Development and Implementation of an Internet of Things (IOT) Based Remote Patient Monitoring System

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Abstract— Web-based solutions that employs the use of Internet of Things (IoT), is continuously creating new application areas, including healthcare. This shows that, iHealth, real-time monitoring as well as remote patients monitoring, are expected to revolutionize the healthcare sector. IoT is nothing but communication between devices that contain embedded technology with existing internet infrastructure. This research work employs a smart data gathering method using a fuzzy logic assisted approach. The fuzzy scheme employed, helps make the system smart by helping the device make decisions on when and what data is to be sent depending on the inference made on various inputs from the physiological sensors. Performance analysis was carried out on the energy consumption pattern of the nodes which indicate that throughout the monitoring period of Ten (10) hours each day, for three days. The average energy consumed by the device when fuzzy assisted logic is used is 90.78 milli Watt (mW), while the average energy consumed when the conventional method is used is 128.5 mW. From the results, it was observed that power consumption is substantially reduced by about 37.72 mW (29.35%), when using the fuzzy assisted method as compared to when using the normal/conventional method.. It was equally observed that while using the fuzzy assisted logic, energy consumption only increased whenever there is an anomaly in the sensor reading.

Keywords— Internet of things, iHealth, remote monitoring, fuzzy logic, energy consumption

I. INTRODUCTION

The worldwide average life expectancy grew by 5.5 years from 2000 to 2016, this account for the most significant increase since the 1960s. This was to a great extent because of huge enhancements in healthcare and medicine. However, in Africa and in Nigeria in particular, the problem of crowded medical healthcare centers and overwhelmed medical caregivers and medical equipments is a prevalent problem, as patients needs to make frequent visit to the doctor and then have to wait long queues. Hence, it is pertinent to develop new technologies that will help solve these problems by collecting patient's vital data remotely and transmitting it via a secure network of devices to the health care giver for diagnosis and constant monitoring.

With the increasing rate of population explosion, cities should promulgate laws to provide effective healthcare to its citizens. Hence, it is pertinent to develop new technologies that will help solve these problems by collecting patient's vital data remotely and transmitting it via a secure network of devices to the health care giver for diagnosis and constant monitoring.

II. INTERNET OF THINGS

Internet of Things is the wireless network of electronic devices, equipped with sensors and actuators that are connected to each other with the purpose of sharing information and data so as to interact and create new information. Smart devices equipped with such sensors and actuators have the capability to collect data which in this case is patient's vital signs, communicate to each other and access Internet services.

A. Internet of Things in Healthcare

The Internet of things in medical services assumes a significant role in giving relief to patients and specialists. It comprises of a system that communicates between devices and objects which are also linked to the same network. These devices can assist patients and medical care personnel alike, to monitor and keep record of patients' vital signs detected and their medical information. Some of these devices are smart chairs, fitness shoes, smart watches and smart IoT enabled wearable clothes. IoT for healthcare purposes, can be accomplished by using smart, non-invasive physiological precision sensors, monitors and analyzes patient physiological vital signs, which indicates health condition of a patient. Such vital physiological signs include

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respiratory rate and heart beat rate, oxygen and glucose level in blood, temperature as well as galvanic skin response to mention a few. Intelligent sensors can be inserted into ingestible drugs and pills containers which have the capability to connect to a network and can transmit alert messages, letting the recipient know if a patient has taken his/her dose of medication at the prescribed interval.

The application of technology to healthcare has improved healthcare service delivery tremendously [1]. The act of monitoring patients remotely, is intended for a particular set of patients, such as aged patients, patients who have just had a surgery, as well as patients with terminal illness. These set of patients need to be watched regularly to ensure they maintain a stable health status [2]. Remote patient monitoring enables patients who are being treated for certain ailment, live in the comfort of their homes instead of staying in the hospitals, where they have to spend more on hospital admission as well as depriving other patients who need the healthcare facilities more than they do. It therefore is a more viable option to physical monitoring in the hospital [3]. Remote patient monitoring devices, that have non-invasive wearable sensors are viable tools to the healthcare personnel for remotely monitoring important physiological signs and activities of the patients in real-time. Thus, it is obvious, that wearable sensors are vital to remote patient monitoring systems [4].

Medical care personnel can monitor a patient at stipulated time intervals but health emergencies could arise at any time, this makes constant monitoring of a patients vital signs necessary. The patient's health status can be under monitoring, thus, health emergencies that need urgent attention can be noticed promptly.

III. RELATED WORKS

Reference [5] proposed extracting health information such as pulmonary artery pressure (PAP) and ECG (Electrocardiogram) and transmitting the encoded information as a text message. It was proposed that a dedicated channel for transmission of medical data with 5th Generation (5G) mobile communication systems, can further improve daily monitoring. This prototype was designed strictly to monitor heart activity and did not consider power and data efficiency as well as security.

Similarly [6], proposed a device used to continuously monitor the Electrocardiogram (ECG). This data is stored in a database and can be displayed in a website that can be accessed only by authorized personnel. This idea is familiar however; it failed to consider the data traffic congestion, which could arise from constant transmission of detected patient vitals. The primary task of this system is to update the data to the database and alert the doctors for any anomaly. It is accomplished by using the combination of Raspberry Pi and GSM module.

Reference [7] proposed an IoT-enabled i-health monitoring system, capable of sending alerts to medical care personnel and care givers promptly. The design focused only on older adults and as such had few sensors to monitor heart activity and patient orientation.

Reference [8], implemented a Help to You (H2U) healthcare system to enhance the quality of healthcare services for the aged. This system makes use of various technologies including wearable devices and biosensors to ensure prompt, constant and continuous monitoring for the elderly. Although this system had more sensors, it failed to address the power consumption issues.

For improved identification of device and information processing, the RFID (Radio Frequency identification), WSN are used in [9]. The proposed system detects a patients temperature and heartbeat. The signals from both sensors are analog signals, thus an ADC (Analog-to-Digital Converter) is employed to convert the signal from analog to digital. The signal from the ADC is then sent to the microcontrollers. The microcontroller then forwards the data to the mobile phone for onward transmission through the internet to a remote storage location. Although the security and patient authentication protocol is improved here, the number of vital signs to be sensed is limited to temperature and heartbeat.

From the foregoing review, it is observed that most of the authors have deployed either wireless body sensor networks or body sensor network, to harvest patient's vital signs measured by wearable devices that combine sensors, processing hardware and a communication platform, for transmitting the patient's data. However, none of the authors addressed the following issues:

1. Persistent issues of huge traffic generated during data collection and transmission,
2. Inefficient power utilization.

Thus, from the foregoing reviews, a fuzzy-assisted inference system is introduced to make the device intelligent to sense the patient's vitals and also make inference on the patients ailment based on the readings from the sensors, and only transmit when there is an anomaly. This will help reduce the power consumption by eliminating constant transmission of unnecessary data.

IV. METHODOLOGY

In this research work, a sensor-cloud fuzzy assisted system is proposed. This system is the core for the remote health monitoring system. The design for the system as shown in Fig. 1 is to be employed for healthcare monitoring. A modular approach will be adopted in this design, and the system as shown in Fig. 1 has two modules: local and remote. The remote module has the task of storing and transmitting the data to remote service seekers such as doctors, emergency services and caregivers. The local section has the task of collecting patient vital readings from the patient. The ATmega 32 collects the readings from the sensors and also processes the data to produce easy to understand information for medical care personnel. This information is then displayed on a web page and also a text message is sent to the care giver or medical personnel. The Sensors used in this patient monitoring system are: body temperature sensor, body position sensor, GSR (Galvanic Skin Response) sensor, heart beat sensor, blood pressure sensor, SPO2 sensor.

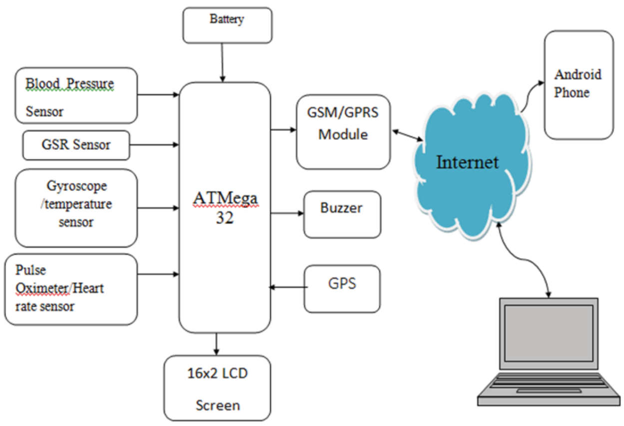

Fig. 1 System Block diagram

The system flowchart is depicted in Fig. 2 as shown below.

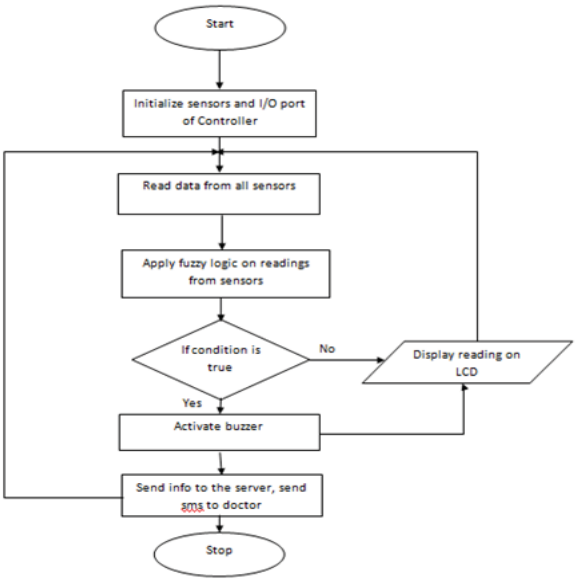

Fig. 2 System flowchart

could pose a serious health hazard to the patient.

A. Event Occurrence Approach

Continuous and constant data acquisition from all the sensors is not needed in the proposed system. Instead, data is obtained, depending on the circumstances regarding the health status of the patient at a given point in time. The device determines the data to be transmitted depending on the present reading gotten from the sensors regarding the present health condition of the patient. Such circumstances that prompt the device to transmit the information are when the readings of particular parameters exceed the pre-set boundary values i.e. designated threshold of particular parameter being detected. Assuming we have three sensor parameters X_1, X_2 and X_3 for a particular patient health monitoring system Q, then:

$$Q = \{X_1, X_2, X_3\} \quad (1)$$

Assuming the values of the parameters are dependent one another, and X_{1th}, X_{2th}, X_{3th} the threshold values of X_1, X_2, X_3 respectively thus the function can be defined as :

$$f(Q_s) = \begin{cases} f(X_1) & \text{if } X_1 < X_{1th} \\ f(X_1, X_2) & \text{if } X_1 \geq X_{1th} \,\&\, X_2 < X_{2th} \\ f(X_1, X_2, X_3) & \text{Otherwise} \end{cases} \quad (2)$$

This method of gathering data based on the occurrence of certain events will reduce the usage of resources (power, data and communication channel) and as a result, cut down on costs. However, a patient's vital data should not be put on a particular threshold because of its nature. Rather, making use of the present condition of particular parameters is better. To achieve this we need to create a system using artificial intelligence that provides the ability to create a set of rules to govern the data gathering principle.

V. Method Using Fuzzy Logic System

The process by which the data collected is shown in Fig. 3. It comprises these three steps, namely: fuzzification, fuzzy inference, defuzzification.

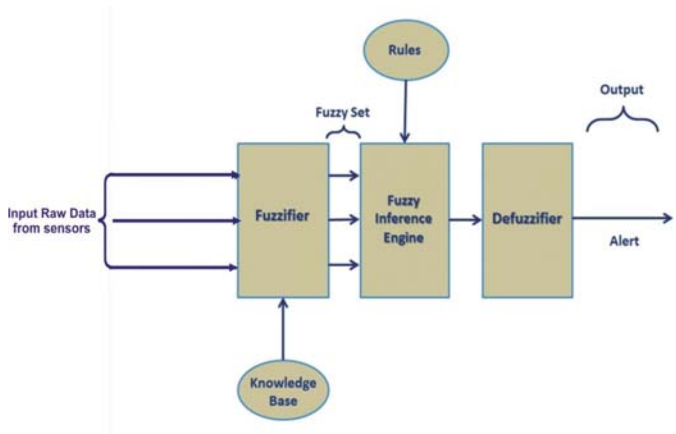

Fig. 3 Fuzzy Logic Diagram

2. Using the IF premise, THEN consequent and also using repository of information gotten from the healthcare personnel, the fuzzy inference system can deduce a diagnosis from the fuzzified inputs in 1 above, and generate a set of output variables.

3. The set of output variables from 2 above is transformed to a set of values by the Defuzzifier.

The remote patient monitoring device consists of many sensors. The device performs a smart diagnosis, by detecting different physiological vital signs in the patient. These vital signs, are then compared to check if they exceed the threshold normal limits or not, before arriving at a conclusion about a specific ailment. The fuzzy logic system employed helps the device make smart decision, based on the readings from different sensors.

VI. Implementation

This work was implemented using non-invasive physiological sensors. The sensors are cited on specific spots on the patients' body where the particular vitals can be monitored, using wired connections. The device utilizes the knowledge base as well as the rule base, to detect any irregular condition in the health status based on the readings from the sensors. In the event of any anomaly, the device sends a text message to doctors, for prompt response to enable the patient receive timely treatment.

In the medical profession, different ailments have different symptoms, which are used in the diagnosis process. For example, heart conditions like myocardial infarction, have symptoms like sweating, low body temperature, high respiratory rate to mention a few. So when a doctor comes in contact with an ailing patient, He looks out for the symptoms to make a diagnosis. Therefore the symptoms put together make the diagnosis.

Data gotten from medical personnel forms the knowledge base and the rules for the fuzzy inference system and are presented in tables' I-V.

TABLE I. BODY TEMPERATURE TABLE

Diagnosis	Body Temperature range
Hypothermia(Low)	<35°C(95.0°F)
Normal	36-38°C(97-99°F)
Fever or hyperthermia(High)	38-40°C(>99-101°F)
Hyperpyrexia(Very High)	>40°C(>104°F)

Table 1 depicts membership functions as regards human body temperature. Body temperature is normal at 37°C, which may change as a result of atmospheric weather conditions, so values from 36° C - 38°C is also normal. for A temperature reading <35°C is considered as Hypothermia, Hyperthermia is between 38°C and 40°C and Hyperpyrexia > 40°C.

Skin conductance rate (SCR) is the rate of conductance of the skin. Changes in the SCR, shows the subject is perspiring. 0 - 3 micro-siemens is normal SCL, 4 - 10 micro-siemens as well as 8 - 25 micro-siemens is highnormal SCR and high SCR respectively. It is shown in Table II.

TABLE II. SKIN CONDUCTANCE RATE (SCR)

Diagnosis	Skin Conductance Range (micro Siemens)
Normal SCL	0-3
HighNormal SCL	4-10
High SCL	8-25

The blood oxygen sensor measures the percentage of blood oxygenation. Blood oxygen range of 93% and above is considered normal. A reading is taken as low when it is between 87 and 92 and critical when it is below 86. This is shown in Table III.

TABLE III. BLOOD OXYGEN LEVEL (SPO2)

Diagnosis	Blood Oxygen Range (%)
Severe SPO2	75-86
Low SPO2	87-92
Normal SPO2	93-100

Blood pressure shows the blood flow pressure, when the blood is being conveyed from the heart through the arteries. Systolic pressure is the pressure of blood when there is heart contraction and when the heart is relaxed the blood pressure is called diastolic. The ranges for systolic and diastolic blood pressure are presented in the Table IV. When systolic pressure and diastolic pressure is < 90 and <60 respectively, the subject is in Hypotension. When Systolic pressure and diastolic pressure are between 90-119, and 60 – 79 respectively, the blood pressure is said to be normal. When the systolic range is between: 120-139 and diastolic range is between80 – 89, the subject is said to be in pre-hypertension. When the Systolic pressure and diastolic pressure are between 140 – 159 and 90– 99 respectively, the subject is said to be in stage 1 hypertension, while systolic blood pressure between 160 - 179 diastolic blood pressure between 100-109 is said to be Stage 2 hypertension. The subject is said to have a hypertensive crisis if blood pressure is >180 for systolic pressure and >110 for diastolic pressure.

TABLE IV. BLOOD PRESSURE

Diagnosis	Systolic(mmHg)	Diastolic(mmHg)
Hypotension	< 90	< 60
Normal	90-119	60 – 79
Prehypertension	120-139	80 – 89
Stage 1 hypertension	140 – 159	90 – 99
Stage 2 hypertension	160 – 179	100-109
Hypertensive crisis	> 180	> 110

Medical literature has it that a heartbeat rate between 65 and 85 is normal, bradycardia means a heartbeat in the range of 20 to 64, and tachycardia if heart beat rate is above 90 as shown in Table V.

TABLE V. HEART BEAT RATE

Diagnosis	Heart rate (bpm)
Bradycardia low)	20-64
Normal	65-85
Tachycardia (High)	86-120

VII. Rule Base

A set of four sample rules were created to form the knowledge base for the fuzzy logic system, and are listed below:

A. Rule 1

When temperature sensor senses a signal below 35°C this means temperature is low, and when skin conductance level readings is high i.e. a reading between 8-25 micro siemens, which means the patient is perspiring), this indicates that the subject is going into shock. One symptom of cardiac arrest in a patient, is acute shock, the system activates other sensors and transmits the patient information to be displayed on the web as well as send a text message to alert the doctor the coordinates (longitude and latitude) are also sent to help medical care personnel locate the patient quicker.

B. Rule 2

When the temperature sensor reads a value >38°C this means that the subjects temperature is high, also if the skin conductance rate sensor reads between 0-3 which means the patient is not perspiring, this indicates subject has a fever, as a result, doctor is alerted.

C. Rule 3

When the body temperature is >38° C, skin conductance level is between 0-3, and blood oxygen level is less than 92%, this indicates the patient has pneumonia When pneumonia is detected, the doctor is alerted and necessary actions are taken by the system.

D. Rule 4

When temperature sensor senses a signal below 35°C this means the subject's temperature is low, skin conductance level reads high which is a reading between 8-25 micro siemens, which means the patient is perspiring), and the heart beat rate is above 86 bpm, heart problem is diagnosed and necessary action is taken.

VIII. Results

First the microcontroller was programmed with the code written for normal method and sensor readings was observed and recorded, the microcontroller is then re-programmed with fuzzy logic code, and readings are taken for another thirty minutes. Results are shown in tables VI and VII and Fig. 4 and Fig. 5 below, comparing the power consumption rate while using conventional data gathering technique and the fuzzy logic system respectively.

TABLE VI. CURRENT AND POWER CONSUMPTION READINGS WITH NORMAL METHOD

	I (mA)	P (mW)
1	25	122.5
2	25	122.5
3	28	137.2
4	26	127.4
5	24	117.6

TABLE VII. CURRENT AND POWER CONSUMPTION READINGS WITH FUZZY LOGIC METHOD.

	I (mA)	P (mW)
1	12	58.8
2	15	73.5
3	12	58.8
4	14	68.6
5	12	58.8

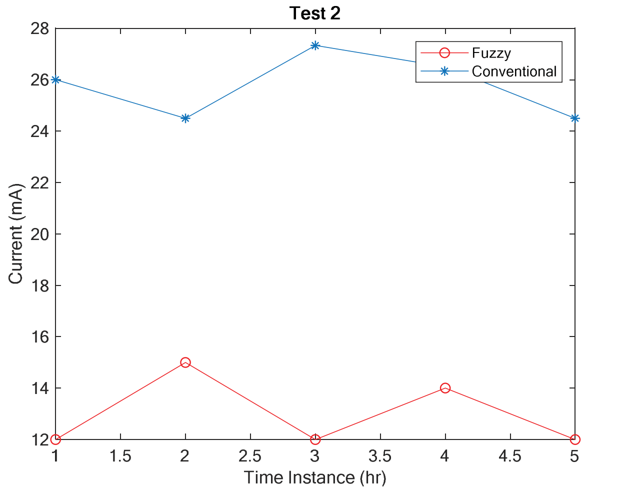

Fig. 4 Current readings for fuzzy logic method against conventional method

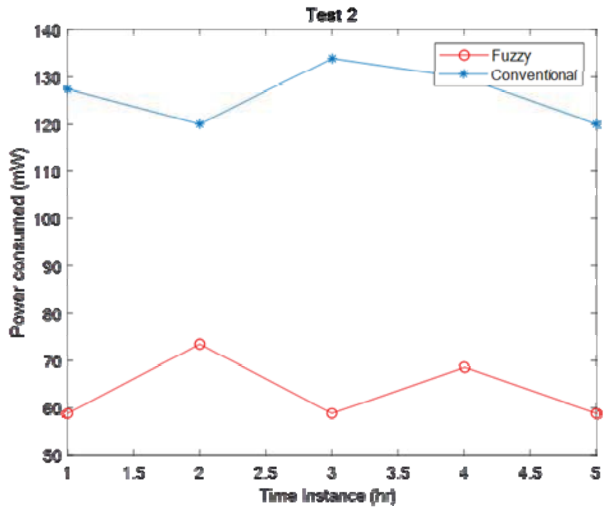

Fig .5 Power consumption for fuzzy logic method against conventional method.

As is evident in the results, power consumption is substantially reduced by about 48mW when using the fuzzy assisted method as compared to when using the conventional method. This also infers that data costs will be considerably reduced as there is no constant transmission of unnecessary data while using the fuzzy assisted method.

IX. Conclusion

In this work, development and implementation of an IoT based remote patient system was carried out. This was achieved by sensing five (5) Physiological parameters (Temperature, Blood pressure, heart beat rate, SPO2 level, and body position). The device was also made more resource efficient by using a fuzzy enabled inference system.it was observed that power consumption reduced by about 37.72 mW (29.35%), when using the fuzzy assisted method as compared to when using the normal/conventional method.. It was equally observed that while using the fuzzy assisted logic, energy consumption only increased whenever there is an anomaly in the sensor reading and the medical personnel needs to be alerted, while for the conventional method, energy consumption is always high, as the device was always transmitting at a preset interval of 30 seconds.

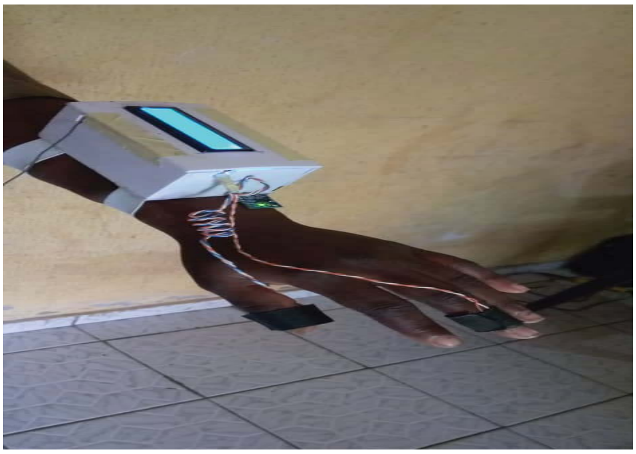

Fig. 6 The Prototype

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