International Journal of Electrical and Computer Engineering (IJECE)
Vol. 9, No. 6, December 2019, pp. 5031∼5045
ISSN: 2088-8708, DOI: 10.11591/ijece.v9i6.pp5031-5045

A novel approach to sensor implementation for healthcare systems using internet of things

Rishabh Mitra[1], Raghavendra Ganiga[2]
[1]Department of Electrical and Electronics Engineering, Manipal Institute of Technology, Manipal, India
[2]Department of Information and Communication Technology, Manipal Institute of Technology, Manipal, India

Article Info

Article history:

Received Jun 20, 2018
Revised Apr 8, 2019
Accepted Jun 27, 2019

Keywords:

Internet of Things
Healthcare
Sensors
Protocol

ABSTRACT

The Internet of Things is touching all spheres of life, be it in connecting cities together, making agricultural farms and health care smarter, predictable and more secure, and in industries it is set out to bring about changes that are similar to those of the industrial revolution that took place in the 19th and 20th century. It is estimated by pundits that in next 5 to 10 years, the Internet of Things will become a 50 billion dollar industry by itself, encompassing everything that it touches and goes upon. In order to get healthcare enabled into the IoT ecosystem, the sensors and the actuators related to it must be able to support the protocols that is required for the acquisition, processing and storing of data from the sensors to the IoT based infrastructure. Here, for a proposed model for a health care monitor using Internet of Things, the sensors characteristics, working principal, the protocol associated with it, it's internal mechanism, and the results obtained when interfaced using a Raspberry Pi are discussed, laying the framework for the future of the sensors that need to be adapted to stay relevant in the future, when IoT transitions from concept to reality.

Corresponding Author:

Raghavendra Ganiga,
Manipal Institute of Technology,
Manipal Academy of Higher Education, Manipal, India.
Email: raghavendra.n@manipal.edu

1. INTRODUCTION

Internet of Things (IoT) [1] technologies connects different objects which is capable of having communication with one another through the medium of internet. The objects have identification units, interconnection, detection and processing capabilities. IoT provides an opening for the new generation healthcare technologies [2,3] by providing monitoring, analyzing, diagnosing, controlling and providing treatment references for chronic diseases, such as obesity and hypertension. IoT has gained lots of attention in healthcare domain due to increase in the number of medical equipments, sensors used for patientś analysis, and smart devices [4] which are interconnected through internet. In IoT, things should be connected, generate data and interact remotely as well as with people involved with the ecosystem.

Current healthcare industry considers IoT as a promising technology. It is capable of improvising treatment processes in hospitals and away from hospitals at the same time. By this technology, patients are able to access and trigger healthcare remotely, self-manage their own diseases and maladies, and receive assistance in emergency cases by sending alert messages to the patient mobile [5] and the doctor associated with it. The devices used for monitoring patient's health status have limited computational and storage capabilities therefore IoT poses many challenges with the following scenario such as data exchange, interoperability and resource availability as well as security and privacy.

The jargon, IoT, is now a widely used for a set of technologies, system and the design principles which try to simplify the already existing processes by the virtue of interconnection with the Internet and the networks associated with it. It looks in many ways similar to a machine to machine communication (M2C), which is achieved by a combination of sensors and other devices connected and communicated via wired or wireless networks.

Studies conducted by the Department of Health and Human Services, United states of America have shown that around 50% of the health risks that professionals face in their work area are mostly related to stress, and that stress has been the single largest contributor in terms of high risk and aggregation of health factors such as high cholesterol, over weight giving rise to obesity, and tendency to consume junk food and alcohol to counter the stress. The stress measurement can also be done using sensors, the parameters for which will be the heart beat rate and the galvanic response from the skin, which can give some insights about the levels of stress that one is going through. Products of the above are available in the market in the form of brackets.

Designing IoT enabled sensing devices still needs technical challenges such as computational requirement and self-powered capabilities. To overcome from the following challenges, the major building blocks of smart devices should follow the required methods those are signal processing, power management, computational and communication architecture [6]. With the following changes the healthcare get large scale cost effective solution from simple self-monitoring to complex interactive task. The fact that everyone and with the dawn of Internet of Things (IoT), everything is connected. Still we can see a lack of adaptation of Technology in Healthcare field, where Internet [7] can help and Benefit the most.

The concept of health interconnection or specifically, technology-enabled care (TEC) is a term which is aimed to make different technologies that exist to converge for intelligent, actionable exchange of health informatics and support the system of real time delivery of the information and the services. For senior citizens and persons with disability, the TEC has been a point of attraction in terms of long term monitoring and support, and has gathered support not only from the industries but also academia [6-10]. The need to provide a healthcare system which is efficient, smart and affordable for the aging population as well as to the community has resulted in innovation and the utilization of the technology that has changed sectors like banking, agriculture, manufacturing, etc. to name a few. Another thing that the technological innovation is bringing to the healthcare system is to compensate the shortage of medical personnel at a given point of time and reduce the time taken to cure a chronic disease [10]. In the year 2015, the population of people aged over 60 was pegged at 901 million, and is said to increase at the rate of 3.26% per year, which is higher than people for other age groups [11]. Alone in the United States, the number of people affected by the outbreak of chronic diseases is estimated to be around 100 million and is accountable for around 70% of deaths. The expenditure on healthcare has been estimated to be about $2.9 trillion in the year 2013, and chronic diseases alone take up 86% of the expenditure [12, 13].

In Technology-enabled Care (TEC), wearable sensing is gaining a lot of momentum. It is a technology which should be able to measure and monitor the health parameters of a patient and detect abnormalities from those. The monitoring will be of blood sugar, blood pressure, heart beat rate, electrocardiogram, the saturation of oxygen in haemoglobin, etc. and the impact that it has on the patient because of the daily activities that one indulge in [9]. The implementation and integration with a conventional hospital setup will give the health personnel an edge, which will the real time monitoring and analysis of health parameters, and will also help to improve an individual to be more independent, and play an active role in the engagement of the healthcare process. Internet of Things (IoT) enable the integration of the sensors, the sub-systems associated with it, creation of wearable devices that are able to transmit and receive data directly for the initiation of immediate action if any alarm is raised, analysis of the data gathered or storage for future use and references [14]. In the wearable devices technology, the most common way of communication is by making use device-to-edge (gateway) pattern, where, by making use of short range low-power wireless communication protocol to a device which is equipped and capable of routing such Wi-Fi, 3G, or 4G/LTE [15]. The data which is acquired by the sensors gets processed automatically, whose processing takes place either locally on the device edge or in the cloud [14]. Figure 1 represents an illustrative example of such a method.

With IoT technology, it is able to support long term monitoring of aged people or persons with disability outside the hospital or a clinic premises, which has attracted both academia and industry. IoT with sensing technology mainly records patient's vital signs such as blood pressure, electrocardiogram, heart rate, oxygen saturation [8, 9], etc and motions without affecting their regular daily activities. Additionally, within the hospital premises also enables monitoring vitals also configured [10]. In the case there is any deviation in the vitals of a Patient, IoT wearable devices sends and receive data directly with healthcare web application for immediate care to the concerned doctor and if the Doctor does not respond within the provided time frame all the push notification is sent to the other doctors from the same department by requesting an urgent attention.

However, on the basis of surveys and conduction of several studies, the high cost of energy incurred by direct streaming of raw wirelessly to servers in distant areas has been found to be a drawback towards the development [16]. To counter the above limitation, the concept of on-node processing of information systems is being developed for applications which require actionable outputs, operate in real-time and energy efficient algorithms, specifically tailored for on-node signal analysis [17-20]. For wearable devices, new methodologies for acquisition of signal on the basis of emerging compressed sensing (CS) framework and analysis of a signal in the compressed domain are also being worked out and explored [21-23]. When it comes to node-sensing, cumulative data of the health parameters obtained are relayed to the user. Entire data or waveforms can also be relayed to the user upon request. For wearable applications, more power efficient processor architectures are being developed, tested an implemented, which often are multi-core processors, simplified instruction set architectures (ISA) and application specific integrated circuits (ASICS), each having own merits and demerits [24-30]. Along with reduction of power consumption by processors and sensors, the technique of harvesting ambient energy is also been taken into consideration as it will help in reducing the power gap and might aid in meeting all the power requirements for the autonomy of the device.

2. PROPOSED MODEL LAYOUT

The system consists of 4 sensors, which are responsible for capturing various health parameters related to the human body. The sensors used are as follows:

(a) DHT11 temperature and humidity module
(b) MPU6050 Accelerometer + gyroscope
(c) Heart beat pulse sensor from pulsesensor.com
(d) DS18B20 digital temperature sensor

The layout is given in Figure 1.

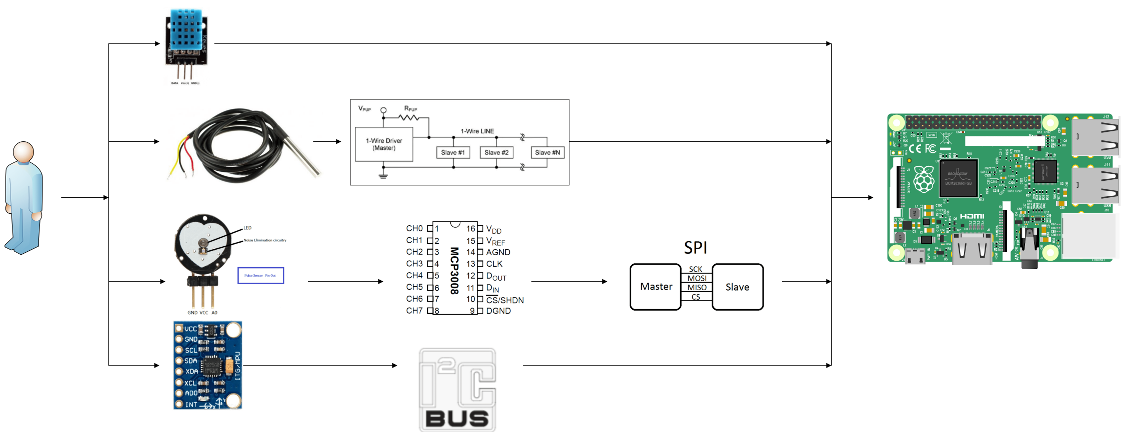


Figure 1. Proposed model of the healthcare monitor system

But, the problem with some of the sensors used above is that they are dependent on some protocol or the other, which makes their operation possible with the Raspberry Pi. Else it would not be able to understand any reading that the sensor captures from the patient. For the operation, Raspberry Pi has some protocols which make the operation of the above sensors possible. The protocols are:

(a) SPI (Serial Peripheral Interface)
(b) I^2C (Inter Integrated Circuit)
(c) 1-Wire System

There is another problem with the Raspberry Pi. The GPIO (General Purpose Input/ Output) pins on the Raspberry Pi accept digital input and yield digital output. As a result, any sensor which yields result in the form of analog range is of no use to the Raspberry Pi. Therefore, a special conditioning circuit called Analog to Digital Circuit (ADC) is made use of. This is responsible for converting the analog output given by the sensor to the corresponding digital value, which is defined by the mathematical formula as given below:

$$Value = \left(\left(\frac{v}{v_{ref}}\right) * (2^n - 1)\right) \tag{1}$$

Where:

(a) v is the voltage given to the ADC.
(b) v_{ref} is the reference voltage applied to the ADC.
(c) n is the number of bits of the ADC that is capable of giving the values in digital form corresponding to the applied analog voltage that the ADC receives from the sensor.

The ADC used in this case is the MCP3008, which is a 10-bit, 8 channel configuration, capable of operating either as separate 8 single ended configuration of 4 pairs of pseudo differential configuration. This is capable of producing values between 0 to 1023, which correspond to the value of the analog voltage the sensor is giving as the output. In Raspberry Pi, this ADC operates using the SPI protocol.

3. SENSORS

3.1. DHT11 Humidity and Temperature Sensor

This sensor is responsible for capturing the environmental temperature and relative humidity. It comes calibrated with a digital signal output. It is coupled with a NTC (Negative Temperature Coefficient) temperature measurement component and a resistive type humidity measurement component, which when connected to an 8-bit high performance micro-controller, it is able to deliver excellent quality, fast response, anti-interference ability and cost-effectiveness. If the cable in connection happens to have a length shorter than 20 meters, then a 5kΩ pull-up resistor is recommended to get the desired results; else if the cable happens to be longer than 20 meters, Then an pull-up resistor is needed to compensate for the excess length of the connection cable. The Module is shown in Figure 2.

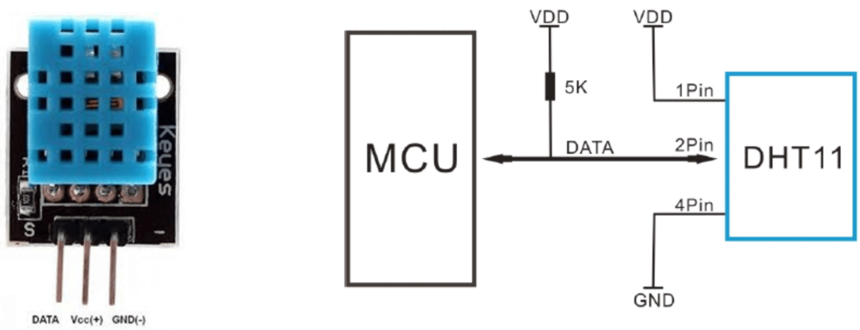


Figure 2. DHT11 Module and connection to the micro-controller

3.2. DS18B20 1-Wire Temperature Sensor Probe Cable.

This is digital thermometer which operates on 1-Wire-bus protocol and provides a 9-bit to 12-bit Celsius temperature measurement. The good thing about this sensor is that each DS18B20 comes with a unique 64-bit serial code, making the operation of multiple sensors on the same port possible without any chance of overlapping. This drives on parasitic power, which means that it can draw power directly from the data line, eliminating the need for an external power supply.

The one that is used here is the waterproof version of the sensor. This helps in capturing the body temperature over a given period and it can be measured in either dry or in wet conditions. It can operate up to 125°C, although it is recommended to keep it within 100°C. The sensor is shown in Figure 3.

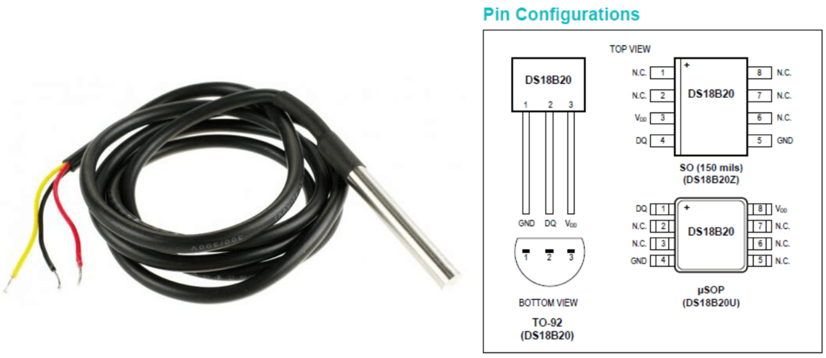


Figure 3. DS18B20 1-Wire Temperature Sensor, Pin Layout

3.3. MPU-6050 GY-521 Accelerometer + Gyroscope

This is a 3-axis accelerometer which is died together with an on board Digital Motion Processor (DMP). The on board DMP possesses the capability of processing and solving complex algorithms, and this accelerometer is free from cross-axis alignment problems that can creep up as a result of the discrete parts. Along with this, it comes has a 3-axis gyroscope built into it.

This sensor has three 16-bit in built ADC (Analog to Digital Converter) which enable us to digitize the values of the gyroscope and three 16-bit in built ADC (Analog to Digital Converter) for the digitisation of the accelerometer values. This sensor communicates with the Raspberry Pi using the I^2C (Inter-integrated Circuit) protocol at 400kHz. Additional features supplemented with this include an embedded temperature sensor and an on-chip oscillator with $\pm 1\%$ variation over the operating temperature range. The following in Figure 4 shows the device.

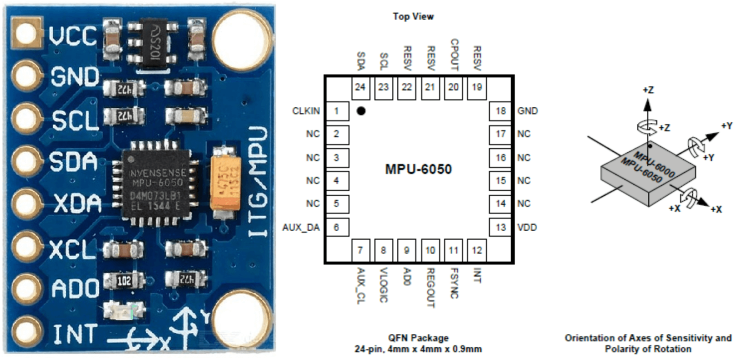


Figure 4. MPU6050 with the pin layout and axes orientation

3.4. MCP3008 8-channel 10-bit ADC

This is an 8 channel, 10 bit ADC (Analog to Digital Converter), used especially in Raspberry Pi because it does not have an in-built ADC like Arduino. This chip is a great option for quick prototyping of sensors which have analog output as the GPIO pins of the Raspberry Pi does not understand analog values at all. It only works on digital input and digital output, that is 1 and 0 only.

It can provide up to eight single-ended inputs or four pseudo differential inputs, depending on the user requirements and system needs. This chip works on the Raspberry Pi using the SPI (Serial Peripheral Bus). SPI can be driven on the Raspberry Pi using either hardware or software based, but since the number of SPI devices used in this project is less than 2, hardware SPI is being made use of for it being faster and giving reliable performance. The MCP3008 features a successive approximation register (SAR) architecture. The block diagram is shown in Figure 5.

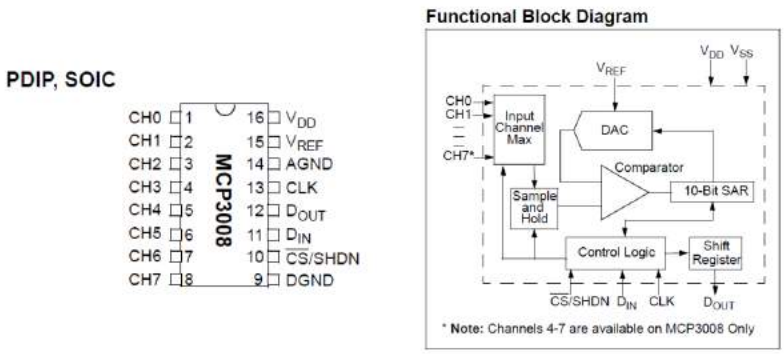


Figure 5. MCP3008 ADC and its block diagram

3.5. Pulse Sensor from pulsesensor.com

This sensor is made by World Famous Electronics llc. started as a Kickstarter project in 2011. It consists of green colour LED, a photo-diode and an in-built signal conditioning circuit, which helps to remove the noise acquired from the skin and filter only the signal necessary to compute the heart beat rate.

This sensor is able to observe changes in the timing between the circuits, giving rise to Heart Rate Variability (HRV). The output of this sensor is analog in nature. This is where the MCP3008 ADC comes into play. The output of this sensor is connected to one of the channels of the ADC, readings are sampled and then quantified to get the desired output as per the algorithm.

This has medical applications that range from predicting clinical abnormalities, to psycho-physiology (measuring emotional states and stress levels). The Pulse Sensor uses a photo-diode to detect the relative reflectivity of blood in capillary tissue. This sensor, too, works on the principle of Photoplethysmography. It measures the change in volume of blood through any organ of the body , triggering a change in the intensity of light which happens to pass through that organ (a vascular region). In case of applications where heart pulse rate monitoring forms the cardinal purpose, the timing of the pulses becomes the most important factor. The rate of flow of blood volume is decided by the rate of heart pulses and since the green light thrown by the sensor gets absorbed by the red blood in conformance with the colour spectrum, the signal pulses are considered equivalent to the heart beat pulses. The sensor is shown in Figure 6.

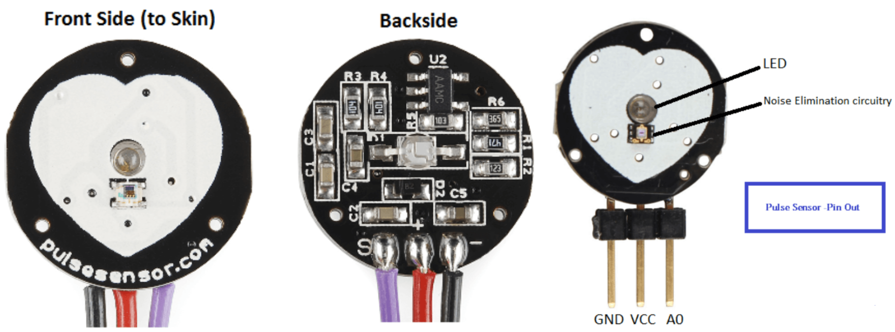


Figure 6. Heartbeat Pulse Module And Layout

4. PROTOCOLS

The operation of the sensors in the above system is made possible due to the presence and the coordination that the protocols do. They act as a bridge between the sensors and the receiving system. The protocols used for the implementation are discussed here in detail as follows :

4.1. SPI (Serial Peripheral Interface)

As the name suggests, this protocol does share properties which is similar to serial communication, but it eliminates the drawbacks of the former, which makes it a very good choice if someone wants to communicate a microcontroller with a peripheral using the principles of serial communication. This is an interface that is commonly used to communicate between the microcontrollers and the peripherals such as sensors, shift registers, ADCs, etc., by making use of separate clock and data lines. This protocol also gives the option of choosing which devices one can communicate at a given time.

The thing that sets SPI apart from serial communication is the ability to operate in a synchronous fashion. By making use of separate data and clock lines, it is able to maintain perfect synchronisation. The clock is responsible for telling the receiver about the rate of data sampling that needs to be done on the data line. It could be either rising edge or falling edge transition depending on the configuration. On the reception by the receiver, based on the edge, it starts to immediately look up in the data line to get the next bit as shown in the Figure 7.

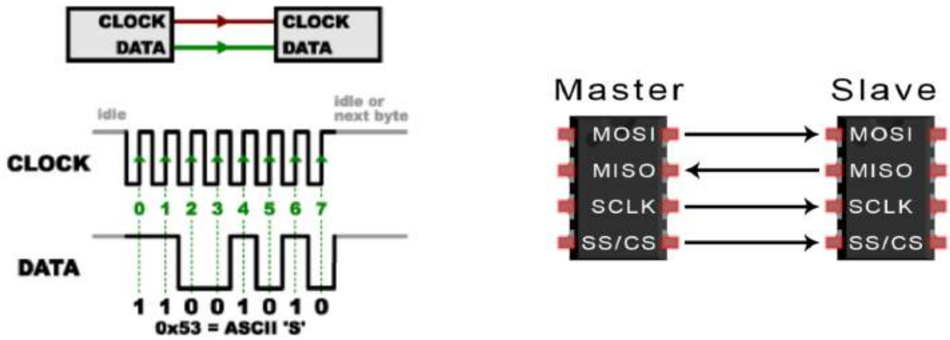


Figure 7. SPI Protocol

Devices that communicate with the SPI protocol usually follow the master slave relationship, where the master is usually the microcontroller or the microcomputer, and the slave is the sensor or the register attached to the former. The slave takes the instructions from the master. The simplest SPI configuration is the single master, single slave, which is shown in the Figure below. However, a master can control more than one slave. The signal pins that are associated with the SPI protocol are as follows:

(a) MOSI (Master Output/Slave Input) –This signal line is for the master to send data to the slave that is attached to system.
(b) MISO (Master Input/Slave Output) –This signal line is for the slave to send data to the master after the appropriate action has been performed by the slave device.
(c) SCLK (Clock) – This generates the clock signal given out by the master to the slave for the synchronous communication.
(d) SS/CS (Slave Select/Chip Select) – This signal line is responsible for the master to select which slave to send data to if there are multiple slaves that are connected to the master.

The steps of SPI data transmission are as follows :

(a) Step 1 - The master transmits the clock signal to the slave device.
(b) Step 2 - The master initiates the transition of the SS/CS pin to a low voltage state, which results in the activation of the slave device.
(c) Step 3 - The master then takes up the task of sending the data, one bit at a time to the slave along the MOSI line. The slave as a consequence ,reads the bits received from the master.
(d) Step 4 - If a response is needed at all, the slave will return data, one bit at a time, to the master along the MISO line. The master then reads the bits as they are received from the slave.

The steps of SPI data transmission is shown in Figure 8.

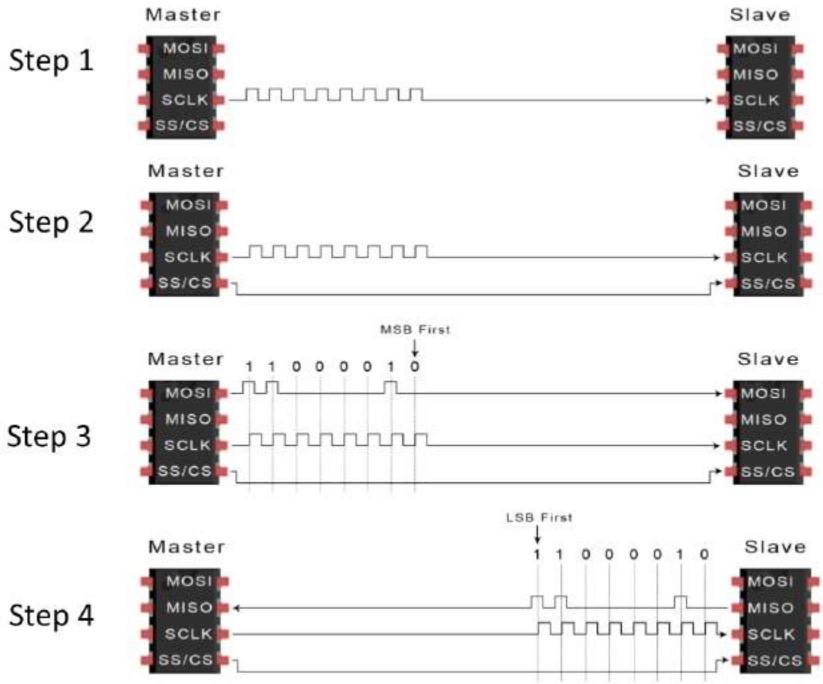


Figure 8. SPI Protocol Data Transmission and Connection

The advantages of this protocol are as follows :

(a) As SPI has no start and stop bits, the transmission of data happens continuously without any interruption.
(b) SPI has no complicated slave addressing system like I^{2}C.
(c) This protocol enjoys higher data transfer rate than I^{2}C (almost twice as fast).
(d) Since this protocol has separate MISO and MOSI lines, the transmission and reception of data can happen at the same time.

This also comes with some disadvantages, which are as follows :

(a) This protocol makes use of four wires compared to other protocols which use two (I^{2}C, UARTs and 1-Wire).
(b) This does not send or generate about the transmission and the reception of data like I^{2}C does.
(c) The concept of error checking for data is missing in this protocol, unlike UART which has a parity bit for error checking.
(d) Only a single master can operate under SPI protocol.

4.2. I^{2}C (Inter Integrated Circuit)

The I^{2}C protocol, or rather known as Inter Integrated Circuit, removes the limitation that SPI protocol offers when it comes to having more than one master at a time. The problem with the serial communication protocol is that since they are asynchronous i.e. no clock rate is transmitted over the period, the devices that are using this must be ahead of the time on a data rate. The difference in time between the devices must be uniform, and if not maintained, it may result in garbled data. Another problem that SPI has is that it requires 4 wires to connect a master with the slave, and if there are more one slave, the number of wires increases, which creates a problem in situations where in PCB designs, it creates a lot of design constraints and routing issues. This protocol tries to combine the best of both the protocols, the serial communication and the SPI protocol. I^{2}C requires just two lines for its operation, just like asynchronous serial. But these two wires are capable of supporting up to 1008 slave devices on a single master. And this also supports multi master system unlike the SPI protocol. The basic layout is given is Figure 9.

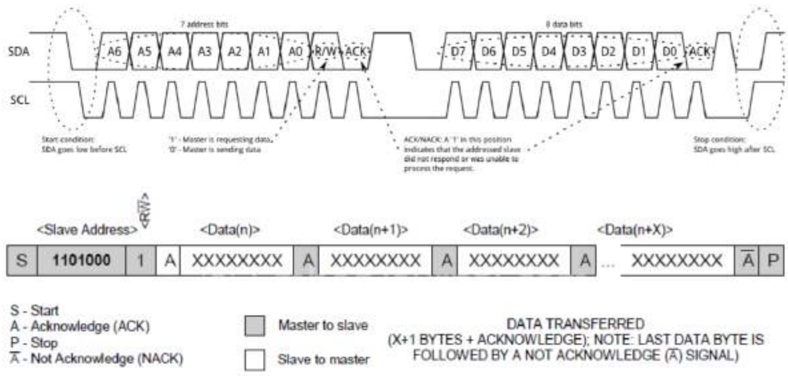


Figure 9. I^{2}C configuration

(a) SDA (Serial Data) – This signal line takes care for the master and slave to send and receive data among themselves.
(b) SCL (Serial Clock) – This signal line is the one that carries the clock signal.

As I^{2}C is a serial communication protocol, the data is transferred bit by bit along a single wire (the SDA line). There is a lot to I2C that might make it sound complicated compared to other protocols, but there are some good reasons why you may or may not want to use I2C to connect to a particular device. A number of reasons make the use of I^{2}C protocol more popular and convenient over others Here are the following advantages as follows :

(a) This protocol makes use of two wires as compared to other protocols.
(b) This protocol has the capability of supporting multiple masters and multiple slaves.
(c) The ACK/NACK bit in the message frame of I^{2}C protocol gives confirmation that each frame is transferred successfully.
(d) The Hardware used for this protocol is less complicated than compared to UARTs and SPI.

However, this protocol has some disadvantages as mentioned below :

(a) This protocol makes use of two wires as compared to other protocols.
(b) The rate of data transmission in I^{2}C is slower compared to SPI.
(c) The size of the data frame in this protocol is limited to 8 bits.
(d) I^{2}C requires more complex hardware to implement it compared to other protocol, say SPI.

4.3. 1-Wire Protocol

This protocol is closely related to the I2C protocol as discussed earlier. The difference between the two is that this operates on lower data rates and longer ranges. This protocol is suited for digital thermometers and instruments. All 1-wire devices have a 800pF capacitor which store charge and helps to power up the device when the data line in active state, making the operation of the devices connected to 1-wire protocol to operate using only two wires like the I^{2}C, namely the data wire and the ground wire. Apple Magsafe chargers and dell chargers also make use of this protocol to validate whether the chargers are genuine or not. There is only one master that takes up the overall charge in the transmission of the data in this protocol. The master is responsible for the initiation of the activity on the bus, and makes sure that collisions are simplified on the bus. After a collision, the master tries once more to do the required communication.

The devices that operate on 1-wire protocol have an unique ID of 64-bits, where the least significant byte indicates the type of the device, and the most significant byte indicates the CRC (Cyclic Redundancy Check), which is used for error detection in digital communication networks. The rate of transfer in the bus is approximately 16.3 kbit/sec. After the initiation of communication by the master, it pulls the wire to 0 volts for a duration of 480 µs. This resets the devices connected across the bus by taking the power out from the bus. For a duration of 60 µs , after the release by the master of the bus, any device on that bus is able to show its presence or detection with the help of presence pulse that it holds during that duration. The 8 bit command after this enables the transmission of data in groups of 8-bits. The uniqueness of this protocol is that since each device has its own unique serial number, the devices can operate under the same bus independently, and it is smart enough to identify which data is coming from which device. The 1-wire configuration is shown in Figure 10.

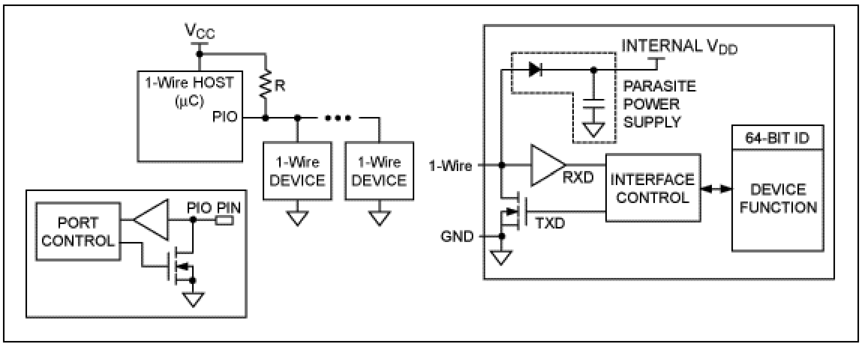


Figure 10. 1-wire configuration configuration

5. SCENARIOS

The choice of the above sensors and the respective protocols for the model has been made by taking various health parameters and issues under consideration. Some of them are as follows:

(a) Case 1 - The skin is one of the most organs in the whole human body when recovering from cuts, scratches or wounds comes into consideration. This is because the skin is perhaps the only functional organ which is exposed to the outside environment. There are certain wounds whose healing time is proportional to the environmental conditions around them. If something goes wrong, not only the healing time increases, but also there are chances that the wound might cause a lot of complications. For instance, when a body is charred in fire, for the purpose of healing, the body is kept in an enclosure where the air around it is sterilized. This is done to prevent the cultivation of any germs or bacteria. Along with that, the temperature and the relative humidity of the surrounding needs to be monitored closely to prevent any bacteria or germs to grow and cultivate. If there is a slight change in the relative humidity of the enclosure, the medical personnel can take the appropriate actions to restore it back to normalcy.

(b) Case 2 - The combination of measuring body temperature independently or with the combination of other medical parameters is done. The body temperature for a human being to be healthy is supposed to be around 98.4OF. If there is a variation in the temperature, it surely indicates fever. But, if it monitored over a long period of time, it may trigger off as an alarm of something more severe. This application is especially applicable for patients in a hospital, where continuous monitoring is a necessity after all, and the attendants do not need to be around each and every patient all the time because remote monitoring becomes possible due to Internet of Things.

(c) Case 3 - The heart beat pulse sensor gives the approximate of the heart beat in BPM (beats per minute), on the principles of photo phlethysmography [31]. The average beat rate for a healthy human being should be around 72-85 BPM. There are other factors which determine the BPM of one human over body over the other. Factors like age, gender, eating habits, exercise etc., determine the BPM from person to person. The sensor captures the BPM by passing light through the issues, and the frequency of the amount of light reflected from the skin tissue gives the BPM. On exercise, the BPM increases. But if the rate of change of BPM is very large over a short span of time, then something is wrong. This sends alarm to the medical personnel and appropriate actions can be taken within the time constraint, before anything goes out of control. Not only that, with the combination of body temperature and BPM, the monitoring of the patient can be done in a more precise manner and various parameters can be monitored, from that the status about the patient's health can be inferred.

(d) Case 4 - The combination of accelerometer and gyroscope helps in keeping track of the body movement of the patient. There are times when the body movement needs to be monitored, probably due to a fracture, or post a surgery performed by medical personnel. If there is even slight movement, it might deter the healing time, resulting in further complications and prolonged time in recovery. With the combination of body temperature, heart beat rate and environmental monitor sensor, the overall health performance of a patient can be estimated and appropriated actions can be taken up by the medical personnel if the health data readings are not in accordance with the ideal readings needed for the wellbeing of a human being .

6. IMPLEMENTATION TECHNIQUE

Figure 11 shows the technique in which the above sensors are interfaced with the Raspberry Pi 3, which in turn was connected to the local web server as well to an IoT service provider, which in case happens to be from AWS (Amazon Web Services) [32]. The IoT core package from AWS used was under the free tier category, which had imposed the limitations of transmission and reception of messages on per day basis, starting from the time of activation of the free tier from the AWS. The Pulse sensor is complemented with an Analog to Digital converter (ADC), which happens to be MCP3006, running on SPI protocol via GPIO pins of the Raspberry Pi. The DHT11 sensor, which is responsible for capturing the parameters of environment temperature and the relative humidity, is interfaced directly with one of the general pins of the Pi. DS18B20, which happens to be responsible for measuring the body temperature over a given interval of time, is connected by making use of the one-wire protocol which happens to be under the aegis of the Raspberry Pi as well. Last but not the least, the MPU6050, sensor responsible for capturing the motion that occurs in the body, with the aid of accelerometer and gyroscope, is driven by making use of the I^2C protocol offered by the Raspberry Pi.

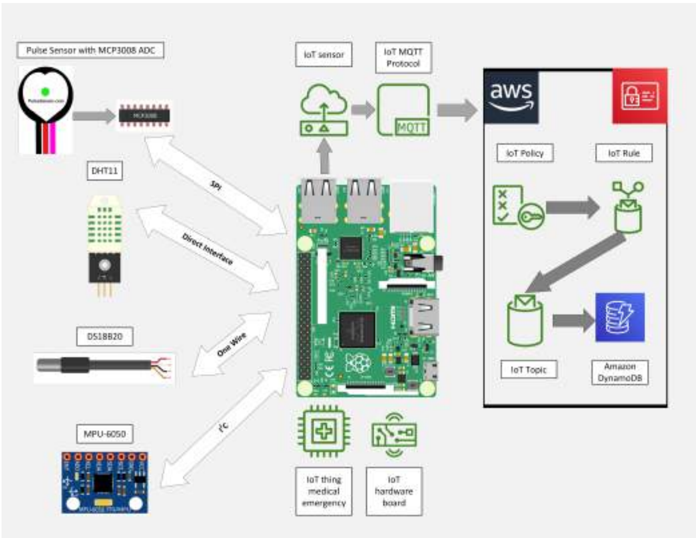


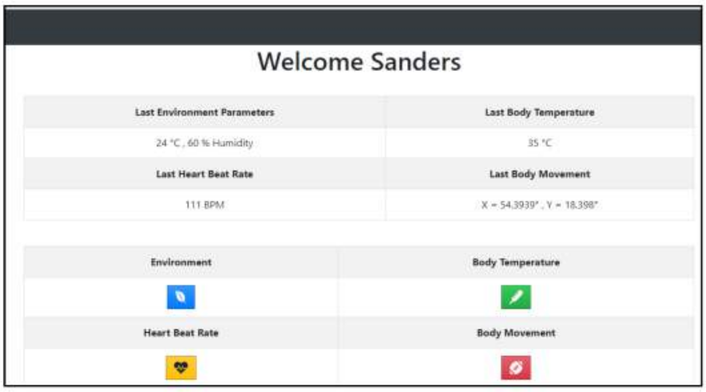
Figure 11. The System implementation using Raspberry Pi 3 and AWS

The Raspberry Pi in this case, happens to be driven by the Raspbian OS, as the distribution is loosely based on the Debian variant of Linux and supports great features and accessibility to the Raspberry Pi, in terms of tweaking of pins at kernel level to assignment of protocols to the pins desired for operation etc., to name a few. Another caveat of using Raspbian as the driving OS is the fact that it offers services to deploy web servers and services exactly similar to those present in Linux, in the form of a stack known as LAMP (Linux for Apache, MySQL, PHP / Python / Perl). The connection to the AWS IoT was established with the means of MQTT protocol, over which the messages were transmitted and received, which happens to be the data acquired by the sensors from a patient over an interval of time, recorded against that individual's credentials.

The system here makes use of an authentication system where each patient is distinct from each other, and in order to get the system up and running for measurements to start, the patient needs to enrol in the central system with the corresponding doctor responsible for the treatment of the patient. Once the registration is done by the patient, a unique ID is generated by the system, which then enables the system to start the measurement of health characteristics. If the unique ID does not exist in the system, it will throw an error stating the absence of the patient in the registry, and will not allow the system at any cost to capture the measurements. Post this, the patient and the doctor associated with the patient can log into the system using the unique ID as the main credential, supplemented with the password, to view results and enable them to analyse the trend over a period of time with the help of graphs. The data is relayed to the AWS IoT core, and it is stored in the Amazon DynamoDB Database against the epoch timestamp, being as the primary key in this case, along with unique ID of the patient as well.

7. RESULTS

The above setup was executed numerous times on different subjects, with their consent. On Figure 12, the top panel shows the home page that the patient is greeted with once all the measurements have captured for a given amount of time as set by the system. The opening page will be greeted by the latest measurement that has been captured till the time it was being recorded and captured by the sensors. The rest of the readings are stored in a MySQL database against the timestamp and the unique ID of the patient. On clicking against the buttons, the detailed listing of the measurements by the sensors get listed. The raft of the data acquired from the sensors can be analysed and visualized graphically for better analysis and diagnosis. The same privileges are available to the doctor as well, where they have the list of patients they are looking after, mapped done with the Doctor's ID with that of the patient.



(a)

(b)

Figure 12. The top (a) shows the home page the patient is greeted with, while the (b) shows the graphical representation of the body movement obtained over a period of time.

The same data is transmitted to AWS IoT Core via MQTT, in the form of messages, which capture at particular periodic intervals defined by the system, and the same is stored in the Amazon DynamoDB database, mapping done with the epoch timestamp as primary key. For the sake of simplicity, the topic in MQTT was kept common, this can be further split into different divisions depending upon the classification as required from one entity to another entity. This is shown in Figure 13.

Figure 13. The result of the patient in AWS IoT using MQTT.

In terms of performance and accuracy of the data captured by the sensors, the rate of error has been compensated by making the system run multiple time, collecting the readings and analysing the variance in the due course. The comparison for temperature of the body was confirmed with a clinical mercury thermometer, while for the room temperature, it was against the mercury thermometer. For the validation of heart beat pulses, keeping the working principle of the sensor, it was validated against a strong strobe of flashlight and camera from a mobile phone of two makes (an Android make and an iOS make), yielding results in conformance with the system designed.

8. CONCLUSION

The healthcare industry will witness a change due to the Internet of Things and the way in which it is evolving. At the same time, while the transition to the Internet of Things in medical sector is slow, the above implementation can speed up the process and help in reducing the time that is needed to develop the sensors. The standardized protocols that exist have stood the test of time, as well as are implemented in many industrial applications. In fact, the basis of Industrial Internet of Things are based on the expansion and proper implementation of the protocols that already exist.

For the above implementation technique, the sensors that need to be implemented in the health care sector and the equipment have a long way to go before they can be conceived into a reality and as the current technological trends stand for, the future seems bright for the healthcare sector in the internet of things.

REFERENCES

[1] L. Atzori, A. Iera, and G. Morabito, ”The internet of things: A survey,” Computer networks vol. 54, no. 15, pp. 2787–2805, 2010.

[2] N. Bui and M. Zorzi, ”Health care applications: a solution based on the internet of things,” in Proceedings of the 4th International Symposium on Applied Sciences in Biomedical and Communication Technologies. ACM, 2011, p. 131.

[3] H. Alemdar and C. Ersoy, “Wireless sensor networks for healthcare: A survey,” Computer networks, vol. 54, no. 15, pp. 2688–2710, 2010.

[4] F. Andriopoulou, T. Dagiuklas, and T. Orphanoudakis, “Integrating iot and fog computing for healthcare service delivery,” in Components and Services for IoT Platforms. Springer, 2017, pp. 213–232.

[5] J. Gubbi, R. Buyya, S. Marusic, and M. Palaniswami, “Internet of things (iot): A vision, architectural elements, and future directions,” Future generation computer systems, vol. 29, no. 7, pp. 1645–1660, 2013.

[6] Y.-L. Zheng, X.-R. Ding, C. C. Y. Poon, B. P. L. Lo, H. Zhang, X.-L. Zhou, G.-Z. Yang, N. Zhao, and Y.-T. Zhang, “Unobtrusive sensing and wearable devices for health informatics,” IEEE Transactions on Biomedical Engineering, vol. 61, no. 5, pp. 1538–1554, 2014.

[7] X.-F. Teng, Y.-T. Zhang, C. C. Poon, and P. Bonato, “Wearable medical systems for p-health,” IEEE reviews in Biomedical engineering, vol. 1, pp. 62–74, 2008.

[8] P. Pierleoni, A. Belli, L. Maurizi, L. Palma, L. Pernini, M. Paniccia, and S. Valenti, “A wearable fall detector for elderly people based on ahrs and barometric sensor,” IEEE Sensors Journal, vol. 16, no. 17, pp. 6733–6744, 2016.

[9] S. Patel, H. Park, P. Bonato, L. Chan, and M. Rodgers, “A review of wearable sensors and systems with application in rehabilitation,” Journal of neuroengineering and rehabilitation, vol. 9, no. 1, p. 21, 2012.

[10] K. Taylor, “Connected health: How digital technology is transforming health and social care,” London, UK: Deloitte Centre for Health Solutions, 2015.

[11] J. Melorose, R. Perroy, and S. Careas, “World population prospects: The 2015 revision, key findings and advance tables,” in Working Paper No. ESA/P/WP. 241, 2015, pp. 1–59.

[12] M. Stanhope and J. Lancaster, Public Health Nursing-E-Book: Population-Centered Health Care in the Community. Elsevier Health Sciences, 2015.

[13] S. A. Cunningham, M. R. Kramer, and K. V. Narayan, “Incidence of childhood obesity in the united states,” New England Journal of Medicine, vol. 370, no. 5, pp. 403–411, 2014.

[14] D. Minoli, Building the internet of things with IPv6 and MIPv6: The evolving world of M2M communications. John Wiley Sons, 2013.

[15] R. Gayathri and S. K. Vasudevan, “Internet of things based smart health monitoring of industrial standard motors,” Indonesian Journal of Electrical Engineering and Informatics (IJEEI), vol. 6, no. 4, pp. 361–367, 2018.

[16] F. Rincón, J. Recas, N. Khaled, and D. Atienza, “Development and evaluation of multilead wavelet-based ecg delineation algorithms for embedded wireless sensor nodes,” IEEE Transactions on Information Technology in Biomedicine, vol. 15, no. 6, pp. 854–863, 2011.

[17] Y.-D. Kim, S.-H. Jung, D.-Y. Gu, H.-K. Kim, and C.-H. Song, “Iot sensor based mobility performance test-bed for disaster response robots,” in Advanced Applied Informatics (IIAI-AAI), 2017 6th IIAI International Congress on. IEEE, 2017, pp. 990–991.

[18] V. Chacko and V. Bharati, “Data validation and sensor life prediction layer on cloud for iot,” in Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData), 2017 IEEE International Conference on. IEEE, 2017, pp. 906–909.

[19] H.-C. Lee and K.-H. Ke, “Monitoring of large-area iot sensors using a lora wireless mesh network system: Design and evaluation,” IEEE Transactions on Instrumentation and Measurement, 2018.

[20] G. Bedi, G. K. Venayagamoorthy, and R. Singh, “Internet of things (iot) sensors for smart home electric energy usage management,” in Information and Automation for Sustainability (ICIAfS), 2016 IEEE International Conference on. IEEE, 2016, pp. 1–6.

[21] D. Belo, R. Correia, P. Pinho, and N. B. Carvalho, “Enabling a constant and efficient flow of wireless energy for iot sensors,” in Microwave Symposium (IMS), 2017 IEEE MTT-S International. IEEE, 2017, pp. 1342–1344.

[22] Y. Obuchi, T. Yamasaki, K. Aizawa, S. Toriumi, and M. Hayashi, “Measurement and evaluation of comfort levels of apartments using iot sensors,” in Consumer Electronics (ICCE), 2018 IEEE International Conference on. IEEE, 2018, pp. 1–6.

[23] A. Noda, O. Fukuda, H. Okumura, and K. Arai, “Behavior analysis of a small animal using iot sensor system,” in Intelligent Informatics and Biomedical Sciences (ICIIBMS), 2017 International Conference on. IEEE, 2017, pp. 9–10.

[24] Y. Takahashi, Y. Nishida, K. Kitamura, and H. Mizoguchi, “Handrail iot sensor for precision healthcare of elderly people in smart homes,” in Robotics and Intelligent Sensors (IRIS), 2017 IEEE International Symposium on. IEEE, 2017, pp. 364–368.

[25] K. Ishibashi, R. Takitoge, and S. Ishigaki, “Beat sensors iot technology suitable for energy saving,” in Integrated Circuits, Design, and Verification (ICDV), 2017 7th International Conference on. IEEE, 2017, pp. 52–55.

[26] N. Hallfors, M. A. Jaoude, K. Liao, M. Ismail, and A. Isakovic, “Graphene oxide—nylon ecg sensors for wearable iot healthcare,” in Sensors Networks Smart and Emerging Technologies (SENSET), 2017. IEEE, 2017, pp. 1–4.

[27] E. S. Pramukantoro, W. Yahya, G. Arganata, A. Bhawiyuga, and A. Basuki, “Topic based iot data storage framework for heterogeneous sensor data,” in Telecommunication Systems Services and Applications (TSSA), 2017 11th International Conference on. IEEE, 2017, pp. 1–4.

[28] P. S. Malvade, A. K. Joshi, and S. P. Madhe, "Iot based monitoring of foot pressure using fsr sensor," in Communication and Signal Processing (ICCSP), 2017 International Conference on. IEEE, 2017, pp. 0635–0639.

[29] A. Vahdatpour, N. Amini, W. Xu, and M. Sarrafzadeh, "Accelerometer-based on-body sensor localization for health and medical monitoring applications," Pervasive and mobile computing, vol. 7, no. 6, p. 746, 2011.

[30] M. Marschollek, M. Gietzelt, M. Schulze, M. Kohlmann, B. Song, and K.-H. Wolf, "Wearable sensors in healthcare and sensor-enhanced health information systems: all our tomorrows?" Healthcare informatics research, vol. 18, no. 2, pp. 97–104, 2012.

[31] N. S. Ali, Z. A. A. Alyasseri, and A. Abdulmohson, "Real-time heart pulse monitoring technique using wireless sensor network and mobile application," International Journal of Electrical and Computer Engineering (IJECE), vol. 8, no. 6, 2018.

[32] A. Rghioui and A. Oumnad, "Challenges and opportunities of internet of things in healthcare," International Journal of Electrical and Computer Engineering, vol. 8, no. 5, p. 2753, 2018.

BIOGRAPHY OF AUTHORS

Rishabh Mitra pursued an undergraduate course, Bachelors of Technology (B.Tech) in the Department of Electrical and Electronics Engineering, Manipal Institute of Technology, Manipal under Manipal Academy of Higher Education (MAHE). His area of interests are in the field of Embedded Processor Architecture, Real Time Systems, Data Structures and Algorithms, Theory of Computation, Computer Networks, UNIX System Management, UNIX Networking, Cloud Computing, Full Stack Web Development, ERP (Enterprise Resource Planning) using SAP, Internet of Things (IoT) and Cryptography etc. Currently he is working with L&T Technology Services, actively pursuing development in embedded software and hardware systems for Automotive and Commercial Vehicles.

Raghavendra Ganiga has received his B.E. degree in Information Technology from Kurunji Venkatramana Gowda(KVG) college of engineering, Sullia and M. Tech. in Networking Engg. from Manipal Institute of Technology(MIT), Manipal under Manipal Academy of Higher Education (MAHE). Received best paper awards at international conferences for his research papers and contributions to the scientific publication. Currently he is working in the Department of Information & Communication Technology in Manipal Institute of Technology, Manipal. His areas of interest are Cloud Computing, Healthcare IT and Information Security.