Australian Journal of Basic and Applied Sciences, 9(16) Special 2015, Pages: 275-281

ISSN:1991-8178

Australian Journal of Basic and Applied Sciences

Journal home page: www.ajbasweb.com

Internet of Things (IoT) Enabled Wireless Patient Monitoring System using CC3200

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A R T I C L E I N F O

Article history:
Received 20 January 2015
Accepted 02 April 2015
Published 20 May 2015

Keywords:
CC3200, IoT, Patient monitoring
Healthcare, Embedded System
ubiquitous data access

A B S T R A C T

Internet of Things (IoT) refers to the interconnection of uniquely identifiable embedded computing devices within the existing Internet infrastructure. It enables remote monitoring of patients in healthcare as well as in handling patient's insurance and billing information. A problem in the IoT area is interoperability. IoT solutions can be used to securely capture patient health data from a variety of sensors, apply algorithms to analyze the data and then share it through wireless connectivity with medical professionals who can make appropriate recommendations. In the proposed IoT based patient monitoring system sensors such as temperature, blood pressure collect medical information from the patient and upload them to Internet through a gateway node (CC3200). Semantic data model is used to store the data and a Resource based data accessing method is employed to acquire and process the IoT data. Message Scheduling is incorporated into this database framework which can improve the reliability of the data being fetched and will also help to improve the response stability. Database management system handles data transfers.

To Cite This Article: R. Ganesan, K. Kanimozhi, R. Prakash, V. Vijaya Chamundeeshwari, A. Balaji Ganesh., Internet of Things (IoT) Enabled Wireless Patient Monitoring System using CC3200. ***Aust. J. Basic & Appl. Sci.,*** *9(16): 275-281, 2015*

INTRODUCTION

Health and wellness is one of the most promising application areas of IoT technology (Ling Li *et al*., 2012). In the IoT, physical objects monitor their surroundings and participate in daily activities, helping create new services and business models, to improve efficiency and optimize business operations. Mobile phones can be used for many physiological monitoring and examination. The potential economic impact of IoT in healthcare could run into trillions of dollars of annual savings (Zhibo Pang *et al*., 2013). Analyzing the data obtained through medical records, equipment and hand-held personal devices will enhance the accuracy of decision-making for professionals and enables patients to take a more active role in managing their personal health.

In order to build intelligent, context-aware health and wellness applications that generate relevant patient-specific cues and alerts, there is a need to integrate data from multiple sources (Li Da Xu *et al*., 2014). These sources include different types of medical devices such as blood pressure, thermometers, pulse-oximeters, glucose meters, ECG monitors, imaging systems as well as equipment such as fitness and strength machines, mobile devices, social network feeds and other web resources.

The necessity for healthcare applications arises from the demographic change in industrialized countries where life expectancy is on the rise and the birth rate is in decline. Keep In Touch (KIT)(Dohr *et al*., 2014) is a technology for collecting and forwarding necessary (health) data for chronically ill and elderly people to monitor the health status and compliance in therapy. KIT is based on RFID in combination with mobile phones and Near Field Communication (NFC). NFC is a wireless connectivity technology which enables short-range communication between smart objects. In KIT every person gets a Smart Card (ID-Card), which is used to identify the patient and to launch a Java software application installed on the mobile phone. After

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launching data can be collected from e.g. a blood pressure meter just by touching the device. AAL entail several benefits, for elderly people, who wish to stay in their traditional, but ambient assisted environment.In another approach (Keerthika. A *et al*., 2013), the pulse oximeter sensor is placed in human body which measures the oxygen saturation value of the person and sensed value is then given to the signal conditioning circuit. This in turn is connected to the PIC microcontroller. These data parameters are sampled by the microcontroller and the data are transmitted using the GSM MODEM. The data received at the GSM MODEM receiver is sent to the Server PC. In PC, the sensed data is processed and if Oxygen Rate is abnormal, SMS Alert is sent.

The introduction of 4G technologies (R. S. H. Istepanaian *et al*., 2012)and networks in this decade will bring new services and consumer usage models that will be compatible with the emerging mobile network architectures. Internet of Things (IoT) and Internet of Services (IoS) will have major impact on future implementation issues of 4G health systems. The advances in both RFID and WSN significantly contribute to the development of IoT. Key enabling Technologies in IoT include Identification and tracking technologies like RFID systems, barcode, intelligent sensors; Communication Technologies in IoT such as WSNs, WLAN and Service management in IoT which refers to the implementation and management of quality IoT services that meet the needs of users or applications. Recent research Trends include IoT, Integrating Social Networking with IoT Solutions, Developing Green IoT Technologies and Cloud Computing.

1. Methodology:

IoT Architecture:

The Internet of Things (IoT) is an environment in which the thing to be monitored or controlled (which may be objects, animals or people) are provided with unique identifiers i.e. they obtain unique IP addresses. These objects hence acquire the ability to transfer data over a network to another device without the need for human or computer involvement. The term IoT can refer to a wide variety of scenarios. Examples of IoT that may utilize Wi-Fi technology for remote monitoring applications include environment monitoring in forests or greenhouses, using implants for monitoring heart condition of chronically ill patients, biochip transponders used on animals as a step towards wildlife monitoring. This helps in keeping track of animal movement patterns, habitat utilization, poaching incidents in order to protect endangered species. Sensors used in automobiles for measurement or calibration purposes, field operation equipment that assist fire-fighters in rescue operations, smart thermostats that automatically make intelligent, and personalized heating and cooling decisions are more advanced applications. IoT applications typically generate large amounts of data from diverse locations that may be in different formats thereby increasing the complexity in storing and processing such data(Rachel L. Richesson *et al*., 2007).Connected medical devices and associated IoT technologies will enable us to achieve the following capabilities: Accessing real time visibility of the patient's condition, his/her activities, context and physiological parameters; Monitor compliance to prescribed treatment and exercise regimes; Provide feedback and cues to patients, family members, doctors and caregivers in order to implement corrective action; Make use of high performance computing for real time feedback. IoT Architecture consists of the following four layersas mentioned in (Boyi Xu *et al*., 2014):

A. Edge layer:

This hardware layer may comprise of sensor or actuator networks, RFID tags and readers or wireless sensor nodes. Many of these hardware elements provide identification such as in RFID tags and also information storage, information collection as in sensor networks (Lei Wang *et al*., 2010)), information processing such as embedded edge processors, communication, control or actuation.

B. Access gateway layer:

The Access gateway layer is the first stage of data handling in IoT architecture. The tasks involved in this layer include message routing, publishing and subscribing to data and cross platform communication when required.

C. Middleware layer:

The Middleware layer operates in bidirectional mode. It serves as an interface between the hardware layer (bottommost layer) and the application layer (topmost layer). It handles critical functions like device and information management. It is also responsible for issues like data filtering and aggregation, access control, semantic analysis information discovery such as EPC (Electronic Product Code) information service and ONS (Object Naming Service).

D. Application layer:

The application layer forms the topmost part of the stack. It is responsible for delivering various applications to a variety of end users. The applications can be for different types of industrial uses such as for manufacturing, monitoring, wild life tracking, remote sensing, shipping, logistics, retail, automobile, healthcare, food and drug. With the involving new trends in RFID technology, numerous applications which will be under the umbrella of Internet of Things are likely to develop in the future.

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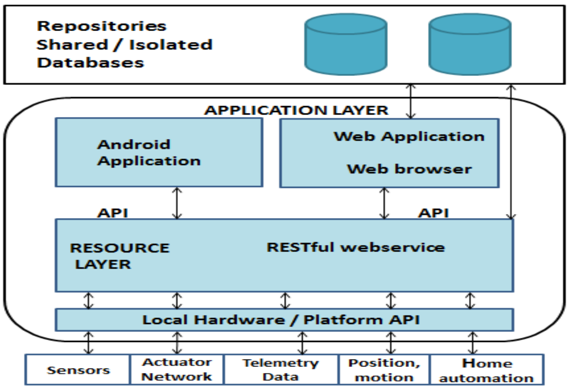

Fig. 1: IoT Architecture.

Web services are open standard (like SOAP(Vinodhini.J *et al*., 2013), HTTP ,REST, XML) based Web applications client and server applications) that interact with other web applications for the purpose of exchanging data. Web services are not accessed directly by humans rather they are accessed by code running in machines. Web services serves as a standard way of providing interoperability between software applications running on a variety of platforms and frameworks. The main purpose of using a web service is due to its major advantage or feature - interoperability and extensibility. Web services can be combined to provide complex operations. Program codes providing API can interact with each other to deliver sophisticated services. SOAP, JSON, XML, REST are some of the web services. REST webservice runs over HTTP and hence allows for interoperability between various types of devices. It uses http GET, POST methods to retrieve and upload respectively.

Application layer includes web services which may incorporate any of the technologies like SOAP(Rumen Kyusakov *et al*., 2013), REST, JSON and XML. REST (REpresentational State Transfer) architecture has become an important technology for Web applications in today's scenario. It is much easier to use and is also more flexible than most of the other architectures. REST can output the data in various formats such as Command Separated Value (CSV), JavaScript Object Notation (JSON) and Really Simple Syndication (RSS). Its importance continues to grow quickly as all technologies move towards API oriented architectural style. Nowadays most of the development languages include frameworks for building RESTful Web services. REST is an architectural style for networked hypermedia applications. It is mainly used to build lightweight webservices that are maintainable and scalable. Services based on REST mechanism are known as RESTful services. RESTful service uses HTTP as its underlying protocol.

Proposed System:

The proposed system in this paper consists of sensors that continuously collect patient information and report to it to the gateway nodes. Data is received at concentration points or gateways within the network where it is further analyzed, filtered and processed for efficient transmission. Wireless communication technology (Wi-Fi) is used by gateway node (CC3200) to acquire an IP address. These gateways can be used to send data to database repositories or host data on a webserver from where various clients can retrieve required data. Scheduling web-based IoT messages supported by a priority queue model can stabilize the response messages as per each client request.In HTTP request/response messaging model every request from client should wait until server responds to previous request. This is inefficient for real time transmission. According to statistics, the arrival and service times follow memoryless behavior of probability distribution.M/M/1 queuing systems assume a Poisson arrival process. M/M/1 is a single server queueing system where arrivals are determined by a Poisson process, job service times have an exponential distribution and unlimited number of waiting positions.

An M/M/1 Queueing system has the following characteristics:

i) It is a single server system with exponential service times and the service rate (μ)customers per time unit.

ii) Customers arrive according a Poisson process with the arrival rate (λ) customers per time unit.

iii) Number of waiting positions is infinite(∞).

A. Sensors:

The accelerometer sensor is used for fall detection. Besides senior citizens, there are many other conditions like painters, mountaineers, construction workers, window washers and activities for which an immediate alert to a possible fall, especially from significant height, would be quite helpful. Temperature sensor reads the patient's body temperature. Pulse sensor captures the patient's haert beat rate. It essentially combines a simple optical heart rate sensor with amplification and noise cancellation circuitry making it fast and easy to get reliable pulse reading .The data can also be sent to a webservice which will store it in a database. The data can also be visualized as a live stream in the form of graphs or gauge meters. The temperature, accelerometer and pulse sensors have to be connected to the CC3200 Wi-Fi board using I2C.

The board must be configured to work in station mode. It connects to the Access point. SSID and password of the favorable Access point must be specified in the code. The CC3200 connects to the access point using Wi-Fi and acquires an IP for itself. The IP acquired by the device can be seen in the serial port. It will also be displayed in the address bar of the web browser (client).

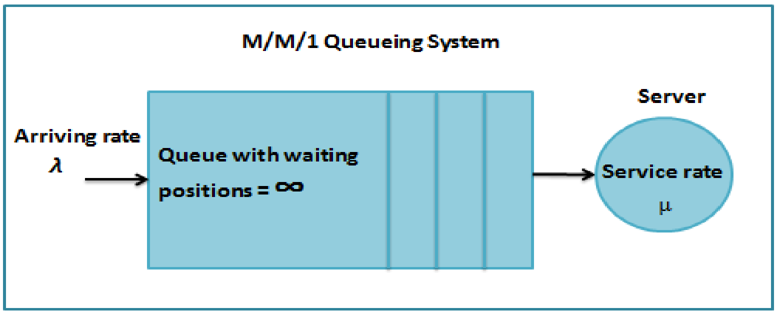

Fig. 2: M/M/1 Queue.

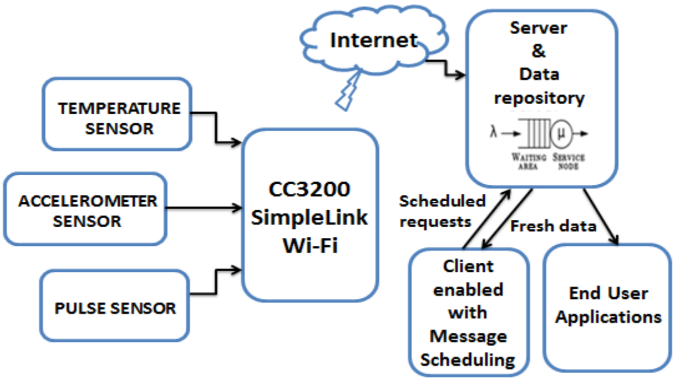

Fig. 3: Block Diagram of Proposed Methodology.

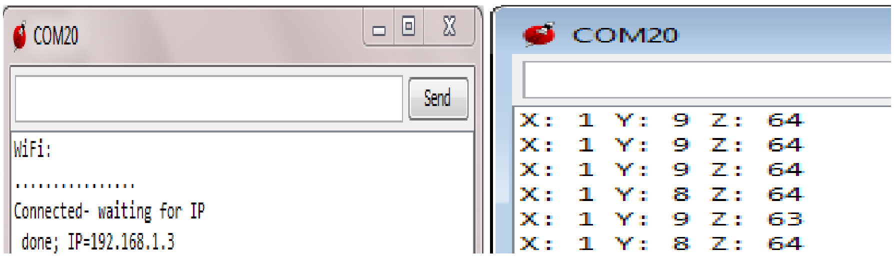

Fig. 4: CC3200 Acquiring IP using Wi-Fi and accelerometer sensor reading.

The IP acquired by the CC3200 board is it's unique identifier which can be used to access the board from anywhere across the world. It is using this IP that the board hosts a Webserver that can display the sensor data. The accelerometer sensor data reading can be viewed as a live stream in the serial terminal. As the CC3200 board uses 80MHz clock frequency the data are displayed in the terminal with a baud rate of 115200 bits per second.

B. CC3200:

The CC3200 board is a SoC (System on chip) containing ARM Cortex-M4 core (having a clock frequency of 80 MHz) that integrates a microcontroller unit and network processor hence making it suitable for developing Internet of Things applications. The board contains on-chip Wi-Fi, Internet protocols support and robust security protocols. The device peripherals include UART, SPI, I2C, SD/MMC, I2S, four-channel ADC and fast parallel camera interface. The CC3200 board can be configured to operate in Station, Access Point or Wi-Fi Direct mode. It also provides support for WPA2 and WPS 2.0 security. The board also has support for embedded TLS/SSL stack, TCP/IP stack, HTTP server, and many Internet protocols. It also has a Crypto Engine which provides 256-bit AES Encryption for TLS and SSL Connections. This feature makes Internet, Wi-Fi connections more secure.

The sensors are interfaced using I2C protocol. The I2C bus uses SDA and SCL signals (I2CSDA and I2CSC) for providing bi-directional data transfer. The I2C protocol defines START and STOP states to begin and end a transaction. The bus is busy after a START condition is applied.The bus remains idle when both the signals are held at logic 1 (high). I2C START condition begins when SCL line is held high and the SDA line transits from high to low (1 to 0). Similarly I2C STOP state is triggered when the SCL line is held high and the SDA line transits from low to high (0 to 1).The bus is free after the occurrence a STOP condition. The STOP bit determines if the cycle stops at the end of the data cycle or continues on to a repeated START condition. The data being sent in the I2C SDA line consists of nine bits of which eight are data bits (MSB is sent first) and the last one is an acknowledgment bit. When the receiver buffer is full and is not ready to receive any more data, it holds the SCL signal low (at logic 0). This forces the transmitter into a wait state and prevents the receiver from being overloaded. The data transfer continues when the receiver releases the SCL signal line.

```
void I2CFIFODataPut(uint32_t ui32Base, uint8_t ui8Data)
{
    ASSERT(_I2CBaseValid(ui32Base));
   while(HWREG(ui32Base + I2C_O_FIFOSTATUS) &
I2C_FIFOSTATUS_TXFF) {  }
   HWREG(ui32Base + I2C_O_FIFODATA) = ui8Data;
}
```

Fig. 5: Writing a byte of data to Transmit FIFO Buffer in I2C.

The above code writes a byte of data to the I2C transmit FIFO. The parameter ui32Base is the base address of the I2C master or slave module, ui8Data is the data to be placed into the transmit FIFO.

The following code reads a byte from the I2C receive FIFO and places it in the location specified by the pui8Data parameter. If there is no data available, this function waits until data is received before returning. The parameter ui32Base is the base address of the I2C master or slave module.

```
void I2CFIFODataPut(uint32_t ui32Base, uint8_t ui8Data)
{
    ASSERT(_I2CBaseValid(ui32Base));
   while(HWREG(ui32Base + I2C_O_FIFOSTATUS) &
I2C_FIFOSTATUS_TXFF) {  }
   HWREG(ui32Base + I2C_O_FIFODATA) = ui8Data;
}
```

Fig. 6: Reading a byte of data from Receive FIFO Buffer in I2C.

C. Web Server:

Web server utilizes Hypertext Transfer Protocol for establishing communication and Hypertext Markup Language for describing how the web content should be displayed to the viewer. HTML GET method is the basic request issued to a server from a user agent (web browser). HTTP POST is used to send data from clients to server side. These methods follow a standard message format dictated by the W3C (World Wide Web Consortium). The server responds with appropriate HTTP messages. These have codes to indicate whether the request was performed successfully or not. For example, HTTP code 200 indicates successful completion of request. HTTP 404 code indicates an error message. Error messages are obtained when the server is down or is unable to complete the request. A webserver servers two main functions: i) deliver content from stored webpages to users and ii) receives content from clients similar to how data is provided by clients while user submits forms, filling up username and password to authenticate a person to access particular data like mail accounts as well as while uploading files. Many web servers are programmed using server-side scripting languages such as ASP.NET, PHP, JavaScript, C#, Perl, Ruby, and Python. HTML documents may be of two types: static or dynamic webpages. JavaScript, PHP, ASP and CSS are used to program a webpage that allows dynamic functionality.Anexample of a dynamic HTML document isa server displaying the current date and time. Static document remain unaltered until web developer alters data in the server. It is much cheaper to develop, fast and cacheable. Dynamic webpages are more interactive to users than static webpages.Web servers can also be found in embedded devices. Examples includerouters, printer and webcams. The web server can be used for controlling or simply monitoring the individual attached to the device or the environment in which the device is placed.

2. *Results:*

Web server is a program that serves the web contents in the form of HTML documents to users whose computers contain HTTP clients. It is based on client-server model. Clients such as web browsers issues requests to server to retrieve required resources such as files or images.

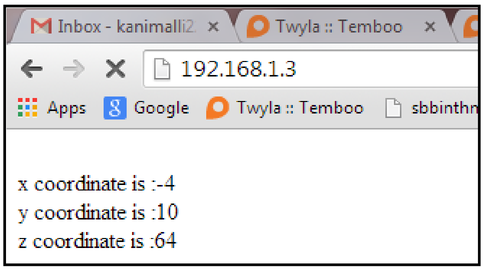

Fig. 7: Webserver displaying accelerometer sensor data.

The Users i.e. the patients can secure their medical records and permit controlled access to their data that is hosted on the server by providing a User login page to view the contents uploaded by their CC3200 board. The Client i.e. hospital operator or doctor has to type the patients Unique IP address in the URL field of a webbrowser and login using Username and Password Credentials. The Client is then able to view the patients data as a live stream .

The temperature, pulse rate and accelerometer data are refreshed by the CC3200 after a time period as required by the patient. For example the sensor data can be refreshed once in every 10 seconds.The sensor data has also been logged onto a gmail account user's spreadsheet as shown in figure 8. This data can be viewed live as it is being logged or can be downloaded later for future references.

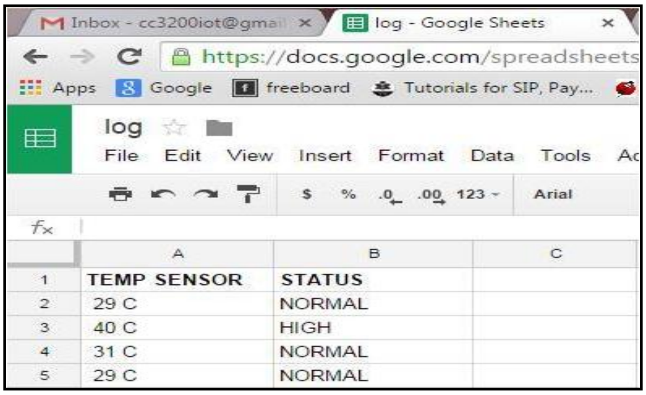

Fig. 8: Data logged onto Gmail Spreadsheet.

Database Management System: The data can also be stored onto a database system either at the patient side or at the hospital side in shared database on a cloud platform. The hospitals have to implement a database management system (DBMS). It handles user requests to create or access data from a database. The most commonly employed DBMS is a relational database management system (RDBMS). While employing DBMS to handle user requests, other programs are relieved from having to locate the data's physically position on the storage media. The DBMS also handles data integrity i.e. making sure it continues to be accessible and is organized continuously as intended. It also enables security measures by making sure only those with access rights can access the data by authentication mechanisms. Structured Query Language (SQL) serves as the user interface for DBMS i.e. the Users issue SQL commands to store or retrieve data from databases.

The hospitals can make Clients programs that retrieve data from the database and display it in more interpretable graphical forms like charts or gauge meters. One such example is depicted below. The continuous changes in accelerometer readings of x, y, z axis is shown in the charts.

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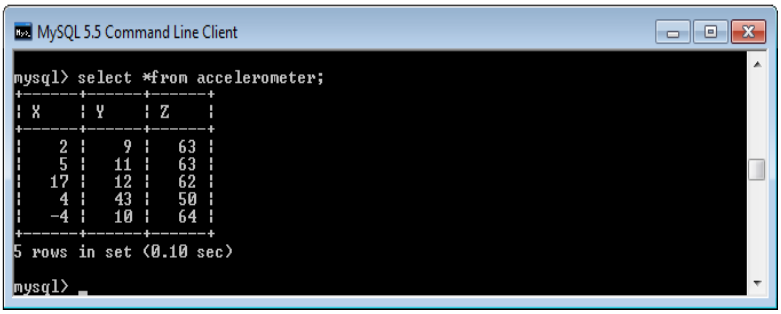

Fig. 9: Sensor data stored in a database.

3. Conclusion:

The objective of this project is to make the sensor data (i.e. patient's health condition) available from anywhere by assigning unique identity to each user or patient. The data have been made available through a webserver in this work. The data has also been logged into the database managed by the hospital. Hospital management can retrieve patient data from these databases for treatment or insurance and billing purpose.

The plan of future work is to use webservice API which enables interoperability. A variety of devices independent of their platform and language can communicate with webservice through HTTP request response messaging for retrieving data. This architecture will not affect the users in case of future extensions or modifications. The changes will be made to the web service alone. The users will remain unaffected. Emergency Decision Support systems can be built based on these IoT architectures.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support from Department of Science and Technology, New Delhi, through Science for Equity Empowerment and Development Division DST file No: SSD/TISN/047/2011-TIE (G) dated 08/05/2014 to Velammal Engineering College.

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