

vi. adds analyzed data to the form,

vii. obtains the time from the system and puts in the format of date type in MySQL database,

viii. retrieves from the database the patient ID which is mapped to the read RFID tag ID,

ix. drops data frames that do not correspond to any patient's ID stored in the patient table, and

x. inserts the read data into the vital_sign table in the thesis database.

- GetChtName(TagFormatClass.TagType _tagType)

  This function sets each tag's name for the grid view based on the tag's type.

- BufferData_Analyze(Byte[] _byteBuffData)

  This function starts the process of analyzing buffered data. It goes through the following procedure:

  i. It sets the tag status by calling the function: SetTagState(byte _byteStatus, ref TagFormatClass _tagData).

  ii. It finds the tag type.

  iii. Based on tag type, it calls one of the three functions: GetTemperature(string _strDataSection), SetGSensorCoordinates(string _strDataSection, string tagID, ref TagFormatClass _tagData) or SetBPSensorCoordinates(string _strDataSection, string tagID, ref TagFormatClass _tagData).

  iv. It calls InsertTemp() function if the tag type is wristband temperature.

- GetTemperature(string _strDataSection)

  This function analyses the temperature data.

- SetBGSensorCoordinates(string _strDataSection, string tagID, ref TagFormatClass _tagData)

  This function analyses the motion data and saves the data into the system's database.

- SetBPSensorCoordinates(string _strDataSection, string tagID, ref TagFormatClass _tagData)

  This function analyses the blood pressure data and saves the data into the system's database.

- SetSPO2SensorCoordinates(string _strDataSection, string tagID, ref TagFormatClass _tagData)

  This function analyses the blood pressure data and saves the data into the system's database.

- SetTagState(byte _byteStatus, ref TagFormatClass _tagData)

  This function sets the battery status of the RFID wristband and finds out whether the locater is being triggered or not and whether the call button is being pressed or not.

- btn_Start_Click(object sender, EventArgs e)

  This function determines whether the "start" button has been clicked and starts receiving data based on that.

- timer1_Tick(object sender, EventArgs e)

  This function proceeds with the monitoring as long as the "stop" button hasn't been clicked.

- btn_Stop_Click(object sender, EventArgs e)

  This Function determines whether the "stop" button has been clicked or not. If clicked, the monitoring is stopped.

- Main_FormClosing(object sender, FormClosingEventArgs e)

  This function calls the function: StopListen().

3.1.3. Foreign Tag IDs

The ID's of RFID tags that aren't mapped to a certain patient and are read by the reader are definitely harmful. If we permitted the data sent by those tags to be saved in our database tables along with the other values read, we will have an overflow of data and a large amount of memory wasted. To avoid that, these frames were dropped as soon as they were detected.

3.2.Database Manager

The system database manager (SDBM) handles the creation and maintenance of the entire patients and staff information including patient's vital signs database. The SDBM creates a database directory structure along with time and date stamped log files for every patient who is entered into the system. Each log file is updated in real-time to ensure minimal loss of data in the event of a system failure. The GUI submits a data packet to the SDBM containing all received patient data from its current patient query. The SDBM interprets the data and adds it to the correct patient log file. Data requests made by the GUI are also handled via the SDBM. When an operator requests history information for a specific patient, the SDBM retrieves the information and passes it to the GUI for display. When the SDBM receives this data request, it loads the entire database into memory and sends all database information to the GUI. The SDBM is also used in the GUI when patient log files and directories are deleted. A delete command is issued by an operator, and the SDBM removes the specified patient's log file or entire log directory from the patient vital signs database. The database is implemented using MySQL database to store patients' and staff information along with the data received by the RFID reader from the blood pressure (BP) Sensor (SBP, DBP, PULSE), temperature sensor, SPO2 sensor (SPO2, PULSE), and blood sugar (sugar) sensor. The database design is described in the following subsections.

3.2.1. Database Design

In order to be able to save all patients and staff records and data read by the sensors, a database is required. Since we will be accessing the database by C#, the database was implemented using a MySQL database which is compatible with C#. The system's database entitled "Hospital" consists of 24 tables. Initially, an Entity Relation Diagram was

developed to assist in structuring the relationship between different entities. The relation between the various entities is shown in Figure 31**,** and the description of each entity follows in the next subsection.

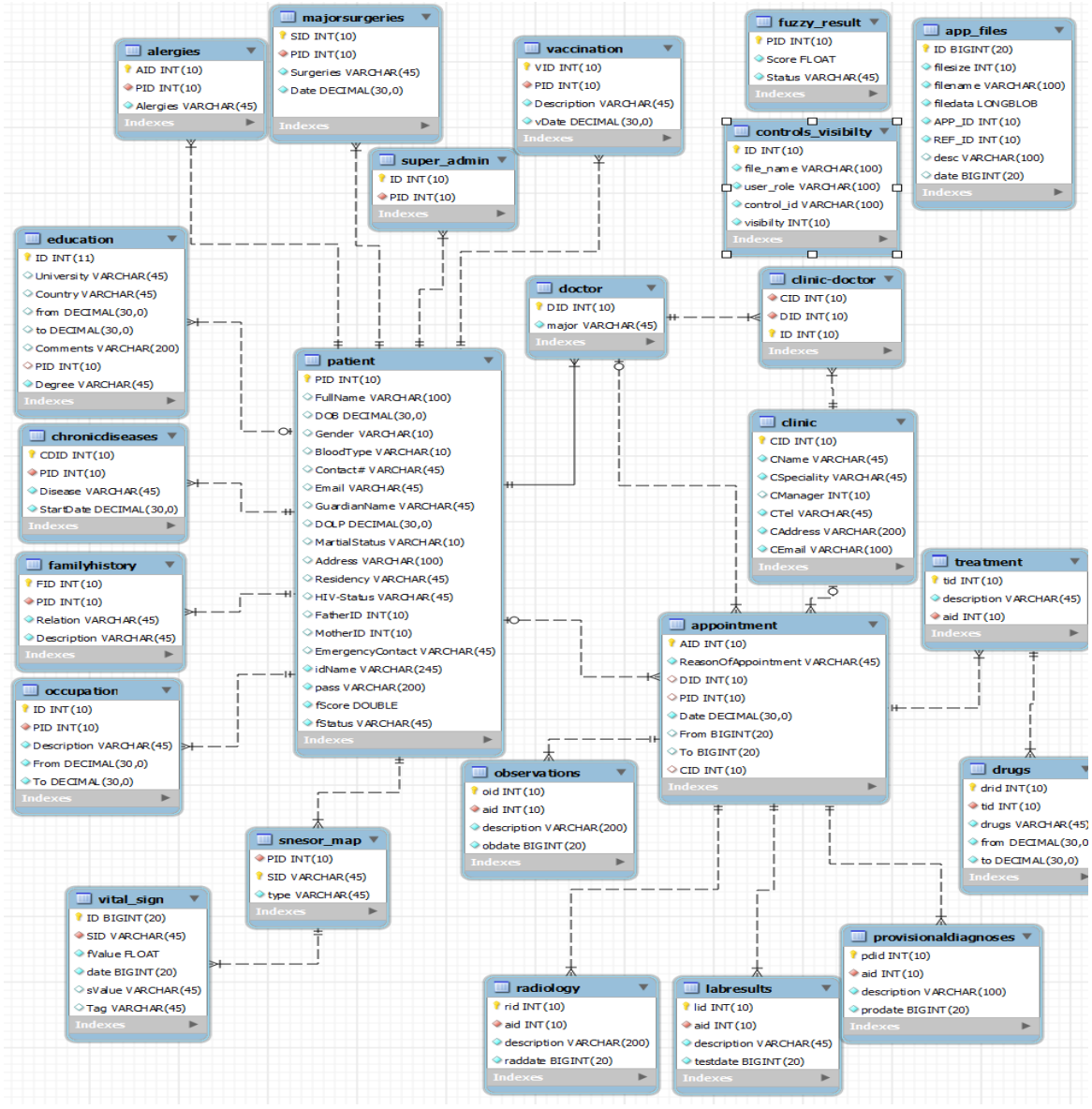


Figure 31: The proposed system Entity Relation Diagram

3.2.2. Database Components

The database of the system is given the name `Hospital` and as depicted in Figure 31 it consists of the following tables;

- TABLE 1: `patient`

  This is the patient's information table that contains the entire patient's personal information.

- TABLE 2:`education`

  In this table, the patient's education background will be saved.

- TABLE 2: `super_admin`

  This is the super admin table.

- TABLE 3: `vaccination`

  In this table, the patient's history of vaccinations will be saved.

- TABLE 4: `vital_sign`

  In this table, the patient's list of real time vital signs will be saved.

- TABLE 5: `majorsurgeries`

  In this table, the patient's history of major surgeries will be saved.

- TABLE 6: `labresults`

  In this table, the patient's lab results after an appointment will be saved.

- TABLE 7: `familyhistory`

  In this table, the patient's family history will be saved.

- TABLE 8: `drugs`

  In this table, the patient's list of prescribed drugs after appointments and observations will be saved.

- TABLE 9: `chronicdiseases`

  In this table, the patient's history of chronic diseases will be saved.

- TABLE 10: Alergies

  In this table, the patient's list of allergies will be saved.

- TABLE 11: `doctor`

  This is the doctors table. It saves the doctors in a specific clinic or hospital.

- TABLE 12: `clinic`

  This is the clinic table where the clinic details will be saved.

- TABLE 13:`clinic-doctor`

  This table links the doctor to a specific clinic based on the doctor's major.

- TABLE 14: `appointment`;

  In this table, the patient’s list of appointments will be saved.

- TABLE 15: `observations`

  In this table, the doctor’s observations of a specific patient will be stated.

- TABLE 16: `occupation`

  In this table, the patient’s list of occupations will be saved.

- TABLE 17: `provisionaldiagnoses`

  In this table, the doctor’s diagnosis of a patient will be stored along with his notes.

- TABLE 18: `radiology`

  In this table, the list of radiology tests of a patient will be stored.

- TABLE 19:`snesor_map`

  This table maps each patient to a specific or unique sensor id.

- TABLE 20: `treatment`;

  In this table, the list of medication's given to a patient by the doctor will be stored.

- TABLE 21: `fuzzy_result`

  This table is the fuzzy result table which stores all the fuzzy results of a specific patient.

3.3.The Fuzzy Logic System

3.3.1. Fuzzy Logic Introduction

The concept of fuzzy logic was first proposed by Dr. Lotfi Zadeh in 1965 in the paper titled "Fuzzy Sets: Information and Control" [54]. In this paper, Dr. Zadeh states, "As the complexity of a system increases, our ability to make precise and significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance become mutually exclusive characteristics" [54]. To precisely describe complex systems, a method is needed that is able to approximate them with a reasonable and track-able model. Fuzzy logic is a multi-valued logic system that fulfills this role. To utilize fuzzy logic, four components are required: fuzzification, an inference, a fuzzy rule base, and defuzzification. One of the basic principles of fuzzy logic is the degree of membership determined by "fuzzifying" each data point using the input fuzzy set. The input fuzzy set is determined by the system designer to break down the complete range of possible input values into membership functions. Each membership function has a value of either 0 or 1 and a minimum and maximum range of input value. Several shapes for the membership function can be used, including trapezoidal, gaussian, and triangular. The most common and simplest to understand are trapezoidal and triangular shaped membership functions, which can be assembled into a fuzzy set by setting the minimum input value of each function to the center point of the previous membership function.

"Fuzzy logic is a form of many-valued logic; it deals with reasoning that is fixed or approximate rather than fixed and exact. Fuzzy logic variables may have a truth value that ranges in degree between 0 and 1 [40]". It is simply a conclusion reached by a computer program, which recognizes that all values are not absolutes such as yes or no, 0 or 1 so

that the calculations can be varied between 0 and 1. The fuzzy logic system is a simple, rule-based system and can be used to monitor biological systems that would be difficult or impossible to model with simple, linear mathematics. Fuzzy-logic-based systems have shown potential to improve a clinician's performance by imitating human thought processes in complex circumstances and accurately executing repetitive tasks to which humans are ill-suited. Nowadays, the use of computer technology has highly increased in the fields of medical diagnoses, treatment of illnesses and patient pursuit. Despite the fact that these fields, in which the computers are used, have very high complexity and uncertainty, the use of intelligent systems such as fuzzy logic, artificial neural network and genetic algorithm have been developed [55].

In this work, the fuzzy logic is based on the modified early warning score (MEWS), which is a simple guide used by hospital nursing and medical staff as well as emergency medical services to quickly determine the degree of illness of a patient [56]**.**

3.3.2. The Modified Early Warning Score (MEWS)

The Modified Early Warning Score (MEWS) is a tool for bedside evaluation of patients and is based on five physiological parameters: systolic blood pressure, pulse rate, respiratory rate, temperature, and AVPU score (A for 'alert', V for 'responsive to verbal stimulation', P for 'responsive to painful stimulation', U for 'unresponsive') as shown in Table 6 [57]. The ability of a MEWS, including relative deviation from patients' normal blood pressure and urine output, to identify surgical patients who would potentially benefit from intensive care, was demonstrated in 2000 [58] The Modified Early Warning Score (MEWS) was validated in medical admissions in 2001 [59]. In 2006, a study was developed to evaluate the ability of MEWS (Table 1) to identify patients at risk and to examine the feasibility of MEWS as a screening tool to trigger early assessment and inpatient admission to the hospital or ICU [60]. MEWS are now commonly used for the assessment of hospital patients in non-acute wards. The Early Warning Score (EWS) is a simple scoring system that can be calculated using parameters which are measured for all critical patients. It can be used to quickly identify patients who are clinically failing and who need urgent intervention. MEWS can be used to monitor medical patients during assessment and transport. The use of MEWS has been shown to be effective in reducing death rates and illness chances of patients whose health slowly worsens.

MEWS	+3	+2	+1	0	+1	+2	+3
Systolic blood pressure	< 70	70–80	81–100	101–199		≥ 200	
Heart rate		< 40	41–50	51–100	101–110	111–130	> 130
Respiratory rate		< 9		9–14	15–20	21–29	≥ 30
Temperature		< 35	35.1–36	36.1–38	38.1–38.5	>38.5	
AVPU/GCS score	< 9	9–13	14	A/15	V/Confused	P	U

The score is calculated by measuring the five parameters as above and adding together the assigned score for each physiological value.

AVPU = Alert, Verbal, Pain, Unresponsive; GCS = Glasgow Coma Scale

Table 6: The Modified Early Warning Score [57]

A MEWS is calculated for a patient using the five simple physiological parameters shown in Table 6; Respiratory rate, heart rate, systolic blood pressure, temperature and AVPU. A score is given to a specific range of values for each of the parameters in the table. The patient's data for each parameter is cross referenced against the MEWS table and a score from 0 to 3 is allocated. The score for each parameter is then added to give the MEWS score. A score of zero shows that the patient case is normal, a score that is more than zero and less than five shows that the patient is in a Low Risk case, and a score of five or more shows that the patient is in a High Risk case, and an admission to an intensive care unit is recommended.

In this work, different MEWS parameters were used in order to calculate the MEWS score. The parameters used are: systolic blood pressure (SBP), heart rate (HR), oxygen saturation (SPO2), body temperature (TEMP), and blood sugar (BS) as shown in Table 7. An expert's knowledge affiliated with Rashid Center for Diabetes and Research (RCDR) was used for dividing the input fields, which will be introduced in the next section.

Modified Early Warning Score MEWS							
Risk Band	**Low**	**Low**	**Low**	**Normal**	**High**	**High**	**High**
Vital Sign	**3**	**2**	**1**	**0**	**1**	**2**	**3**
Systolic Blood Pressure	**SBP<75**	**70<SBP<85**	**80<SBP<100**	**95<SBP<199**		**SBP>185**	
Heart Rate		**HR<50**	**45<HR<60**	**53<HR<100**	**95<HR<110**	**105<HR<130**	**HR>125**
SPO2	**SPO2<85**	**83<SPO2<90**	**87<SPO2<95**	**SPO2>93**			
Temperature		**T<36.5**		**36<T<38.5**		**T>38**	
Blood Sugar	**BS<66**	**63<BS<72**	**-**	**70<BS<110**	**-**	**106<BS<150**	**BS>140**

Table 7: The proposed system Modified Early Warning Score MEWS

3.3.3. Structure of the Fuzzy Logic System

This section describes the fuzzy logic system. The basic structure of our system is shown in Figure 32**.** The fuzzy logic system uses 5 attributes for input and 1 attribute for result as an output. Input fields (attributes) are systolic blood pressure (SBP), heart rate (HR), oxygen saturation (SPO2), body temperature (TEMP), and blood sugar (BS). The output field refers to the patient's case (Risk Group).

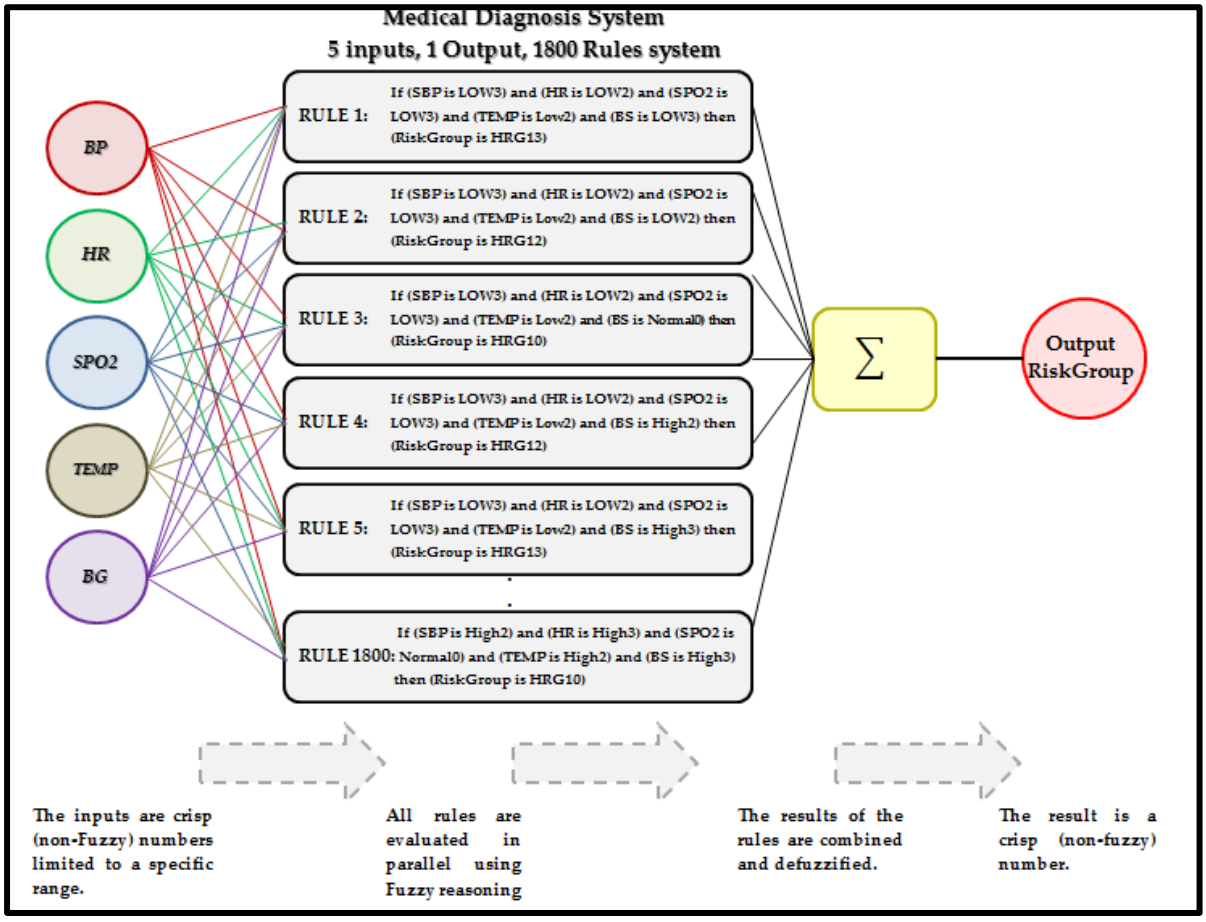


Figure 32: The basic structure of the fuzzy logic system.

Information flows from left to right, processing data related to five inputs resulting in a single output. The parallel nature of the rules is one of the more important aspects of fuzzy logic systems. Instead of sharp switching between modes based on breakpoints, logic flows smoothly from regions where the system's behavior is dominated by either one rule or another. The steps followed to develop the fuzzy logic system including the fuzzy expert system design; membership functions creation, fuzzy rule base development, fuzzification and defuzzification are described in the followed subsections.

3.3.1. FUZZY EXPERT SYSTEM DESIGNING

The typical steps followed in designing expert systems include the determination of the input and output variables, the selection of suitable membership functions, and the creation of the fuzzy rules database. These components are described next.

3.3.3.1.1. Input Variables

- **Blood Pressure:** Different values of blood pressure change the result easily. In this field, we use systolic blood pressure. This input variable is divided into 5 fuzzy sets. These sets are (Low-3, Low-2, Low-1, Normal-0, and High-2); membership functions of the 5 fuzzy sets are trapezoidal. The first step in implementing a fuzzy logic control algorithm is to fuzzify the measured variables. To fuzzify the SBP variable, we first ask what range of values for SBP would be designed unquestionably as normal. Let this be 100 to 185mm Hg (not everyone might agree with this, so this choice merely captures the experience of one particular 'expert`). We thus create a fuzzy set labeled Normal0 and assign values of SBP between 101 and 199 mm Hg to a membership level of 1.0 in this set. Next we address the more vague issue of what range of values for SBP could possibly be normal but also be abnormal. Per the expert advice, the range 185 to 199 was decided to be at the upper end and 95 to 100 at the first lower end. In other words, if SBP is above 199 mm Hg it is unquestionably too high (which is labeled High 2 in the Fuzzy set), whereas between 185 and 199 mm Hg, it could go either way. Using Table 8, the rest of the SBP were similarly determined. Table 3 shows the SBP ranges that correspond to each fuzzy set. Membership functions of blood pressure field are shown in Figure 33.

Input Field	Range	Fuzzy Sets
Systolic Blood Pressure SBP	<75	Low-3
	70 – 85	Low-2
	80 – 100	Low-1
	95 – 199	Normal-0
	>185	High-2

Table 8: The SBP ranges that correspond to each fuzzy set

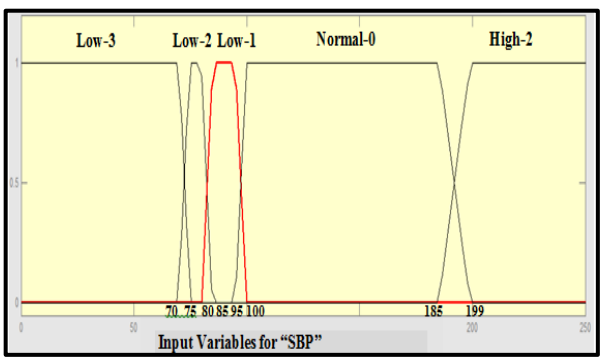


Figure 33: Membership functions of the Systolic blood pressure SBP parameter

- **Heart Rate:** based on the MEWS scoring system and per the expert advice, we use for this input field six fuzzy sets (Low-2, Low-1, Normal-0, High-1, High-2, and High-3). Membership functions of the 6 fuzzy sets are trapezoidal. Using Table 1, the HR values were determined similar to the SBP. Table 9 shows the HR ranges that correspond to each fuzzy set. Membership functions of the Heart Rate field are shown in Figure 34.

Input Field	Range	Fuzzy Sets
Heart Rate **HR**	<50	Low-2
	45 - 60	Low-1
	53 - 100	Normal-0
	95 – 110	High-1
	105 - 130	High-2
	>125	High-3

Table 9: The HR ranges that correspond to each fuzzy set

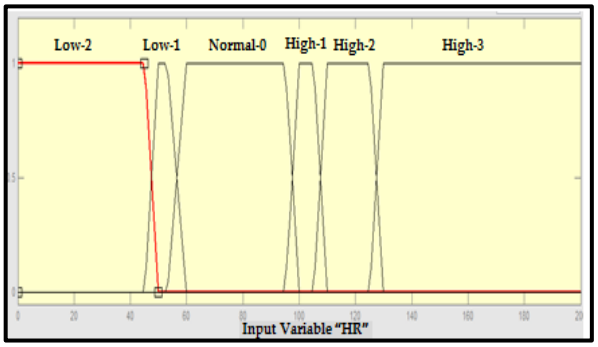


Figure 34: Membership functions of the Heart Rate HR parameter

- **SPO2:** The value of this input field is the oxygen saturation in the patient's blood. In this field, we have 4 linguist variables (fuzzy sets) (Low-3, Low-2, Low-1, and Normal). Any value that is higher than 95 (>95) is unquestionably considered as Normal. In Table 10, these fuzzy sets were defined. Membership functions of the fuzzy sets are trapezoidal and shown in Figure 35.

Input Field	Range	Fuzzy Sets
SPO2	<85	Low-3
	83 - 90	Low-2
	87 - 95	Low-1
	>93	Normal-0

Table 10: The SPO2 ranges that correspond to each fuzzy set

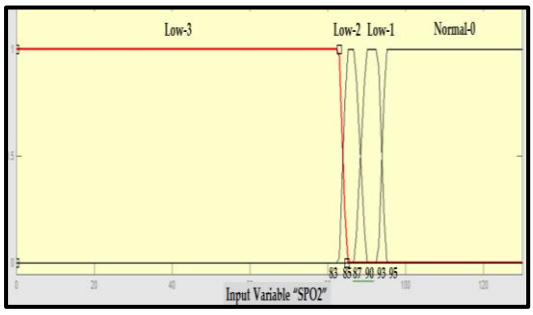


Figure 35: Membership functions of the SPO2 parameter

- **Temperature:** In this field, we have 3 fuzzy sets (Low-2, Normal-0, and High-2). In Table 11, these fuzzy sets were defined. Membership functions of these fuzzy sets are trapezoidal. These membership functions are described in Figure 36.

Input Field	Range	Fuzzy Sets
Temperature **TEMP**	<36.5	Low-2
	36 – 38.5	Normal-0
	>38	High-2

Table 11: The Temp ranges that correspond to each fuzzy set

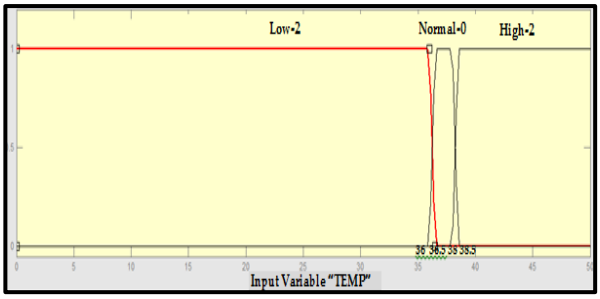


Figure 36: Membership functions of the Heart Rate TEMP parameter

- **Blood Sugar:** Blood sugar input is a very important factor. This input field has five fuzzy sets (Low-3, Low-2, Normal-0, High-2, and High-3). In this system, It has been defined that if the amount value of blood sugar is lower than 66 (<66) then the patient has a low (Low-3) blood sugar, and if it's higher than (>140) then the patient has a Very high (High 3) blood sugar, and the other sets are shown in Table 12. Figure 37 shows the membership functions of blood sugar. Membership functions of these fuzzy sets are trapezoidal.

Input	Range	Fuzzy Sets
Blood Sugar **BS**	<66	Low-3
	63 - 72	Low-2
	70 - 110	Normal-0
	106 - 150	High-2
	>140	High-3

Table 12: The BS ranges that correspond to each fuzzy set

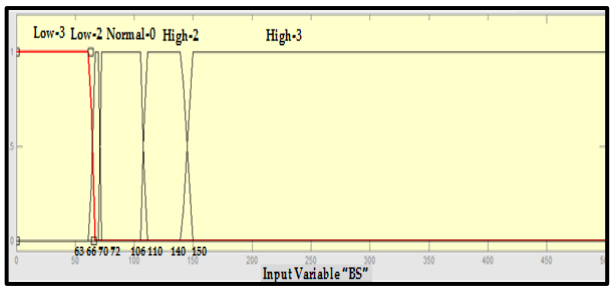


Figure 37: Membership functions of the Heart Rate BS parameter

3.3.3.1.2. The Output Variable

This subsection describes the output of the fuzzy logic engine. There is one output variable "Risk Group", which refers to the degree of risk in a patient's case. It ranges from 0 to 15. The higher the value, the higher the health risk of the patient. In this system, we have 15 fuzzy sets for the output variable risk group (NRM, LRG1, LRG2, LRG3, LRG4, HRG5, HRG6, HRG7, HRG8, HRG9, HRG10, HRG11, HRG12, HRG13, and HRG14). Membership functions for these sets are triangular. The membership functions' details are shown in Table 13 and Figure 38.

Output Field	Range	Fuzzy Sets
Risk Group	0<RG<0.5	NRM
	0.5<RG<1.5	LRG1
	1.5<RG<2.5	LRG2
	2.5<RG<3.5	LRG3
	3.5<RG<4.5	LRG4
	4.5<RG<5.5	HRG5
	5.5<RG<6.5	HRG6
	6.5<RG<7.5	HRG7
	7.5<RG<8.5	HRG8
	8.5<RG<9.5	HRG9
	9.5<RG<10.5	HRG10
	10.5<RG<11.5	HRG11
	11.5<RG<12.5	HRG12
	12.5<RG<13.5	HRG13
	13.5<RG<14	HRG14

Table 13: The Output variable (Riskgroup) ranges that correspond to each fuzzy set

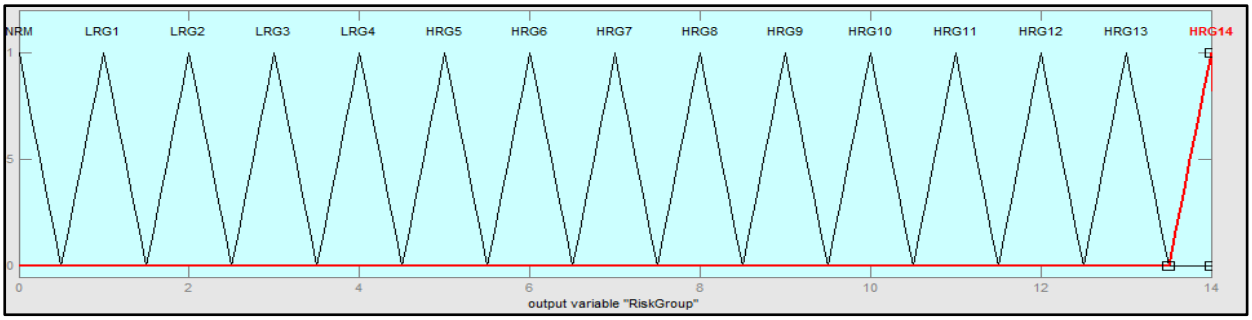


Figure 38: Membership functions of the output variable (Risk Group) field.

3.3.2. The FUZZY RULE BASE

The rule base is the main part in the fuzzy inference system and the quality of results in a fuzzy system depends on the fuzzy rules. The system developed in this work includes 1800 rules that cover all possible cases. The numbers of rules were obtained using the formula of Equation 1 [13].

$$N = p1 \times p2 \times \ldots\ldots\ldots \times pn \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 1}$$

Where N is the total number of possible rules for a fuzzy system and PN is the number of linguistic terms for the input linguistic variable N.

The rules were designed based on the MEWS scoring system. And the results with the 1800 rules tend to be similar to the MEWS scoring system. A sample of the rules has been shown in Figure 39.

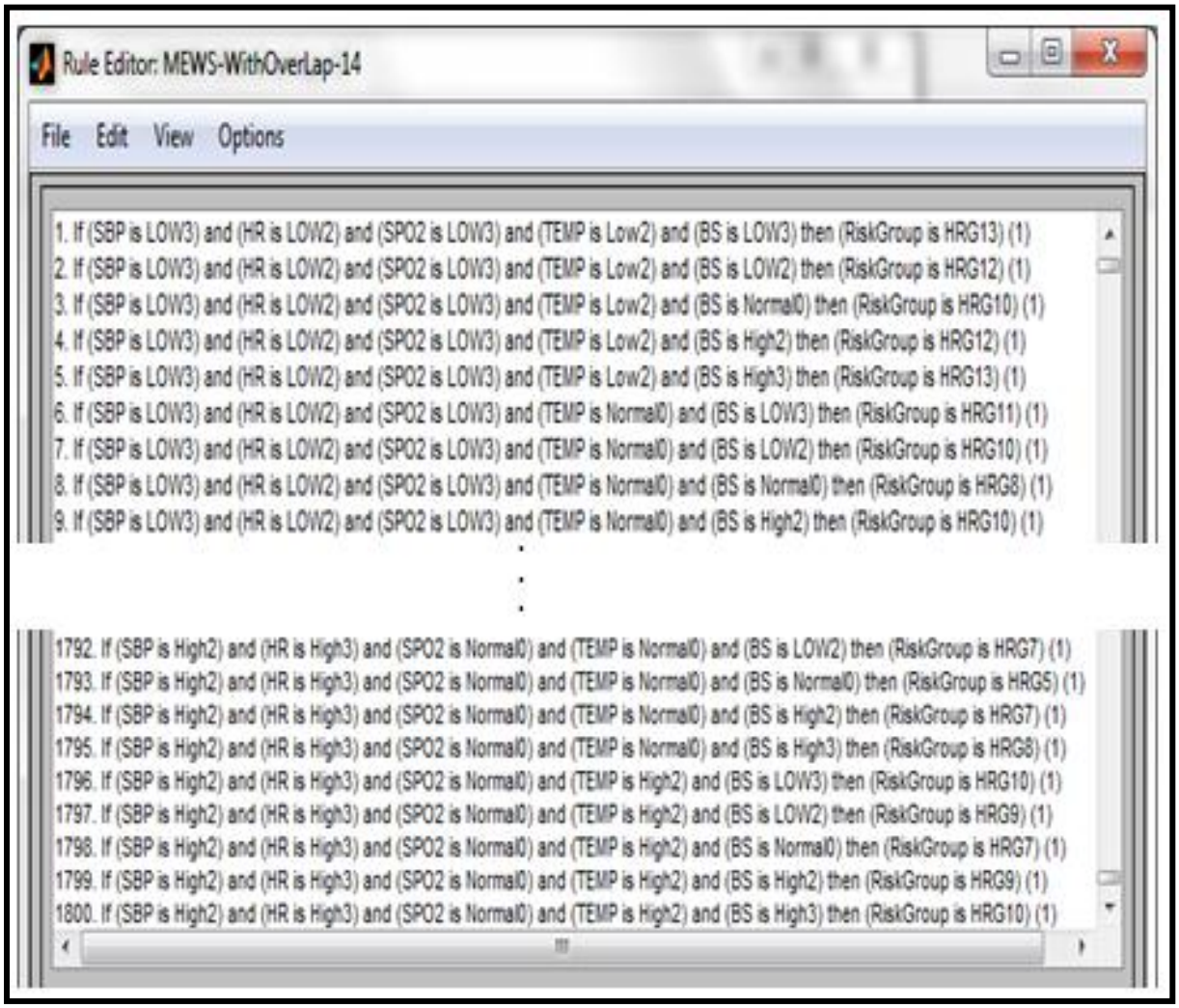


Figure 39: Sample of the Fuzzy Logic System Rules.

3.3.3. FUZZIFICATION AND DEFUZZIFICATION

The designed system uses the Mamdoni inference mechanism approach. In this system, we have a logical combination of inputs with AND because all inputs are dependent on each other. The system has one output that describes the patients' risk state. The crisp value output is given by the defuzzification process after estimating its input value. An example of the designed system results in MATLAB is shown in Figure 40. The following values are given to each input field: Systolic Blood Pressure (SBP)

=100, Heart Rate (HR) =85, SPO2=98, Temperature (TEMP) =37 and Blood Sugar (BS) =95. The fuzzy logic engine is triggered. The MATLAB- rule viewer and simulation results are shown in Figure 40

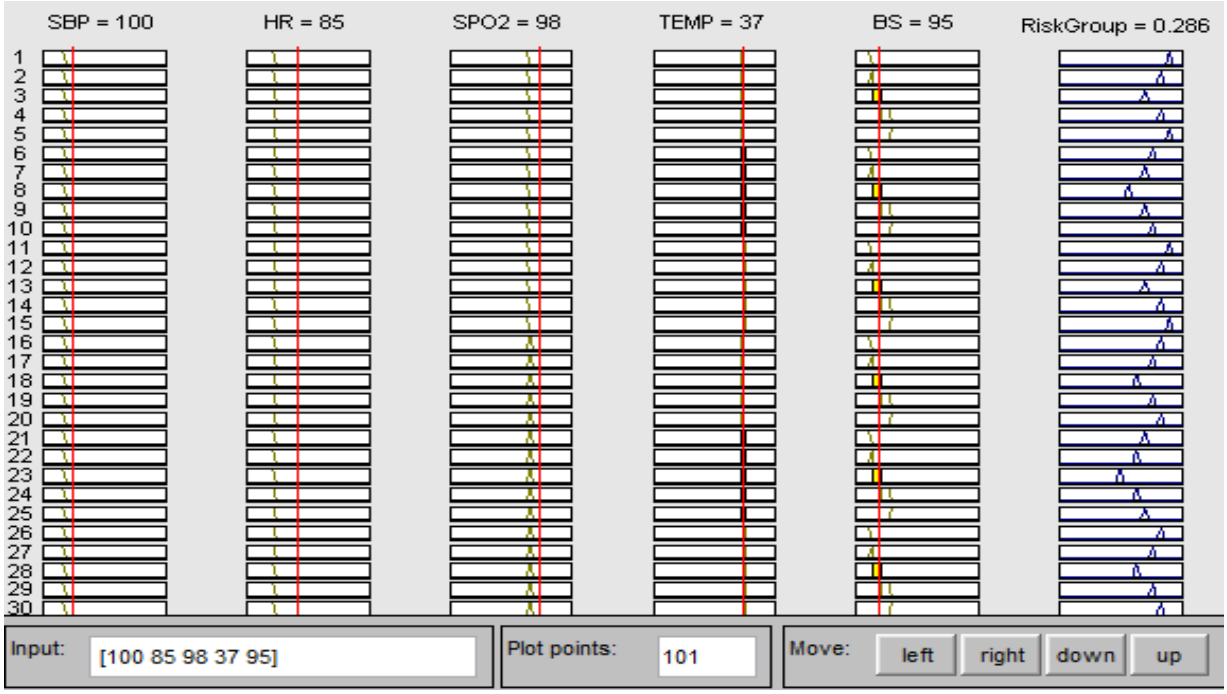


Figure 40: MATLAB- rule viewer and simulation result for fuzzy logic medical diagnosis control system

3.3.4. Interfacing Fuzzy Logic with C#.

As we mentioned earlier, the proposed fuzzy logic system in this work was developed by MATLAB Fuzzy Logic toolbox. In order to interface the fuzzy logic system with the whole system, MATLAB had to be called from COM components and applications. The following functions were used:

- **PutWorkspaceData**

The MATLAB client PutWorkspaceData(h,'varname','workspace',data) was used; this command stores data in the workspace of the server attached to handle h and assigns it to varname.

- **GetWorkspaceData**

The MATLAB client GetWorkspaceData(h,'varname','workspace') was used, this command gets data stored in variable varname from the specified workspace of the server attached to handle h and returns it in output argument.

- **Execute**

The execute function (command As String) was used. The execute function executes the MATLAB statement specified by the string command in the MATLAB automation server attached to handle h. The server returns output from the command in the string, result. The result string also contains any warning or error messages that might have been issued by MATLAB software as a result of the command.

3.3.5. Fuzzy Inference Process

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves all of the pieces that are described in membership functions, logical operations, and if-then rules. The fuzzy inference process comprises of the following five parts:

- Fuzzification of the input variables
- Application of the fuzzy operator (AND or OR) in the antecedent
- Implication from the antecedent to the consequent
- Aggregation of the consequents across the rules
- Defuzzification

The fuzzy inference process is illustrated using two cases as an example. The two cases will be described in the following subsections.

3.3.5.1. Case 1: (One Normal Input, One Fuzzy Input, and Three Un-Normal Inputs)

This case uses one normal input [TEMP = 37], one Fuzzy input [HR = 97], and three un-normal inputs [SBP = 200, SPO2 = 92, BS = 250]. In order to understand how the fuzzy logic engine part works, all the parts are described in the following subsections.

3.3.5.1.1 Step 1: Fuzzify Inputs

The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. Fuzzification of the input amounts to either a table lookup or a function evaluation. Each input in our system has its own set of functions to evaluate the degree to which each given input belongs to each of the fuzzy sets.

Our system is built on 1800 rules, and each of the rules depends on resolving the inputs into a number of different fuzzy linguistic sets: SBP is High2, HR is High1, SPO2 is Low1, TEMP is Normal0, and BS is High3, and so on. Before the rules can be evaluated, the inputs must be fuzzified according to each of these linguistic sets. For example, to what extent is the SBP really High2? The following figure (Figure 41**)** shows how high is the SBP for a hypothetical patient via its membership function.

In the above case, we assumed that the SBP is 200, which, as shown in Figure 41 the graphical definition of High2, corresponds to μ = 1.0 for the High2 membership function. This value can be determined using the $BP_{High2}(x)$ Function presented by Equation 2.

$$BP_{High2}(x) = \begin{cases} \frac{x-185}{14} & 185 \le x < 199 \\ 1 & x \ge 199 \end{cases}, \qquad \text{..... Equation 2}$$

Where $BP_{High2}(x)$ is the equation that describes the membership function of High2 generated with the Blood Pressure BP input. μ is the degree of membership, and x: is

the input value. So for $BP = 200$, μ = 1.0. 185 to 199 are the crossover points between Normal0 and High2. In the upper side, the fraction *denominator* was determined by subtracting 185 from 199 to get 14.

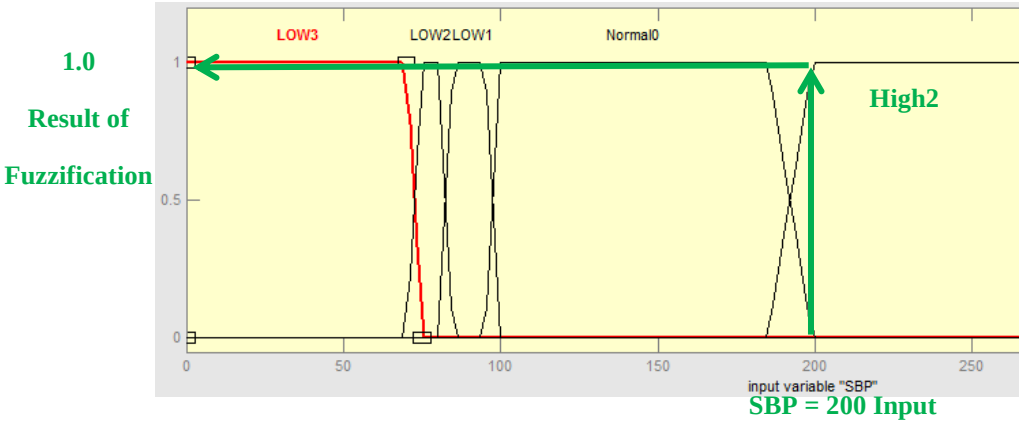


Figure 41: Step 1: Fuzzify Inputs (Fuzzify the SBP input)

In the same case, we assumed that the HR is 97, as shown in Figure 35, our graphical definition of this value, is located between NORMAL0 and High1, which corresponds to μ = 0.6 for the NORMAL0 membership function, and μ = 0.4 for the High1 membership function. These values can be determined using the $HR_{Normal0}(x)$, and $HR_{High1}(x)$ Functions are presented by Equation 3 and Equation 4, respectively.

$$HR_{Normal0}(x) = \begin{cases} \frac{x-53}{7} & 53 \le x < 60 \\ 1 & 60 \le x < 95 \\ \frac{100-x}{5} & 95 \le x < 100 \end{cases} \quad \text{..... Equation 3}$$

$$HR_{High1}(x) = \begin{cases} \frac{x-95}{5} & 95 \le x < 100 \\ 1 & 100 \le x < 105 \\ \frac{110-x}{5} & 105 \le x < 110 \end{cases} \quad \text{..... Equation 4}$$

Where $HR_{Normal0}(x)$ is the equation that describes the membership function of Normal0 generated with the Heart Rate HR input, $HR_{High1}(x)$ is the equation that describes the membership function of High1 generated with the Heart Rate HR input, and μ is the degree of membership, and x : is the input value.

Similarly to previous cases, we assumed that the SPO2 is 92, as shown in Figure 8, our graphical definition of this value, is LOW1, which corresponds to μ = 1.0 for the LOW1 membership function, and. And we assumed the TEMP to be 37, which corresponds to μ = 1.0 for the Normal0 membership function. And finally, the BS was 200 which corresponds to μ = 1.0 for the High3 membership function. These values can be determined using the $SPO2_{Low1}(x)$, $TEMP_{Normal0}(x)$, and $BG_{High3}(x)$ Functions are shown below in Equation 5, 6 and 7 respectively.

$$SPO2_{Low1}(x) = \begin{cases} \frac{x-87}{3} & 87 \le x < 90 \\ 1 & 90 \le x < 93 \\ \frac{95-x}{2} & 93 \le x < 95 \end{cases} \quad \text{..... Equation 5}$$

$$TEMP_{Normal0}(x) = \begin{cases} \frac{x-36}{0.5} & 36 \le x < 36.5 \\ 1 & 36.5 \le x < 38 \\ \frac{38.5-x}{0.5} & 38 \le x < 38.5 \end{cases} \quad \text{..... Equation 6}$$

$$BS_{High3}(x) = \begin{cases} \frac{x-140}{10} & 140 \le x < 150 \\ 1 & x \ge 150 \end{cases} \quad \text{..... Equation 7}$$

Where μ is the degree of membership, and x : is the input value. In this manner, each input is fuzzified over all the qualifying membership functions required by the rules.

3.3.5.1.2 Step 2: Apply the Fuzzy Operator

After the inputs are fuzzified, the degree to which each part of the antecedent is satisfied for each rule will be known. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result

of the antecedent for that rule. This number is then applied to the output function. The input to the fuzzy operator is five or more membership values from fuzzified input variables. The output is a single truth value.

Figure 42 shows the AND operator min at work, evaluating the antecedent of the rule 1600 for the risk group calculation. The five different pieces of the antecedent ((SBP is High2), (HR is Normal0), (SPO2 is LOW1),(TEMP is Normal0), and (BS is High3)) yielded the fuzzy membership values 1, 0.6,1, 1, and 1 respectively. The fuzzy AND operator simply selects the minimum of the five values, 0.6, and the fuzzy operation for rule 1600 is complete. The probabilistic AND method would still result in 0.6.

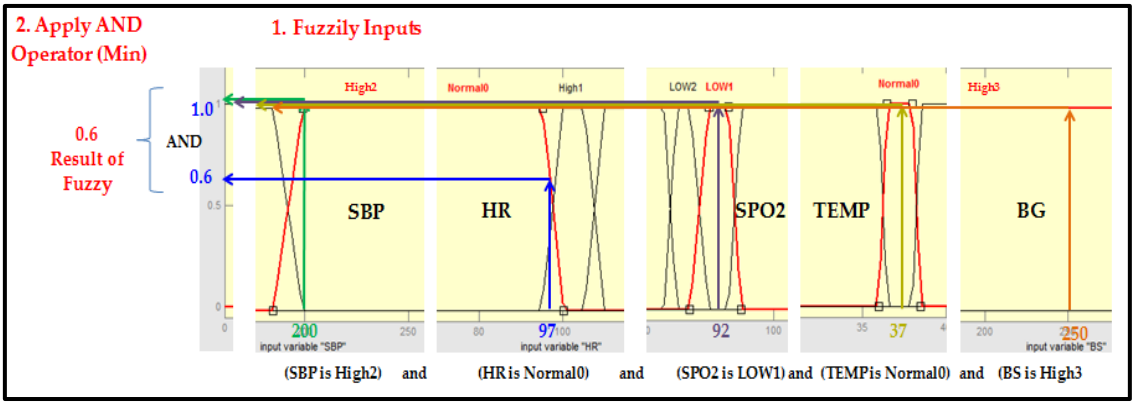


Figure 42: Step 1 & 2: evaluating the antecedent of the rule 1600 for the Risk Group calculation. The five different pieces of the antecedent ((SBP is High2) and (HR is Normal0) and (SPO2 is LOW1) and (TEMP is Normal0) and (BS is High3)) yielded the fuzzy membership values 1 and 0.6 and 1 and 1 and 1 respectively

Now referring back to the rules, the above inputs also select rule number 1660. From this rule, the five different pieces of the antecedent ((SBP is High2), (HR is Normal0), (SPO2 is LOW1), (TEMP is Normal0), and (BS is High3)) yielded the fuzzy membership values 1, 0.4, 1, 1, and 1 respectively. The fuzzy AND operator simply selects the minimum of the five values, 0.4, and the fuzzy operation for rule 1600 is complete. The probabilistic AND method would still result in 0.4. Of the 1800 rules selected, only two rules (rule 1600 and rule 1660) fire or have non-zero contribution. This implies fuzzy output response magnitudes belonging to only risk

group "HRG6" and "HRG7" which must be now inferred, combined, and defuzzified to return the actual crisp output.

3.3.5.1.3 Step 3: Apply Implication Method

Before applying the implication method, you must determine the rule's weight. Every rule has a *weight* (a number between 0 and 1), which is applied to the number given by the antecedent. Generally, this weight is 1 (as it is for the system) and thus has no effect at all on the implication process. From time to time, you may want to weigh one rule relatively to the others by changing its weight value to something other than 1. However, in this system all the rules have a weight of 1.

3.3.5.1.4 Step 4: Aggregate All Outputs

Because decisions are based on the testing of all of the rules in a Fuzzy Inference System (FIS), these rules must be combined in some manner in order to make a decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Aggregation only occurs once for each output variable, just prior to the fifth and final step, defuzzification. The input of the aggregation process is the list of truncated output functions returned by the implication process, step 3, for each rule. The output of the aggregation process is one fuzzy set for each output variable.

In Figure 43 below, the two rules have been placed together to show how the output of each rule is combined or aggregated into a single fuzzy set whose membership function assigns a weight for every output value.

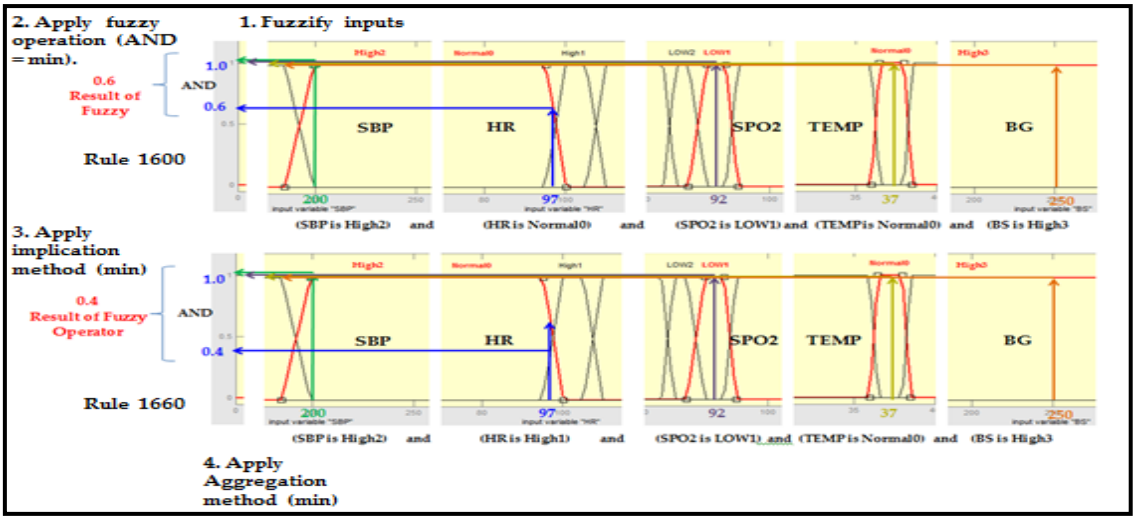


Figure 43: Step 4: Aggregation of the output

3.3.5.1.5 Step 5: Defuzzify

The last step in the example is to determine the firing strength of each rule. It turned out that rules 1600 and 1660 each fired at 60% or 0.6 and 40 % or 0.4 respectively. The logical products for each rule must be combined or inferred (max-min'd, max-dot'd, averaged, root-sum-squared, etc.) before being passed on to the defuzzification process for crisp output generation. Several inference methods exist. The Root Sum Square (RSS) inference engine is employed in this research which has the formula presented in Equation 8,

$$RSS = \sqrt{\sum R^2} = \sqrt{(R_1^2 + R_2^2 + R_3^2 + , \dots , R_n^2)} \quad [61] \ldots\ldots\ldots \text{Equation 8}$$

Where $R_1^2, R_2^2, R_3^2, \dots, R_n^2$ are strength values of different rules which share the same conclusion. RSS method combines the effects of all applicable rules, scales the functions at their respective magnitudes, and computes the "fuzzy" centroid of the composite area. This method is more complicated mathematically than other methods, but is selected for this work since it gives the best weighted influence to all firing rules [61]. This method includes all contributing rules since there are so few member functions associated with the inputs and outputs. For the inputs above, SBP of 200, HR of 97, SPO2 of 92, TEMP of 37, and BS of 250 select regions of the "HRG6" and "HRG7" output membership functions. The respective output membership function

strengths (range: 0-1) from the possible rules (R1600-R1660) are calculated using Equation 9 and 10, respectively.

"HRG 6" Strength = $\sqrt{(R1600)^2} = \sqrt{(0.6)^2} = 0.6$ ……. Equation 9

"HRG 7" Strength = $\sqrt{(R1660)^2} = \sqrt{(0.4)^2} = 0.4$ ……..... Equation 10

The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set), and the output is a single number. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number. However, the aggregate of a fuzzy set encompasses a range of output values, and so they must be defuzzified in order to resolve a single output value from the set. Perhaps the most popular defuzzification method is the centroid calculation, this method returns the center of an area under the curve which is the method used in our calculations.

The defuzzification of the data into a crisp output is accomplished using the 'Fuzzy Centroid' Algorithm. This is the most prevalent and intuitively appealing among the defuzzification methods [62]. It's done by combining the results of the inference process and then computing the "fuzzy centroid" of the area. The weighed strengths of each output member function are multiplied by their respective output membership function center points and summed. Finally, this area is divided by the sum of the weighed member function strengths, and the result is taken as the crisp output. The formula shown in Equation 11 is the Fuzzy Centroid Formula [63].

$$Output = \frac{\sum_{i=1}^{n}(center_i \,.\, Strength_i)}{\sum_{i=1}^{n} Strength_i} \quad \text{……. Equation 11}$$

Where n, is the number of output members. One feature to note is that since the zero center is at zero, any zero strength will automatically compute to zero. If the center of the zero function happens to be offset from zero, then this factor would have

an influence. By using Equation 11, the results of the example's set of inputs are shown in Equation 12.

$$Output = \frac{\left((HRG6(Center)\times HRG6(Strength))+(HRG7(Center)\times HRG7(Strength))\right)}{(HRG6(Strength)+HRG7(Strength))} \quad \ldots\ldots \text{Equation 12}$$

$$= \frac{((0.6 \times 6.5) + (0.4 \times 7.5))}{(0.6 + 0.4)} = 6.9$$

Figure 44 below shows the results of the same set of inputs using the rule viewer. The rule viewer result is approximately the same as the one we got using the calculations. The error between the calculation results and the MATLAB results is given by Equation 13.

$$Error = 6.94 - 6.9 = 0.04 \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 13}$$

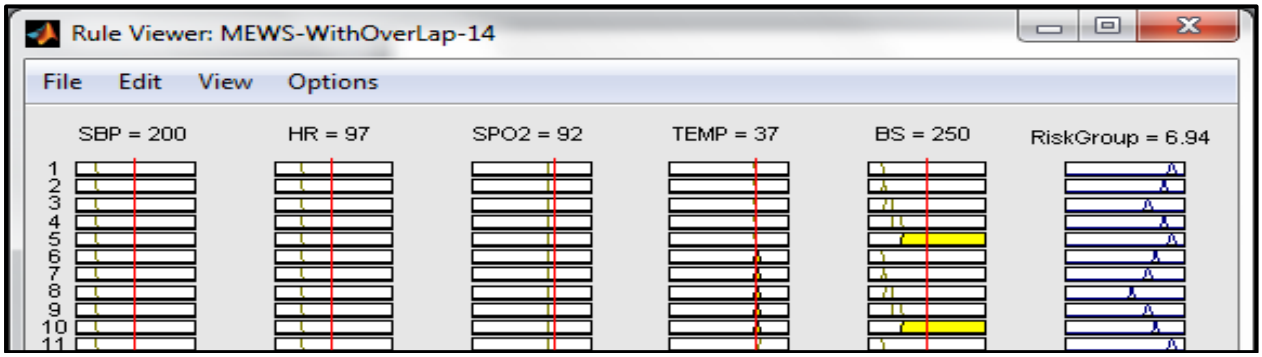


Figure 44: The results of the same set of inputs in the example using the Rule Viewer

3.3.5.2. Case 2: (2 Normal input, 3 fuzzy inputs)

A more complicated case is shown in this subsection. It will be assumed that the system input was given as: for each [SBP, HR, SPO2, TEMP, BS] the following values [98; 59; 98; 37; 108].The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. Fuzzification of the input amounts to either a table lookup or a function evaluation. Each input in the system has its own set of functions to evaluate the degree to which each given input belongs to each of the

fuzzy sets. As we mentioned earlier, the system is built on 1800 rules, and each of the rules depends on resolving the inputs into a number of different fuzzy linguistic sets. Before the rules can be evaluated, the inputs must be fuzzified according to each of these linguistic sets. Table 14 shows the degree of membership for each input.

SBP		HR		SPO2		TEMP		BS	
LOW3	0	LOW2	0	LOW3	0	LOW2	0	LOW3	0
LOW2	0	LOW1	0.142857	LOW2	0	NORMAL0	1	LOW2	0
LOW1	0.4	NORMAL0	0.857143	LOW1	0	HIGH2	0	NORMAL0	0.5
NORMAL0	0.6	HIGH1	0	NORMAL0	1			HIGH2	0.5
HIGH2	0	HIGH2	0					HIGH3	0
		HIGH3	0						

Table 14: The degree of membership for each input

Referring back to the rules, plug in the membership function weights from above. Of the 1800 rules selected, only eight (rules 833, 834, 893, 894, 1193, 1194, 1253, and 1254) fire or have non-zero results. This leaves fuzzy output response magnitudes for only "NRM", "LRG1", "LRG2", "LRG3", and "LRG4", which must be inferred, combined, and defuzzified to return the actual crisp output. In the rule list below, the inputs are combined logically using the AND operator to produce output response values for all expected inputs. The active conclusions are then combined into a logical sum for each membership function. A firing strength for each output membership function is computed. All that remains is to combine these logical sums in a defuzzification process to produce the crisp output. Table 15 shows the firing strength and centroid for each output membership function.

The last step was to determine the firing strength of each rule. The logical products for each rule must be combined or inferred (max-min'd, max-dot'd, averaged, root-sum-squared, etc.) before being passed on to the defuzzification process for crisp output generation. Several inference methods exist, but the ROOT-SUM-SQUARE (RSS) method was used to combine the effects of all applicable rules, scale the functions at their respective magnitudes, and compute the "fuzzy" centroid of the composite area.

Rule #	Operators	Percentage	Centroid
Rule 833	**If (SBP is LOW1) and (HR is LOW1) and (SPO2 is NORMAL0) and (TEMP is Normal0) and (BS is NORMAL0) then (RiskGroup is LRG2)**	**0.4&0.14&1&1&0.5= 0.142857**	**LRG2 → 0.142857 Centroid = 2.5**
Rule 834	**If (SBP is LOW1) and (HR is LOW1) and (SPO2 is NORMAL0) and (TEMP is Normal0) and (BS is High2) then (RiskGroup is LRG4)**	**0.4&0.14&1&1&0.5= 0.142857**	**LRG4 → 0.142857 Centroid = 4.5**
Rule 893	**If (SBP is LOW1) and (HR is Normal0) and (SPO2 is NORMAL0) and (TEMP is Normal0) and (BS is NORMAL0) then (RiskGroup is LRG1)**	**0.4&0.86&1&1&0.5 = 0.4**	**LRG1 →0.4 Centroid = 1.5**
Rule 894	**If (SBP is LOW1) and (HR is Normal0) and (SPO2 is NORMAL0) and (TEMP is Normal0) and (BS is High2) then (RiskGroup is LRG3)**	**0.4&0.86&1&1&0.5 = 0.857**	**LRG3 → 0.4 Centroid = 3.5**
Rule 1193	**If (SBP is Normal0) and (HR is LOW1) and (SPO2 is NORMAL0) and (TEMP is Normal0) and (BS is NORMAL0) then (RiskGroup is LRG1)**	**0.6&0.14&1&1&0.5 = 0.14**	**LRG1 → 0.142857 Centroid = 1.5**
Rule 1194	**If (SBP is Normal0) and (HR is LOW1) and (SPO2 is NORMAL0) and (TEMP is Normal0) and (BS is High2) then (RiskGroup is LRG3)**	**0.6&0.14&1&1&0.5 = 0.14**	**LRG3 → 0.142857 Centroid = 3.5**
Rule 1253	**If (SBP is Normal0) and (HR is Normal0) and (SPO2 is NORMAL0) and (TEMP is Normal0) and (BS is NORMAL0) then (RiskGroup is NRM)**	**0.6&0.86&1&1&0.5 = 0.857**	**NRM → 0.5 Centroid = 0**
Rule 1254	**If (SBP is Normal0) and (HR is Normal0) and (SPO2 is NORMAL0) and (TEMP is Normal0) and (BS is High2) then (RiskGroup is LRG2)**	**0.6&0.86&1&1&0.5 = 0.857**	**LRG2 → 0.5 Centroid = 2.5**

Table 15: The firing strength and centroid for each output membership function.

This method is more complicated mathematically than other methods, but was selected since it seemed to give the best weighed influence to all firing rules. The respective output membership function strengths (range: 0-1) from the possible rules (R1-R1800) that were calculated using the RSS method are shown in Equations 14:

- LRG2 $= \sqrt{(R833)^2 + (R1254)^2}$ ..... Equation 14a

  $= \sqrt{(0.14)^2 + (0.5)^2} = 0.52000784923432273364980732082336$

- LRG4 $= \sqrt{(R834)^2} = \sqrt{(0.14)^2}$ ……. Equation 14b
  $= 0.14285714285714285714285714285714$

- LRG1 $= \sqrt{(R893)^2 + (R1193)^2} = \sqrt{(0.14)^2 + (0.4)^2}$ ……. Equation 14c
  $= 0.42474482135195730064605737754 09$

- LRG3 $= \sqrt{(R894)^2 + (R1194)^2} = \sqrt{(0.14)^2 + (0.4)^2}$ ……. Equation 14d
  $= 0.42474482135195730064605737754 09$

- NRM $= \sqrt{(R1253)^2} = \sqrt{(0.5)^2} = 0.5$ ……. Equation 14e

The defuzzification of the data into a crisp output is accomplished by combining the results of the inference process and then computing the "fuzzy centroid" of the area. The weighted strengths of each output member function are multiplied by their respective output membership function center points and summed. Finally, this area is divided by the sum of the weighed member function strengths and the result is taken as the crisp output. One feature to note is that since the zero center is at zero, any zero strength will automatically compute to zero. If the center of the zero function happened to be offset from zero (which is likely in a real system where heating and cooling effects are not perfectly equal), then this factor would have an influence. Using Equation 11 (the Centroid method), the out of these sets of inputs is shown in Equation 15.

$$RiskGroup = \frac{((0.52\times2.5)+(0.14\times4.5)+(0.42\times1.5)+(0.42\times3.5)+(0.5\times0.0)}{(0.52+0.14+0.42+0.42+0.5)} = 2.020817$$ .. Equation 15

The same inputs was given similar results when they were computed using MATLAB as shown in Figure 45. The error was calculated using Equation 16.

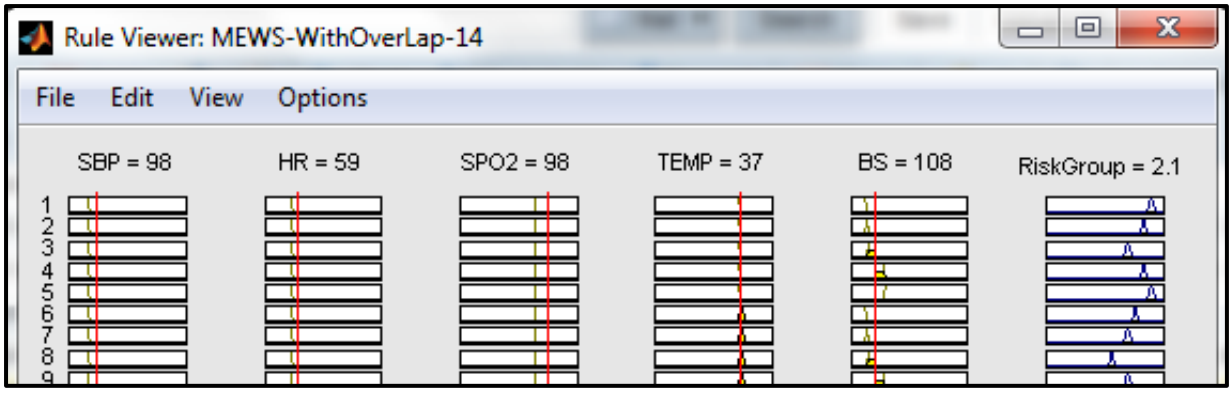


Figure 45: Matlab Rule View for the same example

Results using MATLAB $= 2.1,$ Results using calculations $= 2.0208172$

$$\text{Error} = 2.1 - 2.0208172 \quad = 0.0791828 \quad \ldots\ldots\ldots\ldots \text{ Equation 16}$$

3.4.Graphical User Interface (GUI) and Web-Application

3.4.1. The Graphical User Interface

The system's GUI is the front end control and monitoring interface used by system operators. The GUI includes many different displays that allow operators to add, edit, and view patient information in the system. When the GUI is first launched, the LogIn form, as shown in Figure 46**,** is displayed.

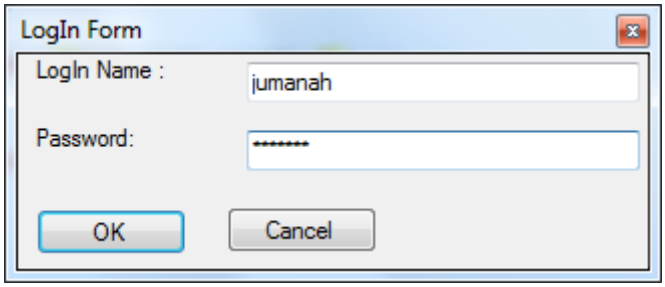


Figure 46: GUI LogIn Screen

Once the administrator enters his/her username and password, it directly goes to the GUI Home Screen. The GUI Home Screen is shown in Figure 47 below.

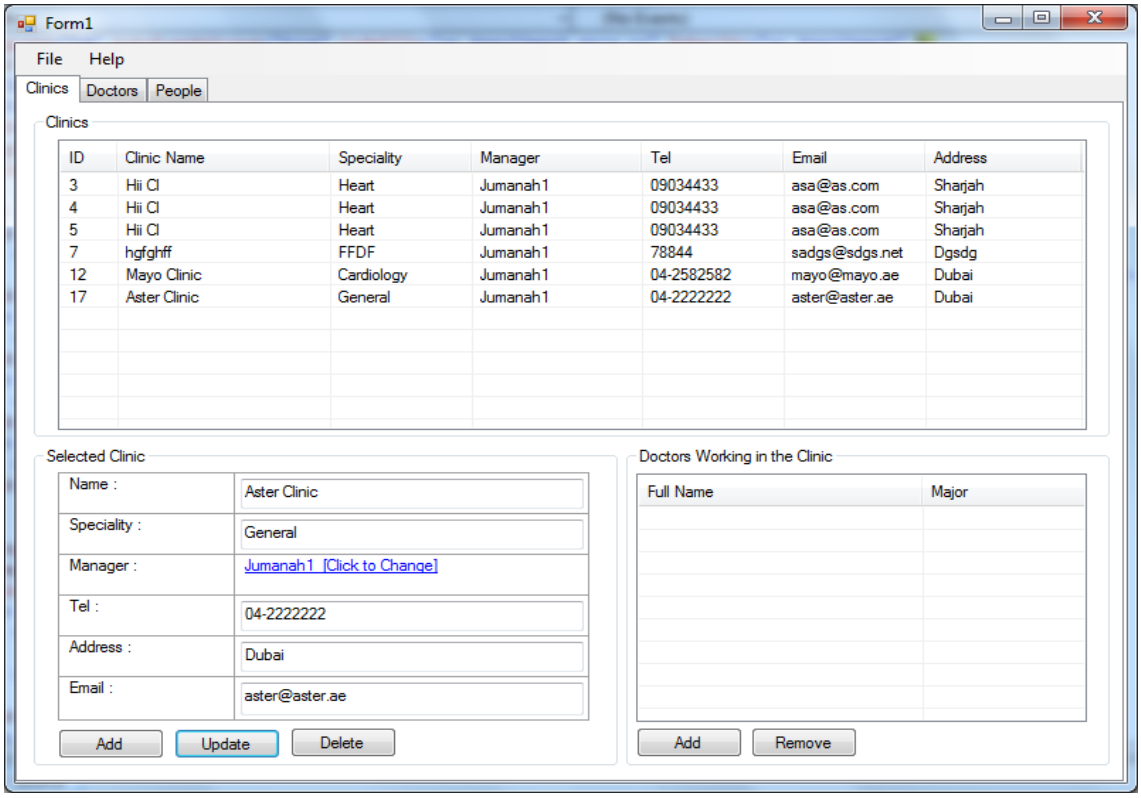


Figure 47: The GUI Home Screen

In the **GUI Home Screen,** there are three sections:

- **Clinics:**

  In this section, the hospital administrator can add, delete or modify clinics in the hospital.

- **Doctors**

  In this section, the hospital administrator can add, delete or modify doctors in the hospital.

- **People**

  In this section, the hospital administrator can add, delete or modify people (i.e., patients, doctors, and staff) in the hospital. In the people section, each patient will be assigned a tag ID number, so each patient will have his/her own RFID Tag sensor.

3.4.2. Web Services

In the mobile patient monitoring system, we designed a web application that allows patient, doctors, nurses, and administrators to view real-time vital signs of patients. Using the web application, real-time data of patients can only be viewed; hence, data cannot be

added, deleted, or modified. Functions are allowed in the web application. When the web application is first launched, the LogIn screen is displayed, as shown in Figure 48.

Figure 48: Web Application LogIn Screen

Once the administrator or doctor enters his/her username and password, the web application goes directly to the Patient Screen. The Patient Screen is shown in Figure 49. In the patient screen, the doctor should enter the patient's ID whom he/she wants to monitor.

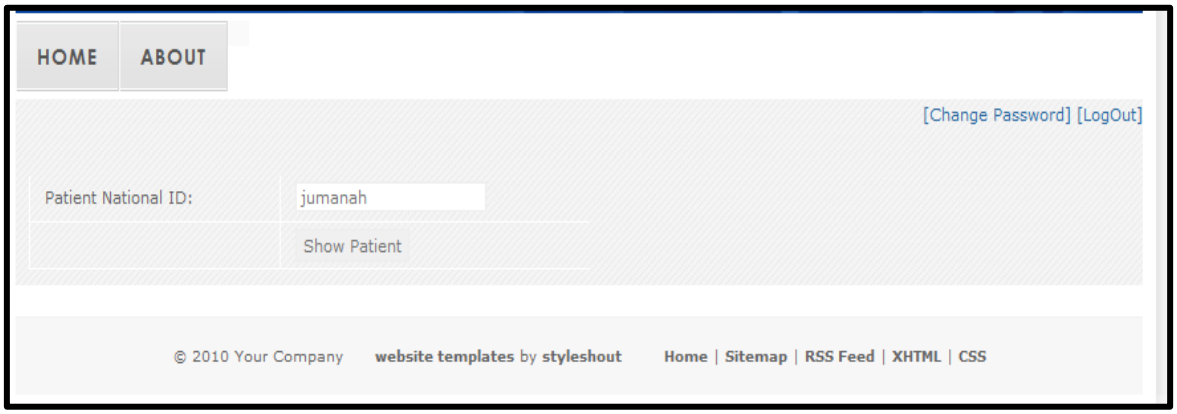


Figure 49: The Patient ID Screen

Once the ID is entered, it goes directly to the patient monitoring information screen as shown in Figure 50. In the patient monitoring screen, the doctor can check:

- The patient's personal information, including his/her national ID, full name, gender, date of birth, blood type, marital status, guardian name, residency, address, and contact information.

- The patient's real time vital signs data, including the patient's temperature , SPO2, pulse rate, blood pressure , and blood sugar.
- Fuzzy results, including the fuzzy logic engine score and status based on the MEWS system. The doctor can make sure that the patient status is normal based on these results.
- Patient's appointments information, such as his list of appointments and major surgeries, along with the patient's family history, allergies, chronic diseases, etc.

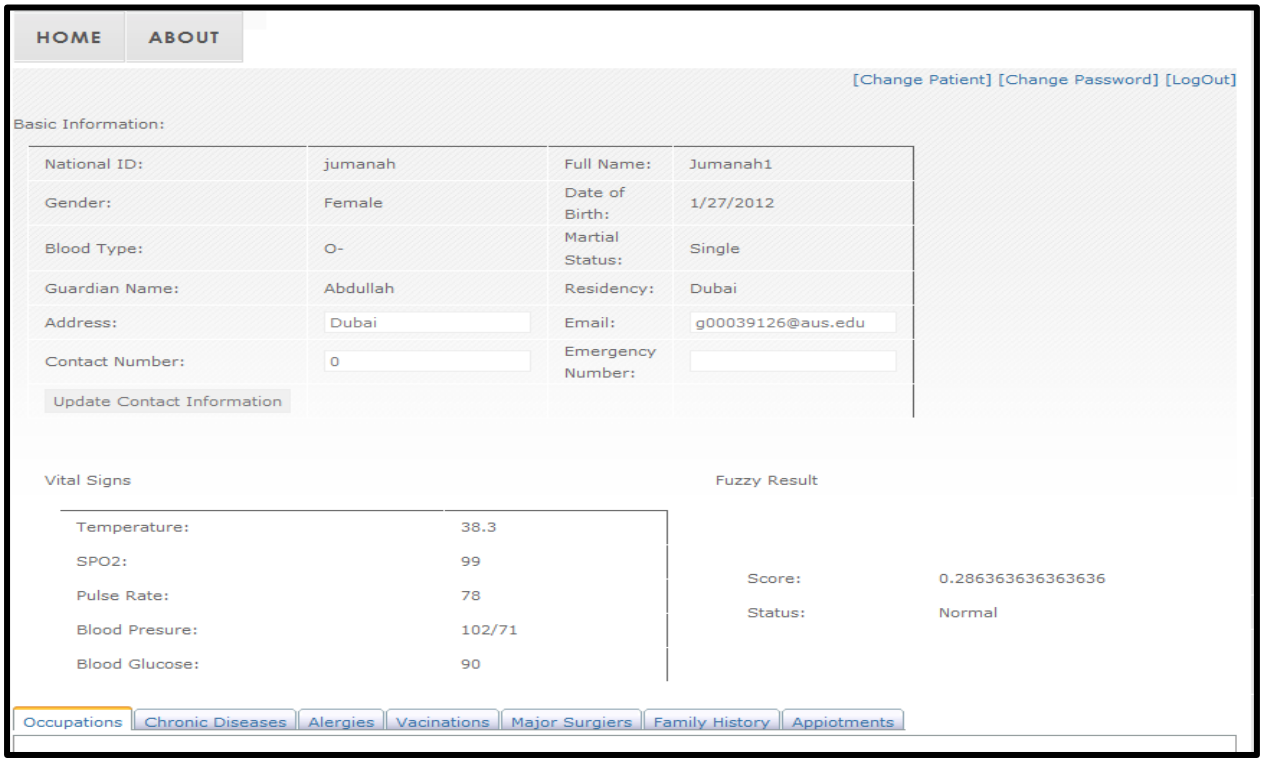


Figure 50: patient monitoring information screen

Chapter 4

Results and Discussion

A close collaboration within a medical facility is an important step in creating a reliable monitoring system. Continuous tests should be held in order to collect enough data from different types of patients, with different health conditions, and from different age groups. This will help to take into account every particular detail and combine a universal set of rules for a reasoning mechanism of the system. As a first step, short term experiments were conducted in order to evaluate the system's medical devices reliability and discover its weak points to simplify future development. The following section represents short profile information of the patients involved in the trials and results for the data analysis. The next step in testing aimed at using the same data collected to validate the RFID system devices in implementing, testing and evaluating the Fuzzy Logic engine.

4.1.Hardware Sensors Validation

The proposed hardware validation was carried in Rashid Center for Diabetes and Research (RCDR) in Khalifa Hospital in Ajman under the supervision and approval of Professor Salah Abusnana, the medical director of the center. The testing was conducted by nurses in the center. The nurses used the RCDR devices and the proposed system RFID devices. The participants in the experiments were 26 diabetes patients from RCDR. These people were chosen by the hospital, and they agreed to participate in the experiment after preliminary consultations. The whole experimental part was conducted in RCDR. The format of the experiment was discussed and approved in a meeting with the medical director of the center beforehand. Data collection was performed with one patient at a time letting him/ her wear each of the system devices along with hospital devices to compare the final results of both devices.

A data collection design was used to gather data on participants of different ages. We measured the participant's blood pressure (BP) level, heart rate (HR), Oxygen saturation level in blood (SPO2), temperature (TEMP) level, and blood sugar (BS) level. This type of design allowed collecting data from different participants using the proposed system's own devices (with RFID Tags) and using the RCDR devices. The design used the collected data to assess and validate the proposed system's medical devices by comparing the results with the RCDR devices.

To fulfill the objectives of this study, the procedure of measuring the participants was done in two steps. First, the nurse measured the participants' vital signs with the center's devices, and then s/he measured the signs again with the proposed system devices. Finally, the results of the two different devices were compared. The results of the experiments were entered into tables with the patient's name, age, gender, height, weight, and BMI. The following sub-sections show the measurements of each vital sign and the accuracy of each device.

4.1.1. Temperature Measurements

The reading of the wristband temperature differs from the usual body temperature. Short experiments were conducted to examine and determine the correction factor of the wristband temperature sensor.

Initially, the participant wore the RFID wrist band temperature tag that measures his/her skin (wrist) temperature degree. After 15 minutes, the temperature was measured again using an oral thermometer. The results of both, the wristband sensor and the oral thermometer, were recorded at the same time. Again, the temperature was measured orally for the same participants after 30, 45, 60, 75, 90, 105 and 120 minutes of them wearing the wristband, and the measurements were recorded. Table 16 shows a comparison between the values retrieved from the RFID wristband tag and the oral thermometer. After 105 minutes, the difference between the wristband RFID sensor readings and the thermometer reading tends to be minimal. Based on the table, it can be noticed that the wrist's temperature is 4.7°C less than the body's temperature. Hence, the correction factor of the RFID wristband temperature sensor is +4.7°C, and the temperature saved in the database should be added with a value of 4.7°C before viewing them on the web-application or using them in the Fuzzy Logic engine.

Time	Thermometer value (Oral Temperature) °C	RFID Temperature sensor value (Skin Temperature) °C	Difference Correction Factor °C
15 minutes	36.7	30.8	5.9
30 minutes	36.8	31.6	5.2
45 minutes	36.8	32.24	4.56
60 minutes	36.8	32.26	4.54
75 minutes	36.6	32.05	4.55
90 minutes	36.7	31.9	4.8
105 minutes	36.7	32	4.7
120 minutes	36.7	32	4.7

Table 16: Comparison between the values retrieved from the RFID wristband tag and the oral thermometer

4.1.2. Blood Pressure (BP) Measurements

The objective of the blood pressure measurements is to assess the RFID BP monitor for measuring blood pressure of patients according to an international validation protocol. The BP device's validation method used in this experiment was partially based on the protocols of the British Hypertension Society (BHS) [64]. The BHS protocol presented the model of categorizing the differences between test and standard measurements according to whether these measurements were within 5, 10, 15, or greater than 15 mmHg. A grade of A, B, C or D will be given to device. The final grade of the system's device was based on the number of differences that fall within these categories. The differences are calculated by subtracting the RCDR device measurements from the RFID device measurements. When differences are compared and classified, their absolute values are used [65]. A difference is characterized into one of the following four groups according to its rounded absolute value for SBP and DBP:

- 0–5 mmHg : These values represent measurements that are considered very precise and accurate (no clinical significant error).
- 6–10 mmHg : These values represent measurements that are considered to be a little imprecise and inaccurate.
- 11–15 mmHg : These values represent measurements considered to be reasonably inaccurate.
- More than 15 mmHg : These values represent measurements considered to be very inaccurate.

The study is based on how values in these groups fall cumulatively into three areas:

- Within 5 mmHg : This area represents all values falling in the 0- to 5-mmHg group.
- Within 10 mmHg: This area represents all values falling in the 0- to 5- and 6- to 10-mmHg group.
- Within 15 mmHg: This area represents all values falling in the 0- to 5-, 6- to 10-, and 11- to 15-mmHg group.

In the international protocol validation procedure, the two devices measurements are recorded on subjects in two phases. Initially, 15 subjects should be employed; devices that pass this initial phase continue to the second phase, in which a further 18 subjects are employed.

The validation of the proposed system RFID BP device was performed on 23 patients all in one phase. The mean age of the 23 patients was 45.5 years (range 20 – 72 years). Ten of the individuals were males, and thirteen were females. A total of forty six measurements were evaluated. One measurement was taken with the RCDR BP monitor, and the another one with the implemented system RFID BP monitor. Those measurements were taken consecutively and simultaneously. The two measurements were independently analyzed, and the mean differences between the blood pressure measurements and the standard deviations of those differences were calculated. The results were analyzed according to the grading system of the used protocol.

In this experiment, the percentage of the RFID device measurements differing from the RCDR device measurements by 5, 10 and 15 mmHg or less are calculated and tabulated in Table 17; the device is then graded as A, B, C or D according to the BHS criteria [64] in Table 18. To reach a particular grade, all three cumulative percentages should exceed the tabulated values. Though the mean and standard deviation of measurements and the mean and standard deviation of the differences are not used for grading purposes, they should be provided, as in Table 17, for information.

When the measurement performed by the RFID BP device was compared with that taken with the RCDR BP device, a difference of ±15 mmHg was observed in 95.65% of the systolic and 95.65% of the diastolic blood pressure measurements; a difference ≤ ±10 mmHg was observed in 86.9% of the systolic and 91.3% of the diastolic blood pressure measurements, which was classified as grade A; a difference ≤±5 mmHg was observed in 65.2% of the systolic and 66% of the diastolic blood pressure measurements, and was classified as grade B.

Differences between RCDR and RFID BP devices (mmHg)							
	BP Device	*Mean ± s.d.*	*Difference ± s.d.*	*≤5 mmHg*	*≤10 mmHg*	*≤15 mmHg*	*Grade*
SBP	*RCDR BP Device*	*146.9565 ± 25.1332*	*1.8696 ± 7.4852*	*65%*	*86.9%*	*95.65%*	*B*
	RFID BP Device	*145.0870 ± 24.7311*					
DBP	*RCDR BP Device*	*77.087 ± 10.5310*	*-4.5217 ± 5.2559*	*66%*	*91.3%*	*95.65%*	*B*
	RFID BP Device	*81.6087 ± 11.9611*					

Table 17: The device validation for of SBP and DBP for the RFID BP Monitor

		Difference between standard and test device (mmHg)		
	Grade	≤5	≤10	≤15
Cumulative % of readings	A	80	90	95
	B	65	85	95
	C	45	75	90
	D	Worse than C		

Table 18: The British Hypertension Society (BHS) Criteria [64]

The mean difference and the standard deviation of that difference for the systolic blood pressure was *1.8696 ± 7.4852* mmHg, and, for the diastolic blood pressure, it was *-4.5217 ± 5.2559* mmHg. The RFID BP Device was graded B which is an acceptable grade based on the BHS protocol and standards. The data for systolic and diastolic pressures are presented in Figures 51 and 52, respectively. These Bland–Altman plots demonstrate acceptable agreement between the RFID test BP device and reference RCDR BP device over the required pressure range [66].

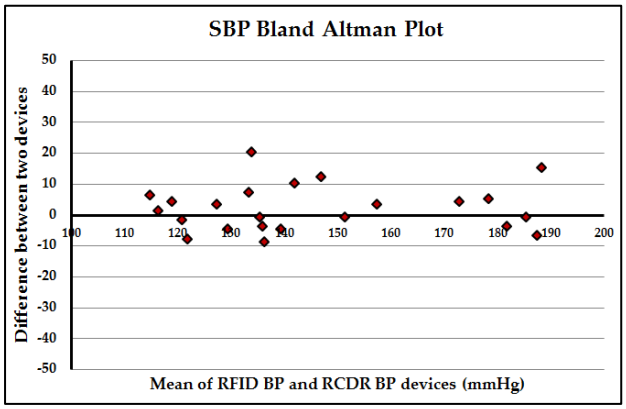


Figure 51: The SBP Bland Altman plot

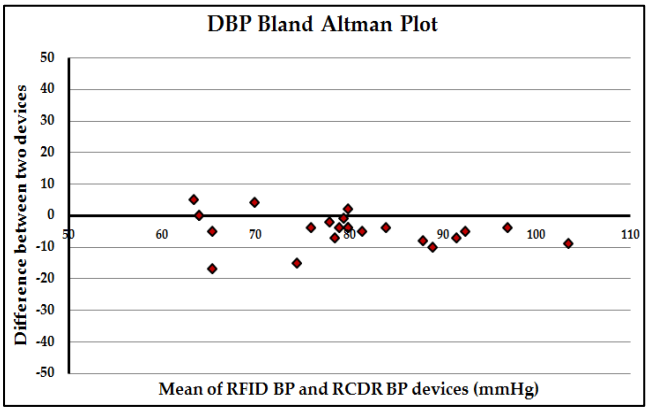


Figure 52: The DBP Bland Altman plot

The SBP and DBP of 23 subjects were measured using the RFID BP monitor and the RCDR BP device. Differences in the values obtained with the proposed RFID device and the one used in RCDR were analyzed, and the device was found to pass the BHS validation protocol requirements. The RFID BP device can, therefore, be recommended for the use of the proposed system experiments.

4.1.3. Blood Sugar (BS) Measurements

The main objective of this measurements study was to evaluate the accuracy and precision of the RFID blood sugar monitor in comparison to the RCDR reference instrument. The evaluation was completed using the Clarke Error Grid analysis method (EGA). This method was developed in 1987 to determine the clinical accuracy of the estimates of the patient blood sugar compared with the value of their blood sugar obtained in their meter [67]. It was then used to measure the accuracy of clinical blood sugar resulting from BS meters as compared with the reference value [68]. Finally, the EGA became accepted as one of the gold standards to determine the accuracy of measuring devices of blood sugar. The results will be displayed on a scatterplot. The grid will split the scatterplot of the referenced sugar meter and sugar meter needed to be tested into five zones:

- Zone A are the BS values that are 20% within the reference sensor,
- Zone B contains points that are 20% outside the reference sensor but would not lead to improper treatment,
- Zone C contains points that will lead to unnecessary treatment,

- Zone D contains points that indicates a possibly dangerous failure to detect hypoglycemia or hyperglycemia, and
- Zone E contains points that would lead to mistreatment of hypoglycemia for hyperglycemia and vice-versa.

In total, 17 participants of RCDR patients participated in this test. There were 13 females and 4 male participants with a mean age of 58.4 ± 9.3 years and a mean Body Mass Index of 31.8 ± 5.4 kg/m2. Data from the performance evaluation of the RFID BS Monitor against the reference RCDR BS Monitor are summarized in Table 19**.** The RFID BS monitor compared close to the RCDR BS Monitor with a correlation coefficient (R) = 0.9843, slope=0.86 and intercept=15. The Clarke EGA shown in Figure 53 showed that 100% of the measured values to be in zone A with zero value in zone B, C, D and E.

BS Monitor	Mean	correlation coefficient (R)	Slope	Intercept
RFID BS Monitor	152.2353	0.9843	0.86	15

Table 19: Summary of linear regression analysis of the RFID BS monitor

The evaluation of the blood sugar monitor used in the proposed system is important to ensure that this meter will have quality, consistency and accuracy in their reports of patient's blood sugar values.

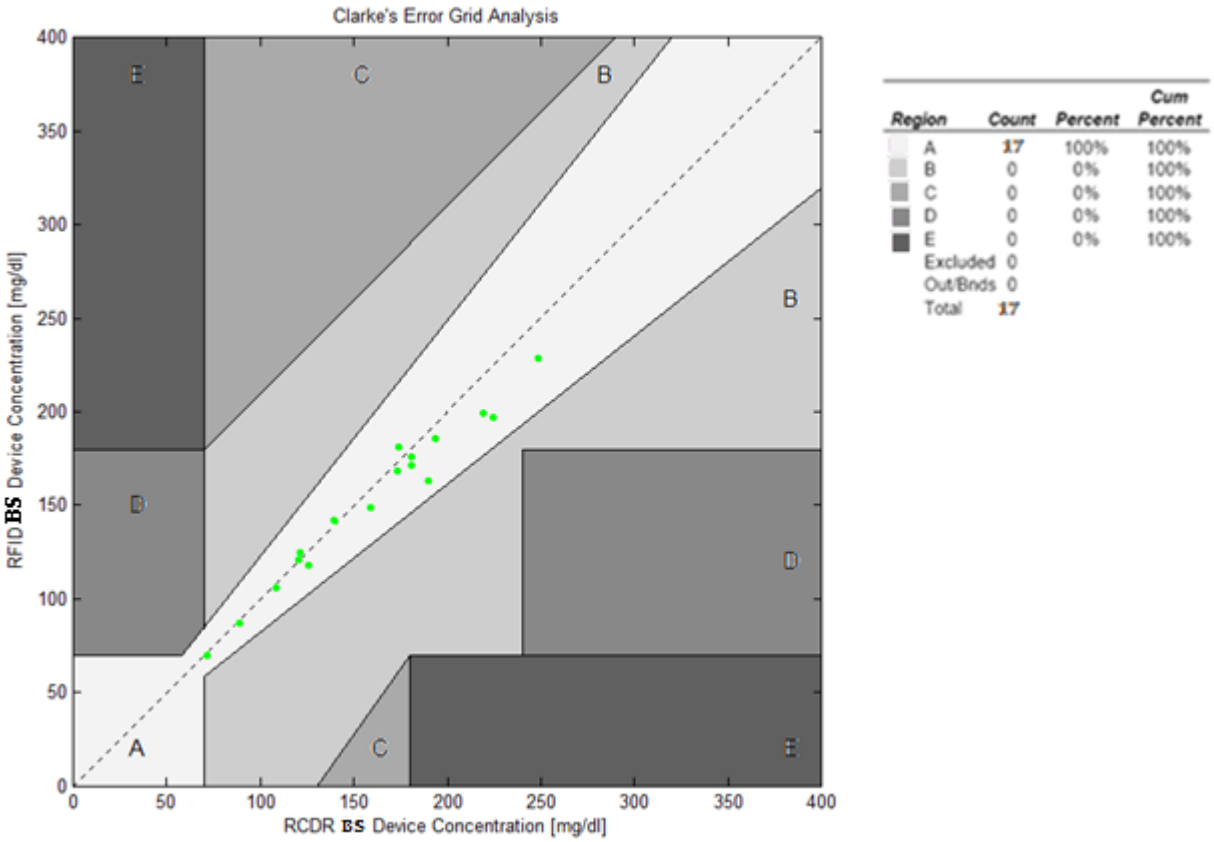


Figure 53: Clarke Error Grid (EGA) analyses the RFID BS monitor advantage

4.1.4. SPO2 (Oxygen Saturation Level in Blood) Measurements

Monitoring oxygen saturation levels using an SPO2 meter in critically ill patients is a common method for evaluating their respiratory status. Typically, the sensor is placed on a finger in adults. The SPO2 meter provides constant, noninvasive information on the oxygenation status of patients. The objective of this set of experiments was to compare SPO2 readings obtained with the RFID SPO2 sensor with SPO2 readings obtained with the traditional SPO2 sensor in RCDR. This test includes 26 participants from RCDR. The mean age of the 26 patients was 49.8 years (range 15 – 73 years). Ten of the individuals were male and sixteen were female.

A method comparison design was used to examine the agreement between 2 different SPO2 sensors, the RCDR SPO2 sensor and the proposed system RFID SPO2 sensor. Both were used for noninvasive monitoring of oxygen saturation. Each subject was measured by

the RCDR and RFID SPO2 sensors simultaneously; measurements were recorded and saved into the proposed system database.

Data was summarized by using descriptive statistics. RFID SPO2 values were compared with RCDR SPO2 values using the method of Bland and Altman as shown in Figure 54 [66] [69]. Bias, precision and root mean square of the differences were calculated to quantify the differences between the noninvasive RFID SPO2 sensor values and the RCDR SPO2 sensor values. Differences and limits of agreement between RFID test sensor and the RCDR reference SPO2 sensor were bias ± precision -0.0385 ± 1.4827% and root mean square of the differences 1.45% as shown in Table 20.

As a conclusion, the RFID SPO2 sensor was found to be an acceptable measurement device to be used in this study.

SPO2 sensors	Range %	Mean %	SD %	Bias % (Difference)	Precision % (SD)	Root-mean-square deviation % (RMSD)
RCDR SPO2 sensor	94 - 100	97.0769	1.3365	-0.0385	1.4827	1.454436
RFID SPO2 sensor	94 - 99	97.1154	1.4120			

Table 20: Oxygen saturation values, difference scores (RFID and RCDR sensor value), and RMSD scores for 26 patients

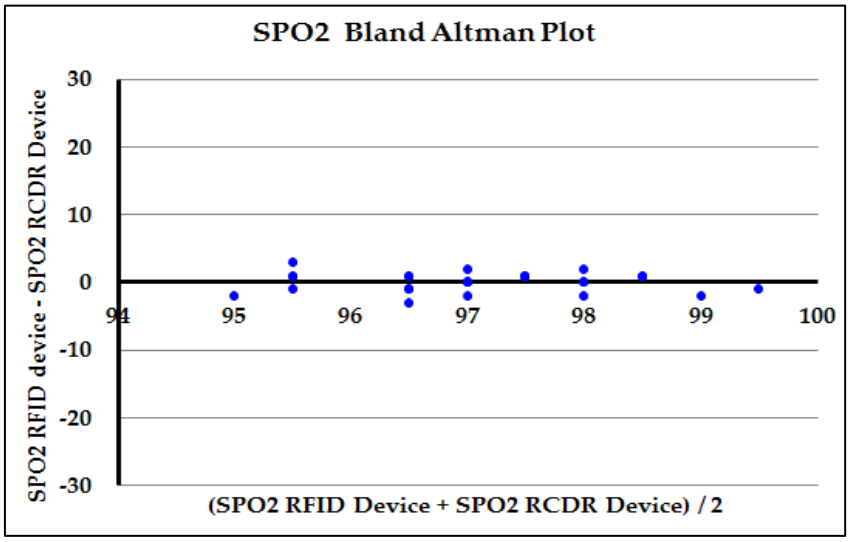


Figure 54: Bland Altman graph depicting the differences between the RCDR reference SPO2 device values from the RFID SPO2 test sensor

4.1.5. Heart Rate (Pulse) Measurements

Measurements were conducted on 26 participants from RCDR including 10 males and 16 females. The mean age of the participant is 49.8 ranging from 15 to 73. During the measurement, each subject was seated with minimum physical activity. After which, the RCDR heart rate device, RFID SPO2 heart rate device, and the RFID BP heart rate device were placed on the subject while s/he was in a resting state. Measurement was commenced simultaneously from the 3 measuring devices. The RCDR HR device measurements were saved manually into the proposed system's database, while both the RFID SPO2 HR device and the RFID BP HR device measurements were wirelessly and automatically saved into the computer database through the API interface. Since three measurements were conducted on each subject at the same time, the measurements resulted in a total of 78 resting HR measurements. The HR in blood pulse per minute (bpm), calculated from the three devices, were tabulated as shown in Table 21.

Measurement	RCDR HR sensor (bpm)	RFID BP HR sensor (bpm)	RFID SPO2 HR sensor (bpm)
1	62	64	69
2	70	71	66
3	92	88	90
4	58	61	59
5	62	67	63
6	82	80	80
7	121	118	118
8	92	95	95
9	76	79	73
10	87	86	82
11	84	79	80
12	92	93	93
13	84	86	91
14	96	99	99
15	89	92	93
16	82	85	83
17	63	65	60
18	70	71	71
19	95	91	87
20	75	69	80
21	65	64	65
22	79	78	80
23	87	90	90
24	92	91	91
25	71	71	71
26	88	87	86

Table 21: Heart Rate data collected for 26 measurements

Pearson Correlation Coefficient (direction of relationship) and the Coefficient of Determination tests (strength of relationship) is used in the validation of the measurement outputs (i.e. HR) of an alternative instrument (i.e. RFID HR devices) against a "gold standard" (i.e. RCDR HR device) to ascertain the nature of relationship between two sets of scores [70]. Using the formula for Pearson's Correlation Coefficient, the Pearson correlation coefficient and the Coefficient of Determination were calculated for both the RFID BP HR device and the RFID SPO2 HR device as shown in Table 22.

Regression Statistics		
	RFID BP HR device	**RFID SPO2 HR device**
Correlation Coefficient	0.9787	0.9658
Coefficient of Determination	0.9579	0.9328
Difference Standard Deviation (SD)	2.9163	3.6494
2xSD	5.8326	7.2988

Table 22: Correlation test between the RCDR HR sensor and both the RFID BP HR and RFID SPO2 HR sensors

From the results shown in Table 22, it can be observed that the HR data between RFID BP HR device and the RCDR HR device was positively correlated (i.e. 0.9787) and the corresponding coefficient of determination is 0.9579. Also, it can be observed that the HR data between RFID SPO2 HR device and the RCDR HR device was positively correlated (i.e. 0.9658) and the corresponding coefficient of determination is 0.9328. These results indicate that the relationship between the HR values measured by both the RFID BP HR monitor and RFID SPO2 HR monitor and the RCDR HR device was almost perfectly linear.

Using Table 21, the HR for RFID BP HR, RFID SPO2 HR and RCDR HR measurements were plotted as shown in Figure 55 and Figure 56. To understand the direction of the relationship, a linear regression approach was adopted to approximate the linear equation to describe the two measurements. The RFID BP HR regression value is 0.97867, and the RFID SPO2 HR regression value is 0.96585 .The regression value being almost 1 indicates an almost perfect positive relationship between the measured data and the linear equation.

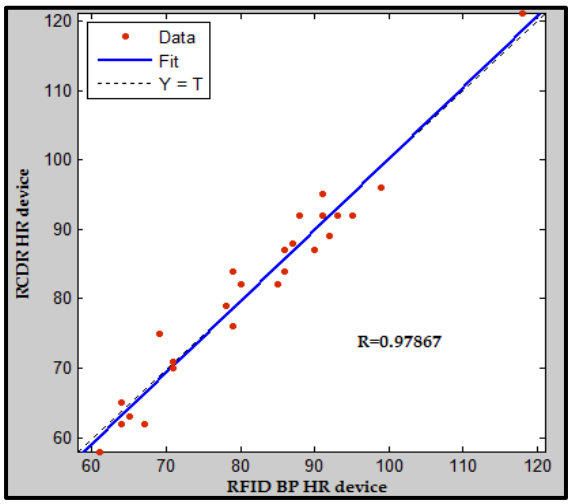


Figure 55: Plot of HR measured from RFID BP HR device and RCDR HR device

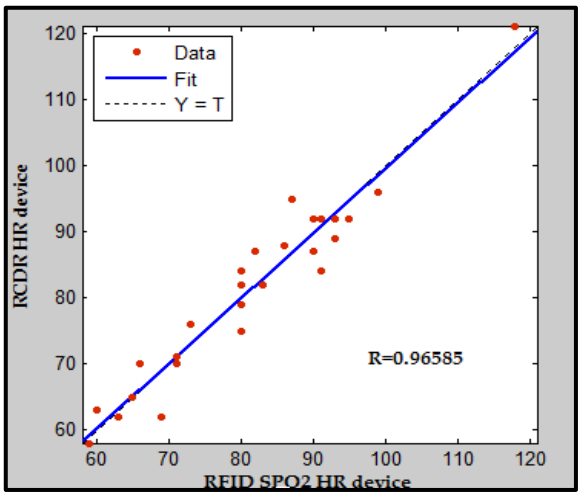


Figure 56: Plot of HR measured from RFID SPO2 HR device and RCDR HR device

Based on the results obtained from this correlation study, it was concluded that the accuracy of the HR measurement between the 3 devices is reasonable and good for use. The accuracy of measurement results is an important step forward as it forms the basis for any scientific validation to be meaningful. From the above testing, the reading accuracy of the RFID devices that were used in the research and the hospital devices is acceptable.

4.2.Implementations, Testing, and Evaluation of the Fuzzy Logic Engine

The evaluation of the fuzzy expert system is the result of the comparison between the risk groups status suggested by the fuzzy expert system (decision support system), and the risk groups status indicated by the MEWS scoring system. The experiments described in this section include 35 patients, out of whom 26 patients are from RCDR and 8 anticipated patients. The 26 patients from RCDR are the same patients who volunteered to validate the systems devices. The data collected from these patients is also used to evaluate the fuzzy logic engine. Table 23 shows the data collected from the patients and the results of it. The data used in the experiment includes:

1. RCDR patients' vital signs values measured by the RFID sensors which include,
    - RCDR patients' temperature value,
    - RCDR patients' SBP value,
    - RCDR patients' heart rate value,
    - RCDR patients' SPO2 value,
    - RCDR patients' blood sugar value.
2. The results of the patients' risk group status and score calculated using MEWS scoring system. These results are considered as the real system results.
3. The results of the patients' risk group status and score calculated using the fuzzy logic engine. A comparison between the MEWS Scoring system results and the fuzzy logic results is then prepared to evaluate the system's fuzzy logic engine. The steps to calculate the fuzzy logic score was shown in Chapter 3. Based on this score, a corresponding fuzzy logic output status is reached.

Patient Num	Vital Signs					RESULTS			
	RCDR					Using MEWS		Using Fuzzy Logic	
	Temp	SBP	HR	SPO2	BS	Status	Score %	Status	Score %
NORMAL (NRM)									
1	37	161	62	97	72	NRM	0	NRM	0.28636
2	36.59	121	79	97	103.5	NRM	0	NRM	0.2863636
3	37	120	65	95	88	NRM	0	NRM	0.2863636
4	37.5	170	80	96	102	NRM	0	NRM	0.28636
5	38.1	127	89	98	89.46	NRM	0	NRM	0.846875
LOW RISK GROUP (LRG)									
6	37.5	139	70	98	120.42	LRG	2	LRG	2.49545
7	37	135	92	96	138	LRG	2	LRG	2.49545
8	37	120	71	98	119.52	LRG	2	LRG	2.49545
9	36.1	129	88	97	134.28	LRG	2	LRG	3.9477273
10	38.2	117	63	98	115	LRG	2	LRG	3.378
11	37	180	92	97	226	LRG	3	LRG	3.504545
12	37	134	84	100	163.26	LRG	3	LRG	3.504545
13	37.5	175	70	97	167	LRG	3	LRG	3.5045455
14	37	184	75	96	156	LRG	3	LRG	3.504545
15	37	144	87	97	206	LRG	3	LRG	3.504545
16	37	147	88	97	277	LRG	3	LRG	3.504545
17	38.2	118	92	96	165	LRG	3	LRG	4.3561224
18	38.2	132	82	95	160.38	LRG	3	LRG	4.3561224
19	37	180	96	98	201	LRG	3	LRG	3.7772727
20	36.6	137	96	100	204	LRG	3	LRG	3.7772727
21	36.6	181	58	96	181	LRG	3	LRG	3.8530675
22	37	151	56	98	237.42	LRG	3	LRG	4.0543478
23	37	118	84	94	161	LRG	3	LRG	4.005
24	37	96	55	96	68	LRG	3	LRG	3.8185096
HIGH RISK GROUP (HRG)									
25	39	137	92	96	253.44	HRG	5	HRG	5.4954545
26	40	134	76	97	184	HRG	5	HRG	5.4954545
27	39	159	65	96	416.7	HRG	5	HRG	5.4954545
28	41	187	87	97	161	HRG	5	HRG	5.9342466
29	38.3	73	97	97	145	HRG	5	HRG	6.9822222
30	37.5	86	48	88	69	HRG	6	HRG	6.5539024
31	38.6	190	120	94	120	HRG	6	HRG	7.8737903
32	38.6	190	127	94	120	HRG	6	HRG	8.3566148
33	36.6	76	40	80	60	HRG	10	HRG	10.5
34	40	300	135	94	160	HRG	10	HRG	10.995

Table 23: A comparison between the MEWS results and the Fuzzy Logic results

Table 23 summarizes the analysis results for the fuzzy logic engine performance validation tests. In this table, the results are divided into three categories; a normal group, a low risk group (LRG), and a high risk group (HRG). These categories are classified based on the output results. The evaluation of the fuzzy expert system is the result of the comparison between the risk group status suggested by the fuzzy expert system (decision support system), and the risk group status result from the MEWS scoring system. The 2D-Cloumn chart of Figure 57 shows the difference between the different cases scores calculated by the MEWS scoring system and the decision support system.

The reference score used for the evaluation of the decision support system is the MEWS scoring system, and it's based on the same set of data. The computed value of the MEWS scoring system indicates the level of agreement/disagreement between the two systems. It is evident that in almost all cases, the fuzzy expert system is able to produce the same score indicated by the MEWS scoring system. The system is intended to be used as a monitoring support system by patients with chronic diseases in the interval between two medical visits.

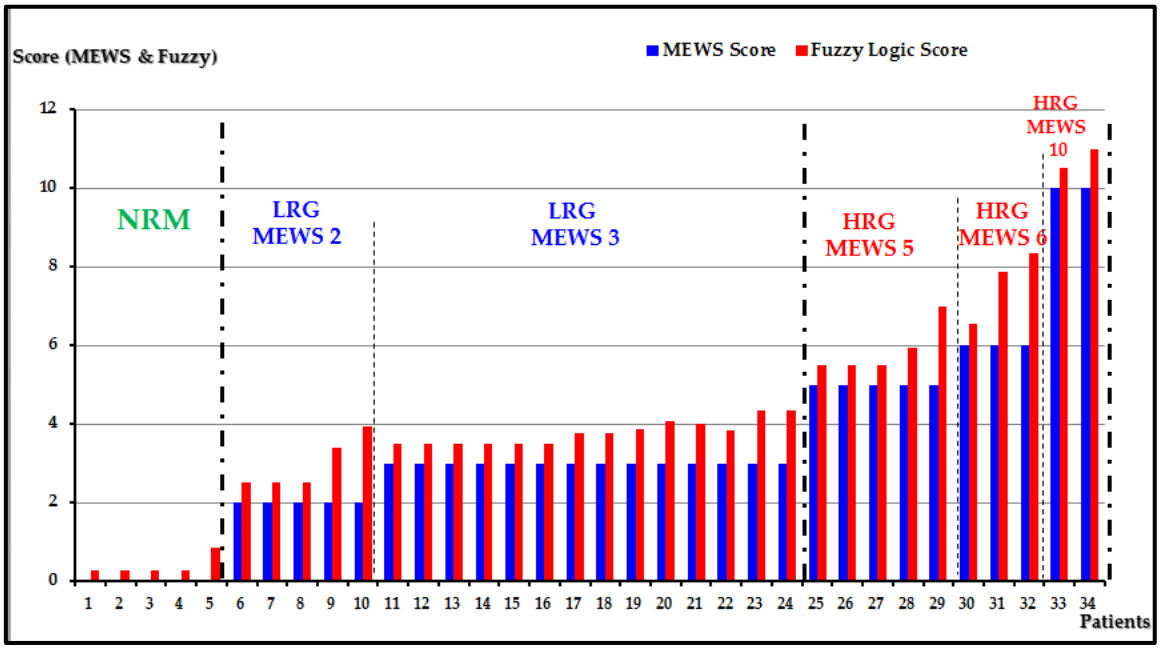


Figure 57: 2D-Cloumn chart for the different cases scores calculated by the MEWS scoring system and the decision support system is shown.

Normal Group (NRM):

In this category, the system was tested using 5 cases. The first 4 cases are similar in having normal vital signs as inputs (the five inputs are normal), while the 5th case is with 4 normal vital signs and 1 fuzzy vital sign. The temperature value is between Normal and High2. It was observed that the MEWS score for the 5 cases was 0 (Status: Normal) which indicates that the 5 patients are with Normal vital signs. However, in the Fuzzy Logic results, the first 4 patients had a score of 0.286 and the 5th case had a score of 0.847, which separates the 5th case from the other. Figure 58 shows the comparison graph of the Normal case.

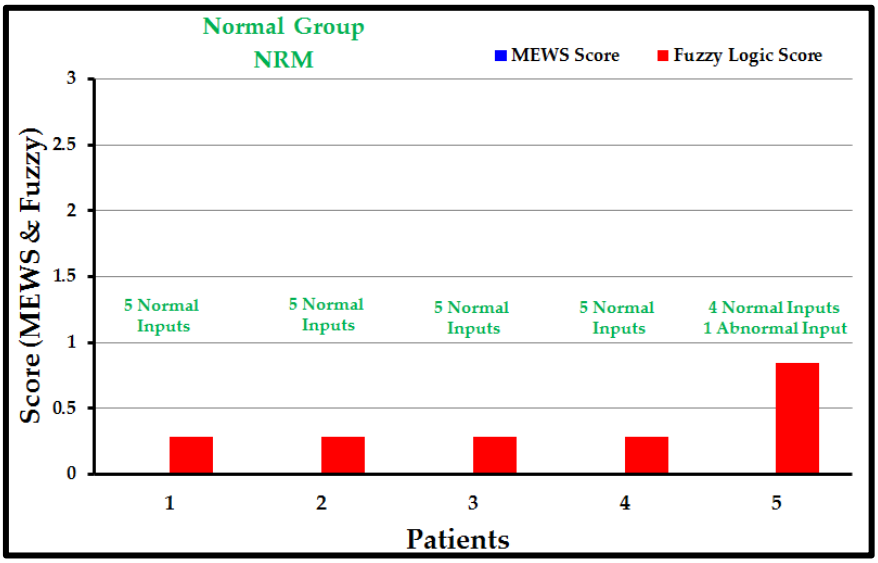


Figure 58: The NRM case comparison graph

Low Risk Group (LRG):

In this category, the system was tested using 19 cases. The first five cases are under the LRG 2 category, and the 14 following cases are under the LRG 3 Category. In LRG 2 category, The first 3 patients have one abnormal input and 4 normal inputs while the following two have one abnormal input, one fuzzy input and 3 normal inputs. In the MEWS results, all had a score of 2, while the last two cases vary in the Fuzzy Logic result from the first three cases. Figure 59 shows the comparison graph of LRG2 case. Figure 60 shows the following 14 cases for the LRG3 category, and it shows the variations of the Fuzzy Logic results from the MEWS scoring system.

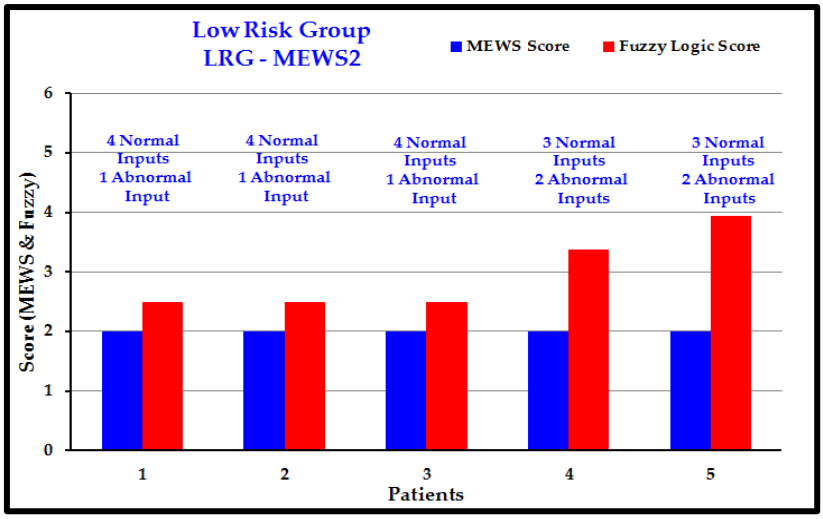


Figure 59: The LRG2 case comparison graph

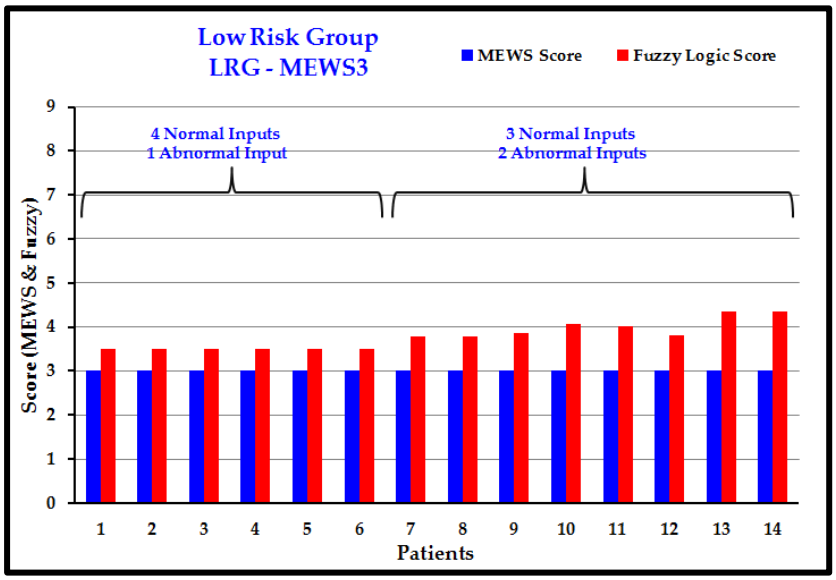


Figure 60: LRG3 case comparison graph

Both patient 4 and patient 5 are patients with 3 normal inputs [SBP, HR, and SPO2] and 2 abnormal inputs [temperature and BS] as shown in Table 24; however, they have a different fuzzy logic score. To explain this difference, the steps of calculating their scores must be described in order to know the rules fired and explain the difference between the scores.

	RCDR					Using MEWS		Using Fuzzy With Overlap	
	Temp	SBP	HR	SPO2	BS	Status	Score %	Status	Score %
Patient 4	36.1	129	88	97	134.28	LRG	2	LRG	3.948
Patient 5	38.2	117	63	98	115	LRG	2	LRG	3.378

Table 24: Patient 4 and 5 vital signs, MEWS and Fuzzy Logic scores

As mentioned earlier, the system is built on 1800 rules, and each of the rules depends on resolving the inputs into a number of different fuzzy linguistic sets. Before the rules can be evaluated, the inputs must be fuzzified according to each of these linguistic sets. Table 25 and 26 shows the degree of membership for each input for patients 4 and 5, respectively.

SBP		HR		SPO2		TEMP		BS	
Input Variable	Membership value	Input Variable	Membership value	Input Variable	Membership value	Input Variable	Membership value	Input Variable	Membership value
LOW3	0	LOW2	0	LOW3	0	LOW2	0.8	LOW3	0
LOW2	0	LOW1	0	LOW2	0	NORMAL0	0.2	LOW2	0
LOW1	0	NORMAL0	1	LOW1	0	HIGH2	0	NORMAL0	0
NORMAL0	1	HIGH1	0	NORMAL0	1			HIGH2	1
HIGH2	0	HIGH2	0					HIGH3	0
		HIGH3	0						

Table 25: The degree of membership for each input for patient 4

SBP		HR		SPO2		TEMP		BS	
Input Variable	Membership value	Input Variable	Membership value	Input Variable	Membership value	Input Variable	Membership value	Input Variable	Membership value
LOW3	0	LOW2	0	LOW3	0	LOW2	0	LOW3	0
LOW2	0	LOW1	0	LOW2	0	NORMAL0	0.6	LOW2	0
LOW1	0	NORMAL0	1	LOW1	0	HIGH2	0.4	NORMAL0	0
NORMAL0	1	HIGH1	0	NORMAL0	1			HIGH2	1
HIGH2	0	HIGH2	0					HIGH3	0
		HIGH3	0						

Table 26: The degree of membership for each input for patient 5

Referring to the rules, the system can plug in the membership function weights from above. Of the 1800 rules selected, only two rule (rules 1254 and 1259) fire or have non-zero results. This leaves fuzzy output response magnitudes for only "LRG2" and "LRG4," which must be inferred, combined, and defuzzified to return the actual crisp output. In the rule list below, the inputs are combined logically using the AND operator to produce output response values for all expected inputs. The active conclusions are then combined into a logical sum for each membership function. A firing strength for each output membership function is computed. All that remains is to combine these logical sums in a defuzzification process to produce the crisp output. Tables 27 and 28 show the firing strength and centroid for each output membership function for patient 4 and patient 5, respectively.

Rule #	Operators	Strength	Centroid
Rule 1249	If (SBP is Normal0) and (HR is Normal0) and (SPO2 is Normal0) and (TEMP is Low2) and (BS is High2) then (RiskGroup is LRG4)	1&1&1&0.8&1 = 0.8	LRG4 → 0.8 Centroid = 4.5
Rule 1254	If (SBP is Normal0) and (HR is Normal0) and (SPO2 is Normal0) and (TEMP is Normal0) and (BS is High2) then (RiskGroup is LRG2)	1&1&1&0.2&1 = 0.2	LRG2→ 0.2 Centroid = 2.5

Table 27: The firing strength and centroid for each output membership function for patient 4

Rule #	Operators	Strength	Centroid
Rule 1254	If (SBP is Normal0) and (HR is Normal0) and (SPO2 is Normal0) and (TEMP is Normal0) and (BS is High2) then (RiskGroup is LRG2)	1&1&1&0.6&1 = 0.6	LRG2 → 0.6 Centroid = 2.5
Rule 1259	If (SBP is Normal0) and (HR is Normal0) and (SPO2 is Normal0) and (TEMP is High2) and (BS is High2) then (RiskGroup is LRG4)	1&1&1&0.4&1 = 0.4	LRG4→ 0.4 Centroid = 4.5

Table 28: The firing strength and centroid for each output membership function for patient 5

From the above tables, it can be noticed that LRG4 has a higher firing strength than LRG2 for patient 4, while LRG4 has a lower firing strength than LRG2 for patient 5. As a result, it is logical that the output score (RiskGroup) should be higher in patient 4 than 5. The defuzzification of the data into a crisp output is accomplished by combining the results of the inference process and then computing the "fuzzy centroid" of the area. The weighed strengths of each output member function are multiplied by their respective output membership function center points and summed up. Equations 17 and 18 show the risk group output for patients 4 and 5, respectively.

$$RiskGroup = \frac{((0.8\times4.5)+(0.2\times2.5))}{(0.8+0.2)} = 4.1 \qquad \text{..... Equation 17}$$

$$RiskGroup = \frac{((0.6\times2.5)+(0.4\times4.5))}{(0.6+0.4)} = 3.3 \qquad \text{..... Equation 18}$$

Based on these results, patient 4's risk group score is 4.1 which is close to LRG4 with the higher firing strength, and patient 5's risk group score is 3.3 which is less than patient 4's score. Looking back at Table 4, The Matlab simulation results for patient 4 and 5 were 3.378 and 3.948 respectively. The simulated and calculated results are shown in the Table 29. The difference between the results is due to the involved software's delay.

Results	Patient 4	Patient 5
MATLAB Simulation	3.948	3.378
Calculated Values	4.1	3.3
Difference	0.512	0.078
Error %	1.75	0.34

Table 29: Comparison of Calculated and Simulated Results of The Fuzzy Logic System for patients 4 and 5

High Risk Group (HRG):

In this category, the system was tested using 10 cases. The first five cases are under the HRG5 Category, the following three are under the HRG6 Category, and the last two cases are under the HRG10 Category. Figures 61, 62, and 63 show the details of the comparison between the MEWS scoring system and the fuzzy logic system results for the HRG.

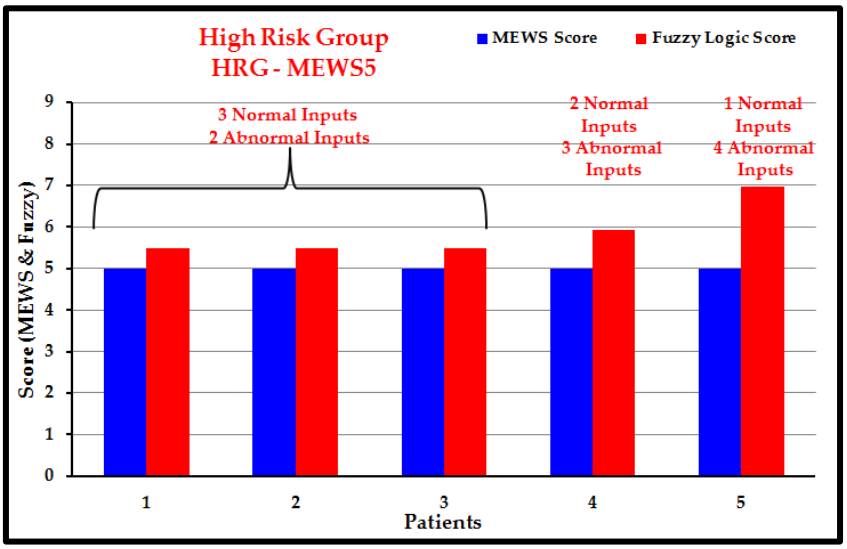


Figure 61: The HRG5 case comparison graph

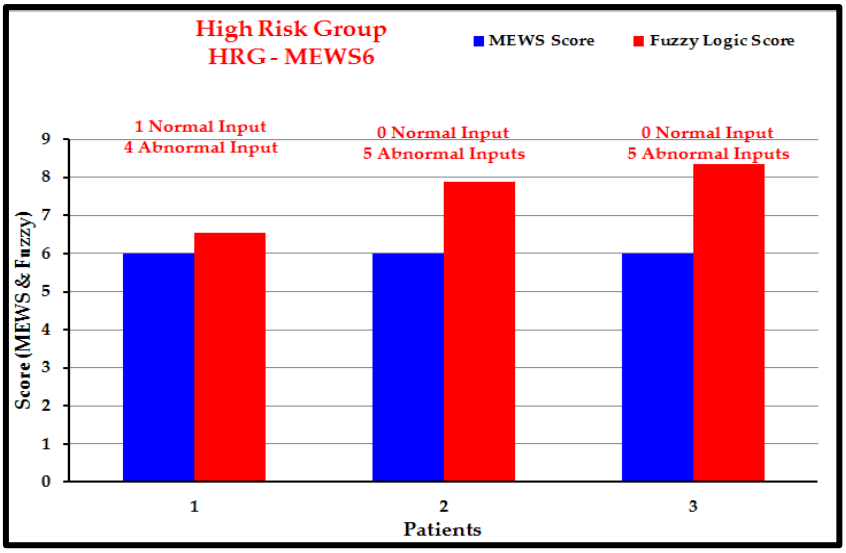


Figure 62: The HRG6 case comparison graph

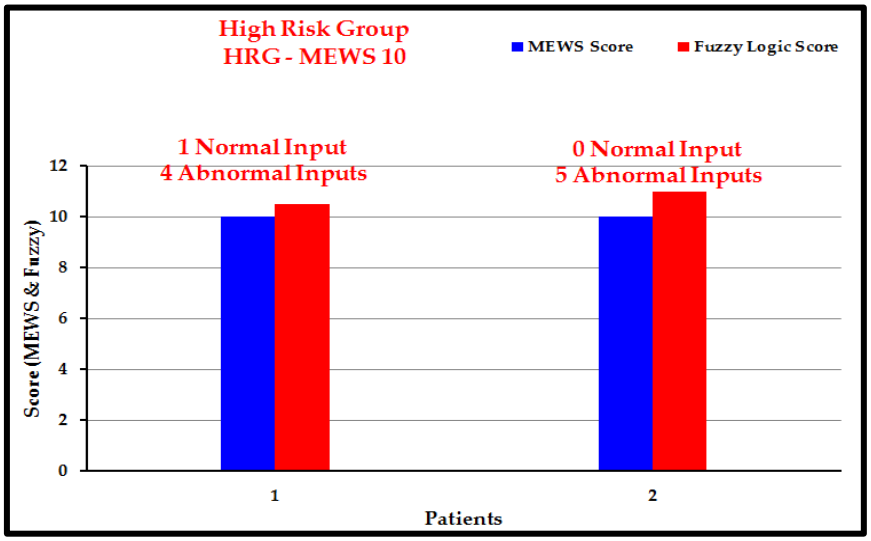


Figure 63: The HRG10 case comparison graph

From this section discussion, it can be noticed that with the fuzziness, the ranges can be divided more precisely than using the MEWS scoring system and the number of factors contributing in the change of output can be easily found. Also, using 15 output ranges is better than the three output ranges because they give a more precise output. It can be noticed also, that the Fuzzy Logic system performed better than the MEWS Scoring system.

Chapter 5

Conclusions and Future Work

5.1. Thesis Summary and Concluding Remarks

The current research has been carried out to develop an integrated RFID healthcare platform that can be used at home or inside the hospital premises. This platform allows patients to be mobile while they are monitored and readings of their vital signs are recorded. The platform is complemented by using a diagnosis system based on Fuzzy Logic techniques.

The system strengthens the capabilities of staff to track patient's vital signs across various locations and in different medical facilities or at home. It includes vital sign monitoring and alarming services, we-based monitoring applications, and rule-based clinical decision support in different environments. The system continuously monitors critically ill patients with the objective of reducing the risk of serious harm resulting from the slow provision of health care.

The complete system was tested on real patients affiliated with Rashid Center for Diabetes and Research (RCDR) in Ajman, UAE. Results indicate that the developed diagnostic Fuzzy Logic warning system outperforms the MEWS system. Hence, the final product can be a very useful tool clinically.

Further, we also believe the system can be extended to most medical domains and integrated with other hospital information systems. With more medical centers linked into the system, the proposed system should provide better and safer medical services to the healthcare industry.

5.2. Future Directions

Possible future research directions include:

- Increasing the sample size from 26 patients to a larger set to enhance the testing and accuracy of the system. A larger population of patients will provide many alternate illness scenarios and hence a better coverage of all possibilities.
- To be able to develop the Fuzzy Logic System to know the abnormal factors (Ex. Temperature).
- To include gender and age factors in the decision making process.

The results of the proposed system confirm the effectiveness of fuzzy logic in patient monitoring, but it still needs to be tested in a real-time environment to show its full clinical worth.

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