GSM Based Smart Patient Monitoring System

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***Abstract*—**In this paper, we propose an intelligent system that is used for monitoring the health conditions of patients. Monitoring the health condition of patients is a complex problem that involves different medical units and requires continuous monitoring especially in rural areas because of inadequate number of available specialized physicians. The proposed system will improve patient care and drive costs down comparing to the existing system in Jordan. The proposed system will be the start point to faster and improve the communication between different units in the health system in Jordan. Connecting patients and their physicians beyond hospital doors regarding their geographical area is an important issue in developing the health system in Jordan. The ability of making medical decisions, the quality of medical is expected to be improved.

***Keywords*—**GSM, SMS, Patient, Monitoring system, Fuzzy Logic, Multi-agent system.

I. INTRODUCTION

WITH the development of intelligent systems, health sector in Jordan is encouraged and can benefit from latest technologies to improve patient care and outcomes and lower healthcare cost. The spread of diseases and certain habits in population will encourage more use of intelligent systems in a form of mobile apps, gadgets and e-heath systems. Intelligent systems are used to analyze patient data and human response and hence guide the implementation and management of therapies and interventions.

The current system in Jordan is based on paperwork. Different units work alone and no electric system is available to join the record of the employee. The proposed system will provide an environment that allows cooperation between different units in the system and enable exchanging medical information that all will help in better diagnosing of the employee and the student. The propose system will provide an intelligent system that will generate initial diagnosing to the patient case. This will assist and advice clinicians at the point of care. The decision is based on demographic data and laboratory test results of patient data. Using such system with the ability of making medical decisions, the quality of medical care in Jordan and specifically in Tafial (city in south Jordan) are expected to be improved. This will provide more accurate, effective, and reliable diagnoses and treatments especially if the physicians have insufficient knowledge.

Elderly people and Patients in Tafial area need continuous health monitoring and consulting by expert from public and private hospital in Amman. This is because of inadequate number of available specialized physicians or nurses in Tafila. This forces patients in current system to travel more than 200km to see physicians. Having such system will make it easier for elderly people to consult physician in their local areas and/or their home. This will decrease healthcare costs by providing a faster diagnosis by reducing the need for specialist consultations

Having e- health system in Jordan will improve patient care and drive costs down comparing to the existing system in Jordan. Having intelligent communication system will faster and improve the communication between different units in the health system of Jordan. This will help physicians in hospitals by faster the access to the updated patients' data and enhance the diagnostic stage in real time. Hospitals and medical providers will also benefit from the proposed system in exchanging patients' data and medical knowledge at much faster rate. The proposed system will be the start point to connect patients and their physicians beyond hospital doors regarding their geographical area. Patients will be able to seamlessly and from anywhere track their healthcare records and be monitored for unusual health issues.

Fuzzy logic [1] is a well-established methodology that is effective for systematic handling of deterministic uncertainty and subjective information. Fuzzy logic is useful especially when a mathematical model of a system is not available and rules of the thumb from domain experts are available. It has been successfully used to solve challenging industrial and medical problems in practice, some of which are very difficult to solve without it. Using Fuzzy rule based approach in this paper is dependent upon air fuel ratio as an input to the system to well define the values of the five major engine emissions. This system makes it easy to know exactly the values at any operating condition which can be used in the future with the ECM to reduce emissions.

In this paper the reasoning is implemented using MATLAB Fuzzy toolbox. The detecting task of the proposed system is performed by the Inference Engine that evaluates all the rules in a knowledge Base and combines the weighted consequents of all relevant rules into a single output fuzzy set that shows the status of an emission. That set is then defuzzified to produce a crisp emission status value. The automotive emission status detector is experience-based as experience plays a key role in the design of the Detector.

II. PROPOSED PATIENT MONITORING SYSTEM ARCHITECTURE

A. Overview of the Proposed Patient Monitoring System

In our previous work [2], we proposed a multi-agent system for monitoring the health condition of elderly people. An agent is assigned to a physician and an agent is assigned to EAs (Fig. 1).

We have further developed the multi-agent system that we conceptually put forward before. In that system, we have developed a GUI for both Elderly agent and Physician Agent.

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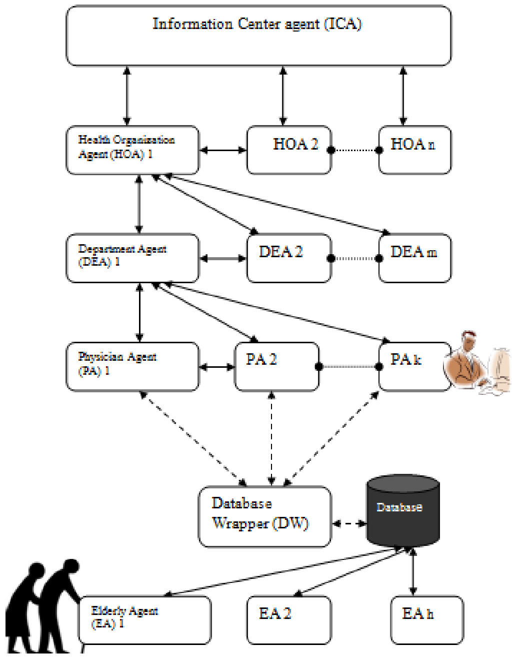

Fig. 1 The proposed Multi-Agent system for monitoring the health conditions of elderly people [2]

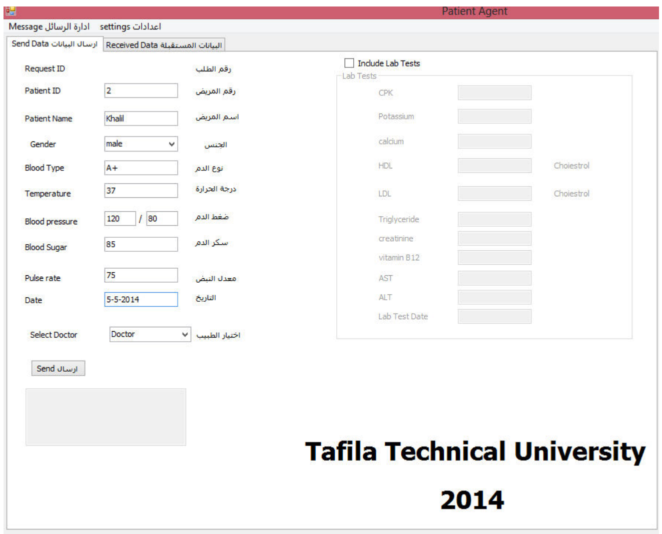

Fig. 2 Elderly Agent GUI

Agents work with each other in a cooperative way to complete certain task that cannot be done with single agent. A set of agents that help one another in solving problems by using cooperation, coordination and negotiation techniques is called a multi-agent system [3]. The multi-agent system is a complex system since the agents must be supported with interaction strategies that make them capable to select the appropriate activity at the appropriate time [4].

B. The Developed Graphical User Interface (GUI)

Elderly Agent (EA) gathers certain medical information of the monitored elderly people such as Blood pressure Levels, Blood Glucose Levels, Cholesterol levels, Temperature, Heart rate, Oxygen level in blood, and other laboratory tests such as Creatinine Laboratory Test and Potassium Laboratory Test. Creatinine Phosphokinase (CPK) Laboratory Test and Transaminases Laboratory Test (either ALT or AST). The developed GUI is shown in Figs. 2 and 3.

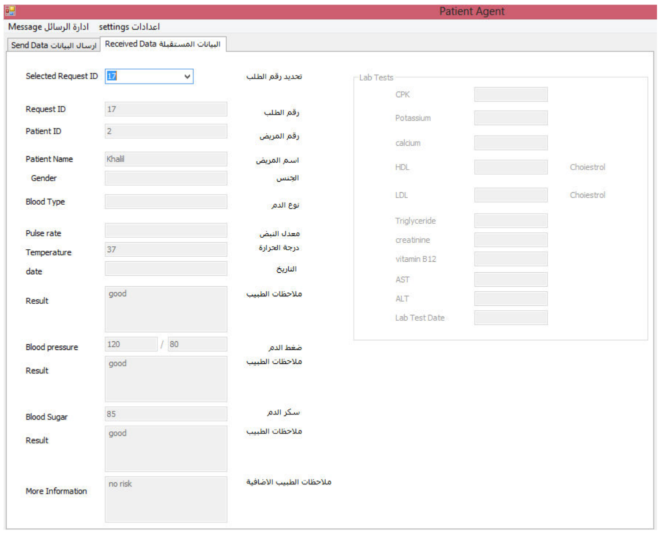

Fig. 3 The received data from the Physician Agent shown in Elderly Agent GUI

Patient data will be entered in GUI as shown in Fig. 2. The entered data will be sent to the specified physician selected in the GUI. More physicians can be added form the setting tab. The evaluated results will be sent back to patient GUI as shown in Fig. 3.

Fig. 4 SIM900 module

The information in the proposed system will be gathered from the elderly people using regular medical instruments and the result will be input to the system through graphical user interface in order to be sent to the database and to his/her physician. This can be done from elderly people houses, medical clinics or even medical laboratory centers. The proposed way of sending the data to the database is not only using regular internet networks but also using GSM technology through SMS messages [5], [6]. Using SMS messages is very helpful in rural areas where the internet connection is not available. This was done using GSM modems (Fig. 4) by AT commands. GSM Modem requires a SIM card (Subscriber Identity Module).The SIM card contains store data that includes subscriber identification, network authorization data, data encryption, personal security keys, contact lists, dialing numbers and stored text messages. AT commands is used to collect information by controlling GSM Modems. A GSM modem is a special device that uses a SIM card, and it operates like mobile phones. AT is the abbreviation of ATtention.

GSM module requires one SIM card [6]. This module is capable to accept any network SIM card. The GSM module has a unique identity number like mobile phones have. The GSM module is used to send an SMS to the user‘s cell phone number. When the patient data has been entered and the send order has been given, a signal to the GSM module which then sends a message to the physician user that is predefined by the programmer. GSM SIM 900 Quad-band GSM/GPRS engine, works on frequencies 850MHz, 900MHz, 1800MHz. It is very compact in size and designed with RS 232 level converter circuitry, which allows you to directly interface PC Serial port. GSM uses a combination of Time Division Multiplexing and Frequency Division Multiplexing. The baud rate can be configurable from 9600-115200 through AT command. This GSM/GPRS RS232 Module is having internal TCP/IP stack to enable you to connect with internet via GPRS. Using this module, we will be able to send & read SMS, Connect to internet via GPRS through simple AT commands. The suitable operating voltage level is 5V-12V DC.

The SMS architecture is shown in Fig. 5. The SMS message will be transmitted from the agent GSM module to nearest Base Transceiver Station (BTS) through a wireless Channel [7], [8]. The SMS will be received and passed to Base Station Controller (BSC). The BSC handles the operation of the BTS. The message will leave BSC and move to the Mobile Switching Center (MSC). The Mobile Switching Center acts like a switching device which switch data between users on the network based on routing information provided by the Home Location Register (HLR). The HLR contains relevant data about network subscribers: their status, location and thus its routing information. The message will be stored within Short Message Service Center (SMSC) which will forward the message when the receiving Agent becomes available. The SMSC is software that manages the processes of queuing the messages, billing the sender and returning receipts if necessary.

The Subscriber details will be validated by Visitor Location Register (VLR) and Equipment Identity Register (EIR). VLR will verify that the message transfer does not violate the supplementary services invoked or the restrictions imposed. The visitor location register is a database that contains temporary information about subscribers homed in one Home Location Register (HLR) who is roaming into another HLR. EIR is a database to determine if the service of a GSM mobile Subscriber is authorized, unauthorized, or if it should be monitored. It uses International Mobile Equipment Identity (IMEI) to identify each Subscriber device. An IMEI is considered as invalid if it has been reported stolen or is not type approved.

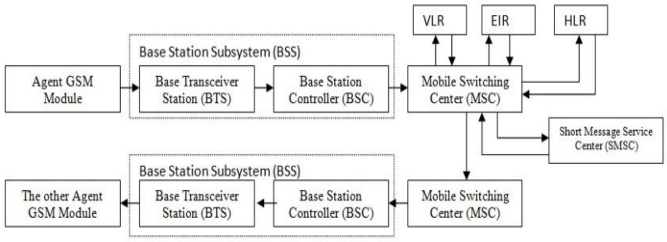

Fig. 5 SMS architecture

MSC asks HLR for reception location. The MSC will deliver the message to the specific mobile subscriber through the proper base station. The message will be released and moved to the appropriate MSC and then forwarded to nearest Base Station Subsystem (BSS) and it will be received to its destination agent.

Physician Agent (PA) helps a physician acquire useful information of the elderly people and make initial decisions about the medical situation of the patients. The PA will perform according its knowledge. The PA has the ability to track the further development of the suspected cases under the help of other agent available in the system. The PA will keep all the cases seen by or forwarded to its physician in electronic records and such records will be updated when new information is being available. The PA can decide to take any of the following actions depending on the decision reached, i.e.:

- To order some extra clinical tests.
- To continue the same medical treatment or to modify it.
- To schedule another visit for the future or transfer the patient, for example, hospitalize him if his health has deteriorated too much. Patients can also be transferred from one of the health centers to another according to the patient needs.

The PA is equipped with the rule-based reasoning capability. More specifically, we have designed a “Fuzzy Risk Level Assistant System”. Fuzzy logic is a well-established methodology that is effective for systematic handling of deterministic uncertainty and subjective information. Fuzzy logic is useful especially when a mathematical model of a system is not available and rules of the thumb from domain experts are available. It has been successfully used to solve challenging industrial and medical problems in practice, some of which are very difficult to solve without it. The Assistant system is a common rule-based system that uses fuzzy sets theory. The PA GUI is shown in Fig. 6. The physician has the ability to analyze patient information and comment on the individual results in the same GUI. The diagnoses of patient case with any taken action will be sent back to the patient. All received data will be stored in Access database.

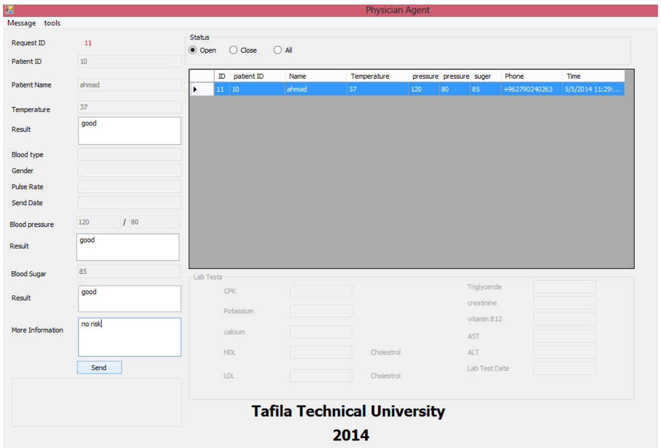

Fig. 6 Physician Agent GUI

C. The Developed Fuzzy System

We have designed and developed a "Fuzzy Monitor Assistant System". Fuzzy logic is a well-established methodology that is effective for systematic handling of deterministic uncertainty and subjective information. Fuzzy logic is useful especially when a mathematical model of a system is not available and rules of the thumb from domain experts are available. It has been successfully used to solve challenging industrial and medical problems in practice, some of which are very difficult to solve without it. The Assistant system is a common rule-based system that uses fuzzy sets theory.

The reasoning is based on fuzzy logic. The structure of the Assistant System (Fig. 7) includes four components: Fuzzifier, Inference Engine, Knowledge Base, and Defuzzifier. The Fuzzifier translates crisp inputs into fuzzy values. The Inference Engine is the part that controls the process of deriving conclusions. It applies a fuzzy reasoning mechanism to obtain a fuzzy output using rules and the fuzzy values. The Knowledge Base contains a set of fuzzy IF-THEN rules and a set of membership functions of fuzzy sets. These rules represent the knowledge that the PA possesses. The Defuzzifier coverts the fuzzy output into a crisp value that best represents the out fuzzy set. The Defuzzifier uses the center of gravity scheme. The implication methods used in the proposed system are min (minimum), which truncates the individual output fuzzy sets, and max (maximum), which scales the resulted output fuzzy sets. The input to the implication process is a single number given by antecedent.

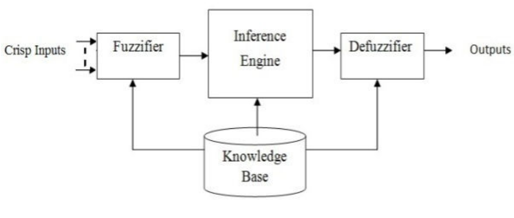

Fig. 7 Block diagram of the proposed fuzzy system

The monitoring task is performed by the Inference Engine that evaluates all the rules in the rule base and combines the weighted consequents of all relevant rules into a single output fuzzy set. That set is then defuzzified to produce a crisp similarity value.

The "Fuzzy Monitor Assistant System" is experience-based as experience plays a key role in the design of it. The similarity rules are used to build the Knowledge Base. The Assistant system uses a number of parameters related to physician experience. They include age, gender, medications, morbidities (chronic and acute), diagnoses, and laboratory test results. The input and output variables will be defined in order to be used by the Fuzzy Inference Engine and each variable is fuzzified by input fuzzy sets.

The developed fuzzy monitoring system is based on 5 cues: Abnormality in Blood Pressure, Blood Sugar Level, Triglycerides, High-density lipoproteins (HDL), Low-density lipoproteins (LDL) [9], [10]. The cues represent the higher-level information that is obtained from the patients' elementary data. 'The detection rules that use the above cues were acquired through the joint efforts of the engineering and medical team members. The detection rules are mentioned in details the following sections.

Diabetes is a major, complex chronic disease [9]. It is an abnormal rise in the concentration of blood sugar. It is caused by the hormone insulin needs. Hormones made in the body which is called insulin and glucagon help control blood glucose levels. A blood glucose test measures the amount of a sugar called glucose in a sample of a blood. Higher than normal blood glucose levels may be a sign of diabetes and if the person has diabetes, it means that the diabetes is not well controlled. For the Blood Sugar Level, there are three fuzzy sets as - *Low, Normal and High* (Fig. 8).

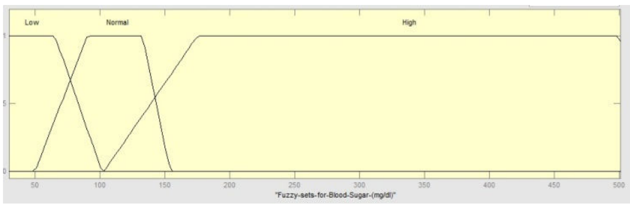

Fig. 8 Membership functions of Blood Sugar Level

Triglycerides can also raise heart disease risk [10]. Levels that are borderline high (150-199 mg/dL) or high (200 mg/dL or more) may need treatment in some people. This input field has four fuzzy sets (Normal, Borderling-High, High, and Very High). Fig. 9 shows the membership functions of Triglycerides. Membership functions of these fuzzy sets are trapezoidal.

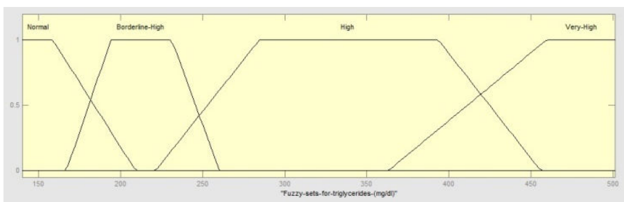

Fig. 9 Membership functions of Triglycerides.

The blood cholesterol level has a lot to do with high chances of getting heart disease. Many people with high blood cholesterol are unaware that their cholesterol level is too high because it does not cause symptoms [9]. High blood cholesterol is one of the major risks that lead to heart or having a heart attack. Having too much cholesterol in the blood as a result of building up fats in the walls of vein can slow down blood flow or even block the flow. There are two types High-density lipoproteins and Low-density lipoproteins.

High-density lipoprotein (HDL - High Density Lipoproteins) helps keep cholesterol from building up in the arteries. this is what is sometimes called good cholesterol or hyperplasia. Normal HDL level is over 40 mg / 100 ml of blood (0.83 to 2.5 mmol / L). Higher numbers for HDL are better [9], [10]. A level less than 40 mg/dL is low and is considered a major risk factor because it increases your risk for developing heart disease. HDL levels of 60 mg/dL or more help to lower your risk for heart disease. Low-density lipoproteins (LDL-Low Density Lipoproteins) the main source of cholesterol buildup and blockage in the arteries so-called some bad cholesterol or malignant, and there is an inverse relationship between the level of LDL and HDL in the blood. The normal level of LDL in the blood is less than 180 mg / 100 ml (0.5 - 3.88 mmol / L).

Both the High-density lipoproteins (HDL) and the Low-density lipoproteins (LDL) are fuzzy variables. There are three fuzzy sets for the input High-density lipoproteins (HDL) - Low, Medium, and High (Fig. 10), and four fuzzy sets for the other input variable Low-density lipoproteins (LDL) Desirable, Near Desirable, Border High, High, Dangerous (Fig. 11).

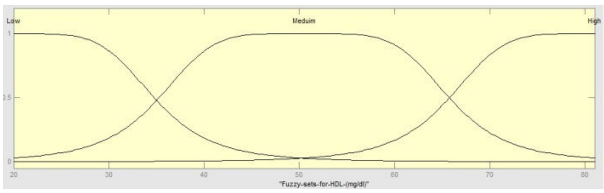

Fig. 10 Fuzzy sets for High-density lipoproteins (HDL)

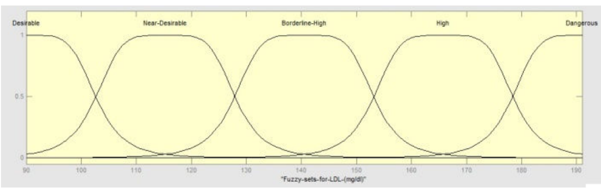

Fig. 11 Low-density lipoproteins (LDL)

Blood pressure used in clinical environments to measure systolic and diastolic blood pressures which represent force of blood pushing the walls of the blood vessels that passed through it. The Systolic Blood Pressure (SBP) measure is the top number. It measures the pressure of the blood within the vessels when a heart contracts. The average measure for systolic is 120. The Diastolic Blood Pressure (DBP) measure is the bottom number. It is the pressure of the blood within the vessels when the heart is resting and then refilling. The average diastolic measure is 80. The normal measurement of blood pressure is 80/120.

The Systolic Blood Pressure (SBP) and Diastolic Blood Pressure (DBP) will be the input to the system and the abnormality value in blood pressure will be the output. Both the inputs and the output are fuzzy variables. There are three fuzzy sets for the input variable Systolic Blood Pressure (SBP) - Low, Medium, and High (Fig. 12), three fuzzy sets for the input variable Diastolic Blood Pressure (DBP) - Low, Medium, and High (Fig. 13), and three fuzzy sets for the output variable Abnormality in Blood Pressure- Low, Medium, and High (Fig. 14). Here are some of the rules:

- If Systolic Blood Pressure Value is *Low* and Diastolic Blood Pressure Value is *Low,* then Abnormality in Blood Pressure Test is *Low*.
- If Systolic Blood Pressure Value is *Low* and Diastolic Blood Pressure Value is *High,* then Abnormality in Blood Pressure Test is *Medium*.
- If Systolic Blood Pressure Value is *High* and Diastolic Blood Pressure Value is *Low,* then Abnormality in Blood Pressure Test is *Medium*.
- If Systolic Blood Pressure Value is *High* and Diastolic Blood Pressure Value is *High,* then Abnormality in Blood Pressure Test is *High*.

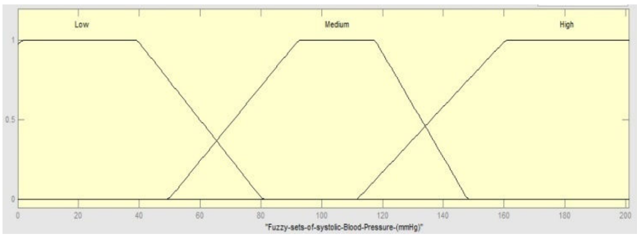

Fig. 12 Membership function of Systolic Blood Pressure (SBP)

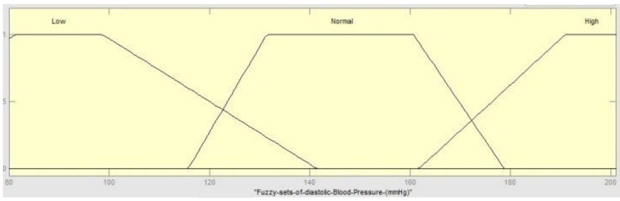

Fig. 13 Membership function of Diastolic Blood Pressure (DBP)

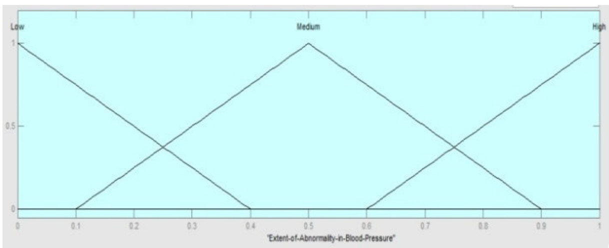

Fig. 14 Membership function of the Abnormality in Blood Pressure.

A risk factor is a value that shows the chance of getting a disease and/or the health risk of the patient. The strength of the risk is called "Degree of Risk". The Degree of Risk is a fuzzy variable whose values are represented by triangular fuzzy sets categorized as ”Very High,” ”High,” ”Medium,” ”Low,” and ” Very Low” (Fig. 15).

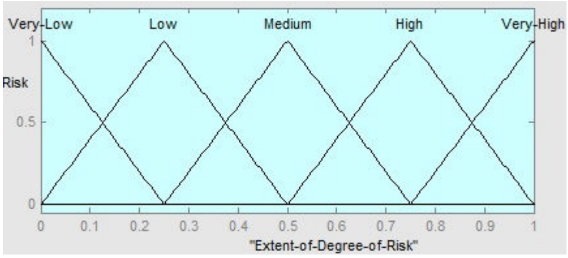

Fig. 15 Membership of Degree of Risk

Based on the experience of the physicians worked with the team, we define the fuzzy rules to link Abnormality in Blood Pressure, Blood Sugar Level, Triglycerides, High-density lipoproteins (HDL), Low-density lipoproteins (LDL) to Degree of Risk. A sample of the rules used to determine Degree of Risk:

- If Abnormality in Blood Pressure is *Low*, Blood Sugar Level is *low*, Triglycerides is *Normal*, LDL is *Desirable*, HDL is *High*, then Degree of Risk is *Low*
- If Abnormality in Blood Pressure is *Low*, Blood Sugar Level is *low*, Triglycerides is *Normal*, LDL is *Very High*, HDL is *Low*, then Degree of Risk is *High.*

The selection of the weights for combining fuzzy rules in the fuzzy inference engine is a crucial issue. The weights control the importance of the corresponding factor. In case of equally importance, the weights will have the same value. The resulted Degree of Risk scores are between 0 and 1 and a higher score represents a higher health risk.

III. System Implementation

The Mamdani fuzzy system is developed and implemented using the Fuzzy logic toolbox in MATLAB. The rules are obtained from the knowledge of the experts and entered in the rule editor. The distributed Graphical User Interface (GUI) was created using VB.NET. Figs. 16 and 17 show how the GSM module is connected to an empty USB on the Laptop in the implemented system. This is done for both Physician Agent and Elderly Agent Laptops. A serial port to USB adapter is used to connect GSM modem to the USB port on the Laptop.

Fig. 16 Implemented system

Fig. 17 The used GSM module

The proposed system is highly needed in rural areas because of inadequate number of available specialized physicians or nurses. Such monitoring must have autonomous interactions between these medical units in order to be effective. Such software relies on having patient's medical records and history which will be provided by the proposed system. Having software that can assist in confirming diagnosis is very beneficial in the medical world. Nowadays expert systems become more trustworthy.

The current system relies on direct visit of the patient to the doctor. Absent of such smart distributed medical network makes patient in rural areas travel long distances to take consultation from specialist doctor. This becomes an obstacles to the patient that could prevent them from going to the specialist especially when they think that there case is not that sever. Got the wrong diagnosis and give the wrong therapeutic method and medical, it may kill the people. This will contribute in making their medical condition worse. If it is a simple sick with typical symptom, it is easier to ask the doctors through online network as proposed in this system and if the physicians find the illness are complicated than the doctor will recommend visiting a doctor.

IV. Experiment Results

We carried out some preliminary experiments to evaluate the proposed system. More specifically, we sought to assess the Physician Agent ability to monitor Elderly Agents and hence their Elderly people. The system works perfectly as designed.

V. Conclusion

In this paper, we have further developed the multi-agent system for patient monitoring system that we conceptually put forward before. As a first step, we have designed GUI of the Elderly Agent and Physician Agent and implemented it using VB.NET and MATLAB software packages. We have also developed a fuzzy ruled based system that can be used in monitoring the health conditions of elderly people based on the received vital signs. This fuzzy system provides will generate initial diagnosing to the patient case. This will assist and advice clinicians at the point of care. This will provide more accurate, effective, and reliable diagnoses and treatments especially if the physicians have insufficient knowledge. Using real patient data, we have tested the proposed GUI system. We have also preliminarily assessed its detection performance.

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