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IoT based Real Time ECG Monitoring System using Cypress WICED

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ABSTRACT: Smart and cost effective healthcare has been in increasing demand to meet the needs of growing human population and medical expenses. It is a known fact that country like India has become heart disease capital of the world. There is a urgent need to develop an effective health monitoring system, that can detect abnormalities of health conditions in time and make diagnoses according to the gleaned data. ECG monitoring is a widely studied and applied approach to diagnose heart diseases. However, existing portable wireless ECG monitoring systems cannot work without a mobile application, which is responsible for data collection and passing on the messages to doctors. Recent advances in mobile technology and cloud computing have inspired numerous designs of cloud-based health care services and devices. Within the cloud system, medical data can be collected and transmitted automatically to medical professionals from anywhere and feedback can be returned to patients through the network. In this paper, we propose a new method for ECG monitoring based on Cypress Wireless Internet Connectivity for Embedded Devices (WICED) Internet of Things (IoT) platform. ECG data are gathered using a wearable monitoring node and are transmitted directly to the IoT cloud using Wi-Fi. Internet of Things utilizes open source protocols like CoAP/HTTP, MQTT, TLS/TCP, DTLS/UDP and OMALWM2M for data communication and device management.

KEYWORDS: Internet of Things (IoT), Health monitoring, ECG, Wearable sensors, Wireless Internet Connectivity for Embedded Devices (WICED), IoT cloud

I. INTRODUCTION

By 2020 unprecedented growth in the Internet of Things (IoT) technologies will make it possible to talk about 50 billion connected devices through the internet [1]. Body-worn sensors are the most among the other devices that monitor personal health conditions. There has been a increasing interest in wearable sensors in recent years and an emerging set of new products are commercially available for activity recognition, personal health monitoring, and fitness. For clinical use, long-term patient monitoring and management has also been considered. The two driving factors of this technology are the IoT-based data collection and cloud-based analytics. [2]. Development of mobile Internet and wireless sensor networks (WSNs) [3] have led to birth of wearable ECG monitoring systems. This gave rise to the idea of building an integrated IoT and cloud based solution for healthcare applications. For instance, smart phone based bio-signal monitoring approach is demonstrated by [4]. A systematic review of various mobile healthcare approaches was carried out by [5]. A mobile cloud-based ECG monitoring service was presented [6].

These are able to detect ECG signals using a non-intrusive sensor and transmit the signal to the smart phone through wireless transmission techniques, such as Bluetooth or Zigbee [7, 8, 9, 10, 11]. However, nearly all existing systems cannot work without a smart phone, which is used as a receiver and processor of the ECG data [12, 13]. Due to limited power and computational capabilities, the complex tasks of data transportation and processing may have a great impact on the daily use of the smart phone. Furthermore, in order to support all the OS platforms of smart terminals, great efforts are required for the cross-platform development of the mobile application. Accurate ECG monitoring of a patient is possible using low-cost wearable cypress devices. This monitored data can be transmitted to the database, linked with the health records of the patient. Statistical inference algorithms can compare this patient's data to a large database of other patients and provide the doctor with a rich set of suggestions [14]. A wearable ECG monitoring

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system can transmit the data directly to the IoT cloud using Wi-Fi without the need of a mobile terminal. Wi-Fi can provide higher data rates and wider coverage areas compared with bluetooth or Zigbee [15].

In this paper, ECG monitoring system architecture based on the Internet-of-Things (IoT) cloud is proposed. A low power wearable ECG monitoring system using PSoC [14] is used to sense the ECG signal from the human body. ECG monitoring system is connected to low power, high speed WICED which will transmit the data directly on to the Amazon Web Services (AWS) IoT cloud. Compared with Bluetooth or Zigbee, Wi-Fi can provide higher data rates and wider coverage areas. Due to the power limitations of transmitting device, most of the processing is pushed to the server side. IoT lets RFID, BLE, Wi-Fi and other sensor networks empower computers to perceive the world for themselves [28]. IoT Cloud In order to provide convenient and timely access to ECG data for users, both the HTTP and MQTT servers are deployed in the AWS IoT cloud. AWS IoT is a managed cloud platform that lets connected devices easily and securely interacts with cloud applications and other devices. AWS IoT can support billions of devices and trillions of messages, and can process and route those messages to AWS endpoints and to other devices reliably and securely. With AWS IoT, ECG monitoring system can keep track of and communicate with doctors all the time, even when they aren't connected.

II. ARCHITECTURE OF IOT-BASED ECG MONITORING SYSTEM

Figure 1 illustrates the architecture of the IoT-based ECG monitoring system. It mainly consists of three parts, i.e., the ECG sensing network, IoT cloud and GUI.

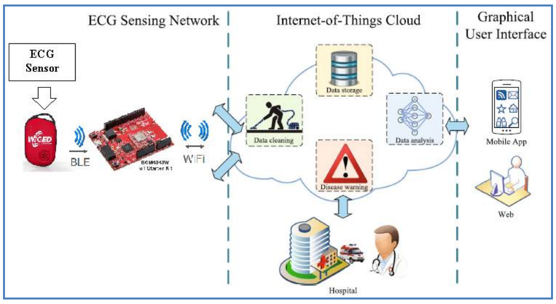

Fig. 1 Architecture of the IoT-based ECG monitoring system.

A. ECG Sensing Network: The ECG sensing network is the heart of the entire system, which is responsible for collecting physiological data from the body surface and transmitting these data to the IoT cloud through a wireless channel. Wearable ECG sensors are used so that it will have little impact on the user's daily life. ECG data can be recorded over long hours or even days using these sensors. Then, the ECG signals are processed through a series of amplification and filtering processes to improve the signal quality and to meet the requirements of wireless transmission.

The ECG data gathered from sensors are transmitted to the IoT cloud via a Bluetooth, Zigbee or Wi-Fi [16]. All the three protocols can provide sufficient data rates for transmitting ECG signals with satisfying power consumption. Due to the limited communications ranges of Bluetooth and Zigbee, a smart terminal (such as Avnet BCM4343W IoT Kit) is usually needed to receive the ECG data and then send the data to the IoT cloud through the Wi-Fi.

B. IOT Cloud: IoT establish bridge between the 'Digital world (Internet)' and the 'Real world (physical device)'. The devices objects are connected to the cloud and create unique identification over the internet. As shown in figure 2, IoT is basically categorized into 6 major layers. They are,

- Smart devices and Controllers
- Connectivity and protocol Communication
- Cloud Server and
- Data Storage and Accumulation

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- ❖ Data analysis and Computing
- ❖ User Application and Report Generation.

In IoT, the 'things' have memory shortage, processing power constraints and also battery consumption issues, which are all critical concerns for mobile devices. Therefore, most of the processing is pushed to the server side, which is following a centralized design. Due to the development of advanced IoT techniques, ECG data can be stored and analyzed effectively and efficiently on the cloud [17].

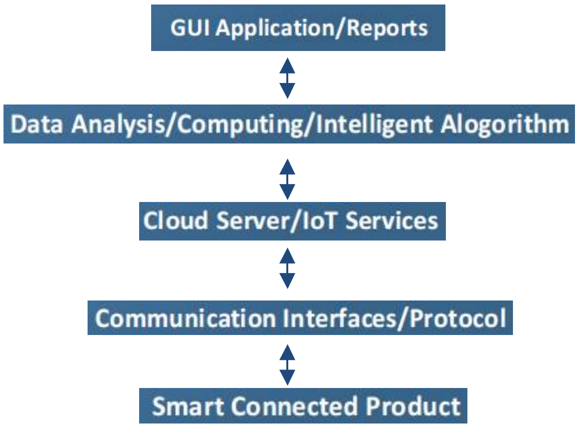

Figure 2: IoT Building Blocks

In general, ECG monitoring system developed using IOT consists of four important modules, i.e., data gathering and filtering, data storage, data analysis, Abnormality warning.

1) *Data gathering and filtering:* There are different features that can be extracted from ECG signals so as to detect potential heart diseases. However, during the processes of ECG data collection and transmission, noise may be introduced into the ECG signal, which would result in erratic data. To overcome this filters digital filters are used to eliminate noise in the data [18].

2) *Data storage and Analysis:* Historical ECG data plays a vital role in the diagnosis of heart diseases. Thus, data are needed to be stored in the database for further study and analysis. The ECG data is digitized first and stored in timely manner. IoT cloud often provides a data analysis platform to extract useful information from the ECG signal [19]. Specific data mining or machine learning approaches can be applied to these data. For example, after extracting the significant features of the ECG signal, a support vector machine can be established to diagnose certain heart diseases [20, 21, 22].

3) *Abnormality warning:* Sudden heart attacks seriously threaten the lives of cardiac patients, especially when patients are alone. Therefore, disease warning on the IoT cloud has become important for protecting patients from being injured. Based on the results of data analysis, the IoT cloud is able to understand the real-time health conditions of the patient. In the event of any suspicious readings, the IoT cloud will notify the family of the patient and the doctor in time.

C. GUI: The GUI is responsible for data visualization and management. It provides simple and easy access to the data in the IoT cloud. Users can log onto the cloud to acquire visualized ECG data in real time on mobile or computer system. Generally, two kinds of GUIs are available for users to visualize ECG data, i.e., mobile apps and web pages. A mobile app can provide an immediate response to user input, while web pages are more convenient in terms of maintenance and upgrade.

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Table-1 IoT Device Characteristics

Technology	Bluetooth	Bluetooth Low Energy (BLE)	Wi-Fi	Zigbee	2G-3G
Power Consumption	Low	Low	High	Low	High
Data Rates (Kbps)	700	1000	100000	250	5000
Coverage in Meters	30	7	15	300	Network dependent
Cost to Build IoT	Less	Less	Average	Less	High
IoT Target Application	Data Exchange in Medium distance, with medium scale of data	Fitness Tracking, Health Monitoring	Interface with Internet, IoT Server communication	Automotive product support, Sensor Interface, Home Automation	Interface with Internet, IoT Server communication

III. IoT BASED ECG MONITORING SYSTEM IMPLEMENTATION

Based on the proposed solution “Architecture of IoT-based ECG Monitoring System”, an IoT-based ECG monitoring system is implemented using the advanced techniques of mobile sensing, cloud computing and Web. Details of the monitoring node, IoT cloud and GUI are explained below.

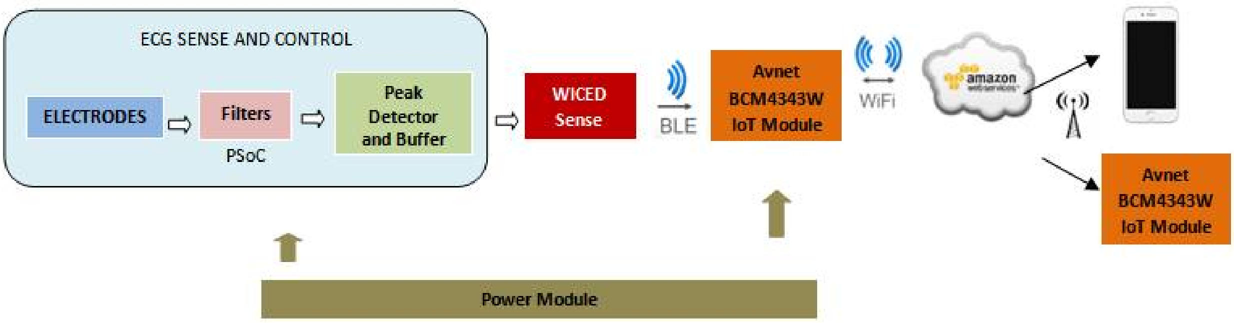

Figure 3: Block diagram IOT based ECG monitoring system

As depicted in Figure 3, the ECG monitoring system mainly includes:

1) ECG Sense and Control node
2) WICED Sense module
3) Avnet IoT module
4) Power module.
5) Cloud and End user

1) *ECG Sense and Control node:* This node is responsible for collecting ECG signal from the human body and then sending the data to WICED sense module. This node is designed using low power Programmable Systems on Chip (PSoC). Following modules are used to design this node. They are,

- ECG electrodes
- Filters

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- Peak Detector and Buffer.

A PSoC is a mixed-signal array low power programmable Systems on Chip (SoC). This allows configuring, programming of analog and digital components that are typically used in embedded systems. It also has a built-in microcontroller which integrates and controls all of the programmed components. PSoC extends its computational capabilities by using mixed signal array, complex computations such as filtering, compression or suppression can be implemented at individual nodes. This affects in reduction of the data throughput over the network. Hence results in reduced transmission time and increased battery life of sensor node.

Adhesive electrodes cannot be used for long term ECG monitoring. Nodes with non contact electrodes [23, 24, 25] are preferred for such patients. With the aid of the ECG electrodes and certain peripheral circuit, weak ECG signals can be detected with satisfactory accuracy [26]. ECG monitoring system designed using microcontrollers require external amplification and filter circuits to acquire ECG signal. This external amplification and filtering is done by PSoC analog and digital blocks.

Peak detector is used to detect peak R to R signal between two consecutive ECG waves. Based on this data pulse rate is calculated. If any abnormality is found an alarm signal can be sent to the doctors so that immediate attention can be drawn. The ECG data is buffered and later sent WICED sensor module via USB for further transmission.

2) WICED Sense module: WICED sense kit is built by Broadcom BCM20737 SoC. It supports Bluetooth Low Energy (BLE) with wireless charging. Buffered data from ECG sense and Control node is stored on EEPROM of WICED Sense node via USB-UART (Serial Command Interface).

Bluetooth low energy technology is used to streams the connected devices information to Internet-based services and applications in limited power usage. Bluetooth low energy has significant features in IoT domain compared with other wireless technologies' seamless supports for smart phones and tablets. Bluetooth low energy protocol allows a Bluetooth device to transfer small chunks of data in periodic interval. BLE device is connected with sensors, actuator and other measuring devices which require low power consumption during connectivity.

Bluetooth Smart BLE devices are optimized and operated with small coin battery, device consumes low cost and low power consumption, it is capable of sensor and attenuator information transfer. Bluetooth Smart Ready BLE devices are for low energy with support of Classic mode of Bluetooth operations. Devices like mobile phones, tablets, and computers are used as gateway to pair with BLE devices. Bluetooth low energy uses a Client- Server model. The Client connects and accesses one or several Servers. Client devices operate as e Central role expect to get the sensor information, pass control information and the Server operate as Peripheral role which collects sensor information transit to central, has connected with sensor and attenuators. The gateway typically takes on the Client / Central role. There are four stages for data transactions.

- Scanning
- Advertising
- Initiating
- Connecting

Bluetooth smart device transmit non-connectable advertising packets periodically over the air medium, anyone willing to receive them. Bluetooth Smart Ready Repeatedly scans the preset frequencies to receive any non-connectable advertising packets currently being broadcasted. The WICED sense device is "advertising" when he wants to connect. The Smart Device is scanning for new devices, When the Observer finds a new device it wants to connect to it. Then it initiates a connection and pair it. The advertisement may contain broadcasted data.

WICED sense device pair with smart device and transmit real time data to paired device. Android/IoS based Smart phone has wireless supports like Wi-Fi, Bluetooth, NFC and Develop Application for communicate with WICED sense. Smart devices has Bluetooth capability to pair with WICED sense kit, sends sequence bytes of sensor data. Smart device send initialize configuration and sensor on/off to WICED sense kit. Then Smart device start to receive encoded byte of information from WICED device.

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Smart phone Connect to the IoT Foundation Cloud using Client application which passes URL, Port number and Client ID. The server is identified by client host name, port number and registers itself. Once connection is established with IoT server register with the callback function, notification messages intimates data processing. Sensor messages packetized and published to IoT server. Message payloads are encapsulated with various attributes. Payloads uploaded to IoT server continuously with fixed interval of time. During message transaction disconnect information receives via callback notification.

After receiving the payload information, the IoT server decodes information and display in messages with time information. Messages are different types of event, connection oriented message, published sensor message. Decoded payload data are stored into database for final report generation or, UI application development for end-customer.

3) Avnet BCM4343W IoT Module: This module receives BLE Notifications from WICED sense module. PSoC 4XX8 BLE 4.2 incorporates a Bluetooth Smart subsystem that contains the Physical Layer (PHY) and Link Layer (LL) engines with an embedded AES-128 security engine. The physical layer consists of the digital PHY and the RF transceiver that transmits and receives GFSK packets at 1 Mbps over a 2.4-GHz ISM band, which is compliant with Bluetooth Smart Bluetooth Specification 4.2. The baseband controller is a composite hardware and firmware implementation that supports both master and slave modes. Key protocol elements, such as HCI and link control, are implemented in firmware. Time-critical functional blocks, such as encryption, CRC, data whitening, and access code correlation, are implemented in hardware (in the LL engine). The RF transceiver contains an integrated balun, which provides a single-ended RF port pin to drive a 50-Ω antenna via a matching/filtering network. In the receive direction, this block converts the RF signal from the antenna to a digital bit stream after performing GFSK demodulation. In the transmit direction, this block performs GFSK modulation and then converts a digital baseband signal to a radio frequency before transmitting it to air through the antenna. The some of the important features are highlighted in the block diagram shown in figure 4.

4) *Power Module:* PSoC and Avnet IoT module operates on onboard high capacity 5V to 3.3V regulated supply. It can be powered up using AAA or coin cell battery. Hence PSoC's are designed for low power consumption. The power module provides a reliable power supply to each and every module in the ECG monitoring node. Two power modes are provided for users, i.e., the USB and the lithium battery. This is done due to their long lifetime and high portability.

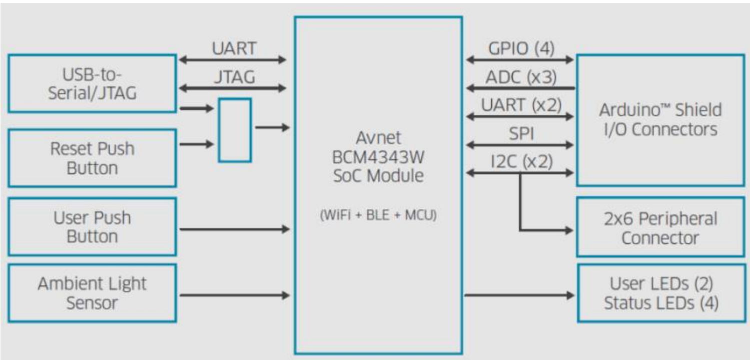

Figure 4: BCM4343W IOT starter kit block diagram

5) Cloud and End user: Android application connects to IoT Foundation server. MQTT library provides Message Queue, MQTT services, Telemetry Transport and light weight messaging protocol. MQTT client open source libraries support for different platforms, like C, C++, Java, JavaScript, and Ruby. Android application do IoT service configuration and registration as MQTT device as explained in Reference [29]. The payload message is

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encoded in JSON format and published to IoT server in fixed interval of time. Two event types of information display in server, Device Status and Message are published. Device Status interested on device is connected or disconnected with time information. Message status displays the complete payload message sent by the WICED sense device. Devices tab has device type information, Last Synced details, Message reporting interval and owner of the module.

IV. EXPERIMENTAL SETUP

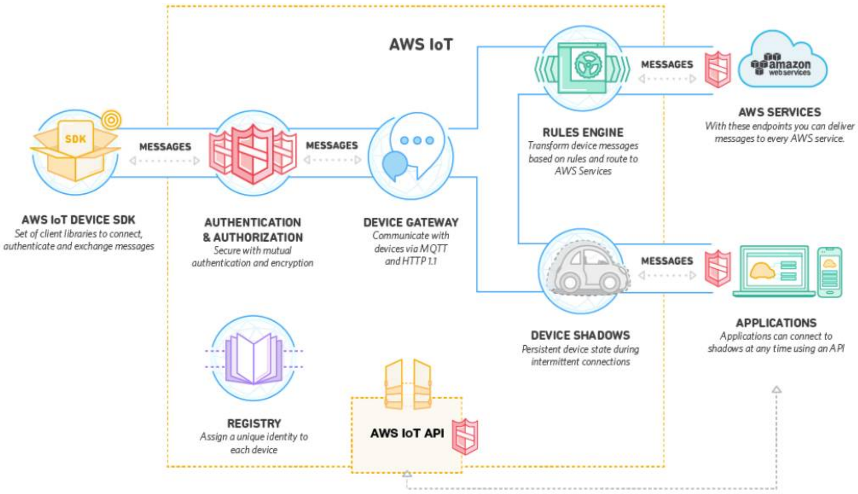

Figure 5: Amazon Web Services (AWS) IOT

A. AWS IoT Service Overview: AWS IoT enables Internet-connected THINGS (apps, sensors, devices, actuators) to easily and securely interact with each other and the cloud. A THING / DEVICE reports the STATE by PUBLISHING messages to a BROKER via TOPICS. A BROKER delivers all received messages to all of the clients SUBSCRIBED to that TOPIC. THING SHADOW is a JSON document located. It is located in the cloud, which is used to store and retrieve current STATE info for a THING. It also provides a persistent record of the physical device. By design this typically has only intermittent connection to the Internet. RULES ENGINE evaluates inbound messages published to AWS IoT. It then transforms and delivers these messages to AWS Services or External Endpoints via AWS SNS and AWS Lambda

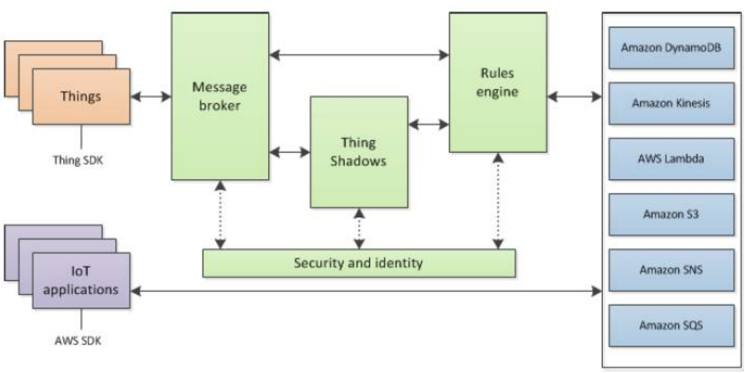

Figure 6: Simplified view of AWS IoT

B. Procedure to set up AWS IoT:

1) At launch of the Shadow App, the Starter Kit software retrieves it's X.509 CERTIFICATE and PRIVATE

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KEY that you previously stored in the MCU's DCT flash memory.

2) Using these credentials it then establishes an authenticated. TLS secured connection with the specified MQTT MESSAGE BROKER.
3) When the USER Pushbutton is pressed on the Starter Kit, - an MQTT protocol message is published to this MQTT.
4) Broker and the SHADOW JSON description of PATIENT1 ECG data is stored and status is indicated by toggling LED (ON or OFF)
5) From the AWS IoT Console webpage, a User edit to the SHADOW record then demos the ability to remotely control the state of the physical PATIENT1 LED on the Starter Kit.
6) From AWS IoT Console set-up a RULE to action the AWS SNS service to send a text message to Doctors cell phone, each time the PATIENTS ECG data is logged on the Starter Kit.
7) From WICED SDK, edit the Shadow app so that sensor data is sent to the cloud each time the PATIENTS ECG data is logged.
8) A template for sampling an I2C sensor (via Pmod interface) and publishing this data to AWS IoT will also be provided.

AWS IoT makes it easy to use AWS services. They are AWS Lambda, Amazon Kinesis, Amazon S3, Amazon Machine Learning, Amazon DynamoDB, Amazon CloudWatch, AWS CloudTrail, and Amazon Elasticsearch Service with built-in Kibana integration. These services are used to build IoT applications that gather, process, analyze and act on data generated by connected devices. These services need not have to manage any infrastructure.

V. RESULTS AND ANALYSIS

ECG signal gets corrupted from sources like electrical interference from surrounding equipment, measurement (or electrode contact) noise, electromyogram noise (muscle contraction), movement artifacts, instrument noise (such as artifacts from the ADC conversion). Thus ECG signal has to be filtered using digital filters. Following filters are used to detect ECG signals.

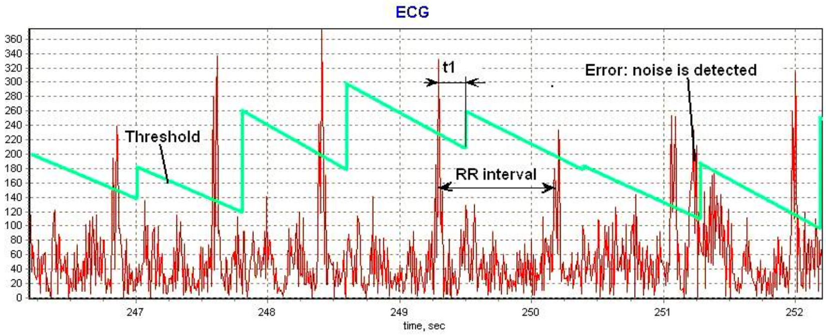

Figure 7: ECG thresholding and noise detection

1) Second order IIR Low Pass Filter: A cascade of three second-order IIR lowpass filters the ADC samples. In general, an IIR filter is represented by equation 1 in which the output signal at a given instant is obtained as a linear combination of I/O signal samples at earlier times. These filters are designed to suppress the 50 and 60-Hz interference. Each has the following transfer function with a cut-off frequency of 25 Hz.

$$H(z) = \frac{0.0625(1+Z^{-2})+0.125z^{-1}}{1-0.75z^{-1}+0.25z^{-2}} \qquad (1)$$

2) Differentiator: The first-order IIR high-pass filter with a cut-off frequency (FC) of 70 Hz determines the first derivative of the ECG signal used for pulse rate calculations. This is represented by equation 2. The derivative picks out the QRS complex from the ECG signal.

$$H(z) = 0.5(1-z^{-1}) \qquad (2)$$

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1- 0.015625z-1

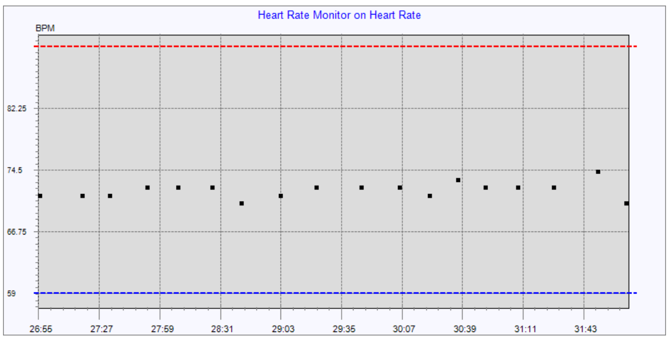
3) Peak Detector: A smart peak detector with automatic threshold adjustment is used to detect R-R peaks. R-R interval is measured. Heart rate is calculated by taking reciprocal of this mean pulse interval value over a fixed period of time of 60 sec and then scaling to units of beats per minute (BPM). This calculated heart rate is made pass through averaging filter. Filter calculates average of last two detected heart rates. This is done to improve accuracy of the system.

4) Threshold adaptive algorithm: Thresholding technique helps in detecting ECG signal. Threshold value increased from low level, till it reaches the desired high level. Whenever ECG signal crosses this threshold value, a QRS complex will be detected.

To reduce the detection of false beats, after every detected QRS complex, the algorithm performs the automatic threshold level adjustment and noise detection in 240 msec, this is shown in Figure 7.

Algorithm works as follows,
Step1-Find maximum absolute value in an interval of t1 = 200 msec after the last detected complex.
Step2 –Update threshold value with 0.75 × max [E], where E is the differentiated ECG.
Step3- Decrease threshold value till it reaches predefined value.
Step4- During interval between 200 msec to 240 msec following last QRS detection, if E becomes greater than threshold value then goto step 5. Else, goto Step1.
Step5- Display “noise” is detected. Increase threshold value, recount current R-R interval. Goto, Step1.

ECG data that is recorded BPM inside PSoC is shown in Figure 8. Table 2 shows the heart rate classification based on the number of Beats Per Minute. This data is sent onto AWS IoT cloud by first sending it onto WICED and later onto IoT board.



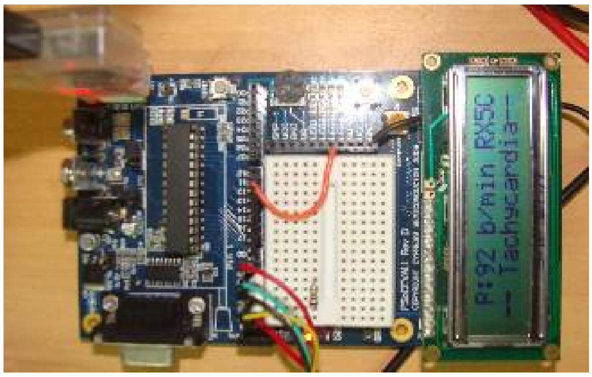


Figure 8: ECG data logging inside PSoC

TABLE 2: HEART RATE CLASSIFICATIONS

Heart Rate	**State**
30-60BPM (default values, adjustable)	Bradycardia
60 -90 BPM (default values, adjustable)	Normal
90-120 BPM (default values, adjustable)	Tachycardia

Calculating R-R interval: To calculate power consumption by the transmitter, we need to calculate minimum and maximum heart rates that are transmitted per minute. R-R interval can be calculated using following formula,

R-R interval in seconds = 60sec/observed heart rate. (3)

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When heart rate is normal, heart rate is never transmitted to the base station. If bradycardia or tachycardia is observed, it is abnormal heart rate. Transmitter will be switched on and transmits heart data of one byte.
Highest heart rate from Table 1 achieved is 120BPM. From equation 3, we can calculate R-R interval as 0.5 Seconds. Meaning, heart rate transmission happens every half a second.

TABLE 3: Key Parameters of the ECG monitoring system

Parameters	Type	Values
ECG Sensor	Output power Output Current	11.393 mW 3.452 mA
Wi-Fi module	Wireless transmission protocols Power voltage Power consumption	IEEE 802.11 b/g/n 3.3 v <46 mA
Bluetooth Low Energy	Power consumption protocol	<16 mA BLE Protocol
Server	CPU Operation system HTTP server Database	Intel Xeon E5-2680V4 Broadwell 2.4 GHz LGA 2011-3 120W Server Processor Ubuntu 12.04 LTS, 64 bit Apache web server with PHP Amazon RDS
Data Sample	Gender Age Height Weight	Male 30 179 cm 75 kg

VI. CONCLUSION

In this work we designed and implemented an ECG monitoring system based on cutting-edge cypress WICED IoT technology. The architecture of the IoT based ECG monitoring system was presented at the beginning. Various ECG sensing networks including Wi-Fi, Bluetooth, Zigbee and BLE were introduced and compared. Based on the proposed architecture, an IoT-based ECG monitoring system was implemented. Through a wearable monitoring node with three electrodes, real-time ECG signals can be collected with satisfactory accuracy. The gathered data were transmitted to the IoT cloud using Wi-Fi, which supports high data rates and wide coverage areas. The IoT cloud is responsible for visualizing the ECG data to users and storing these valuable data for further analysis, which is implemented on the basis of three servers, i.e., the HTTP server, MQTT server, and storage server. Eliminating the need of mobile applications, the web-based GUI provides a versatile means independent of any mobile OS platform for users to access to the ECG data. Further studies on ECG monitoring are still needed in the future. AWS IoT is a new managed service that enables Internet-connected THINGS (apps, sensors, devices, actuators) to easily and securely interact with each other and the cloud.

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