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Internet of Medical Things for Cardiac Monitoring: Paving The Way to 5G Mobile Networks

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Abstract— **Health and medical care are considered as one of the most fascinating applications that can fully benefit from the IoT deployment. In this work, we built a prototype of the Internet of Medical Things (IMedT) for monitoring cardiac activity in the form of phonocardiograph (PCG) signal. The prototype comprises of an agent and a manager. An agent runs a special task to collect heart sound signals and conditioning the signals. A manager, on the other hand, performs some tasks including: (i) gathering signal from some an agent or sensor node, (ii) operated as a web server to make the data available online locally and globally for doctors in order that the data can be accessed anywhere with certain authorization schemes, (iii) it is equipped with ability to do data mirroring to a data center in the cloud system in such a way that the most updated file can be copied to the targeted location to ensure the authorized healthcare providers and doctors anywhere around the globe to get the latest heart sound data for cardiac monitoring and diagnosing. Some issues regarding future development of the IMedT system were presented including smart diagnosis capability, security issues, and extension to the 6LoPAN as well as its compliance to the emerging 5G mobile networks.**

Keywords—Internet of Medical Things (IMedT); Internet of Things (IoT); cardiac monitoring; tele-auscultation; 5G mobile networks

I. Introduction

In one of its white papers, Cisco released an annual report of the Virtual Network Index (VNI) that awakes our imagination about what the Internet will be. According to the paper, we have a quantitative evidence that proliferation of global IP traffic will exchange data that reach the order of Zettabyte (ZB) by 2020 [1]. This massive amount of data will be driven mainly by the number of connected devices to IP networks, such as smartphones, tablets, sensors and Machine to Machine (M2M) applications that are estimated to be more than three times the global population. In this era just about every physical object we see (e.g. cars, machinery, appliances, etc.) will also be connected forming the Internet of Things (IoT).

The IoT offers appropriate solutions for connecting wireless devices to exchange data of a wide range of applications and services that may include traffic monitoring, smart cities, agriculture and forest monitoring, waste management, logistics, industrial control, battle field and health care [2]. Considering the most current development, IoT communications from devices to devices could be enabled by radio access technologies such as cellular communication, wireless LAN and wireless WAN, as well as Bluetooth, Radio Frequency Identification (RFID), Zigbee and Near Field Communication (NFC). To further intensify this ubiquitous connectivity idea and in order to allow seamless integration for various standards, data rate and latency, the ongoing research are now being conducted. Furthermore, the public-private partnership for 5G mobile networks (5G-PPP) has been summoned in Europe to work and evaluate on various 5G standardizations that are expected to accommodate the exponential growth of data rate as a result of billion Internet-connected devices in the future [3].

Health and medical care are considered as one of the most fascinating applications that can fully benefit from the IoT deployment. The IoT that employs various sensor and smart medical devices may serve in, for example, tele-auscultation, remote health monitoring, remote diagnostics and possibly treatment as well as elderly care [4]. The term that refers to the specific utilization of IoT in health care services is Internet of Medical Things (IMedT). The IMedT is expected to reduce consultation and transportation cost and to shrink the gap for those who live in the isolated area where the present of doctors are void. In addition, the IMedT that is equipped with ubiquitous identification, sensing and communication apparatus could be used to monitored and tracked not just only the state of patients health, but also the medication process and its direct effect to the patients. From the perspective of health information management, the IMedT could assist logistics of medicine and manage their entire value chain.

In this work, we built a prototype of the IMedT for monitoring cardiac activity in the form of phonocardiograph (PCG) signal. However, it can be easily substituted with electrocardiograph (ECG) signal by replacing the sensor node. The module is equipped with a single board computer Rasberry Pi 3 as a main data processor for noise removal, presenting the PCG or ECG signal in the web-based media, identifying the heart sound signal components and possibly other signal processing techniques to display a readable and easy diagnostic heart sound signal. With this single board device, despite its powerful processor, it gives advantages of being portable allowing the module to be operated all over the place as long as

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internet connection is available. Further, our prototype is supported with ability to synchronize the data in the local storage to a cloud server makes it available to physician and researchers to access the signal around the clock. Hence, the proposed model in this work reveals a unique design of a mobile device module compared to the previous works [7-12], including utilization of the Raspberry Pi 3 as a web server and its synchronization to a cloud system. The model is still under continuous development. We have a great enthusiasm that in the future this model might be able to comply with 5G mobile networks.

The remaining of the paper is organized as follows. Section 2 elaborates the development of the most current IoT for cardiac monitoring. Sections 3 presents our proposed prototype for capturing, storing and monitoring heart sound signal activities in the form PCG signal. Future research direction will be presented in Section 4. Finally, conclusion will be drawn in the last section of this paper.

II. IMEDT FOR CARDIAC MONITORING

Based on the latest data released by the World Health Organization (WHO) in 2014, deaths caused by cardiovascular disease in 2012 has reached 17.5 million deaths, or 46% of the total number of non-communicable diseases deaths in the world [5]. In addition to that, in another WHO report states that in 2020, it is estimated that the coronary heart disease will be the major killer diseases in countries throughout Asia-Pacific [6]. Based on those facts, there can be seen urgent need for assisted technologies that will be able to counteract or at least to do early detection for the diseases. To anticipate terminal ill (that mostly leads to deaths) initiated by the cardiovascular diseases, real time monitoring and online diagnosis will enable health care providers to immediately detect and deliver proper treatment. Example of the most recent works that had been proposed to utilize the so-called online observation and detection models for cardiac monitoring can be seen in [7-12].

In order to provide reliable services and applications for cardiac monitoring, the following are specific requirements for the system [13,14]: (1) real time and periodic transmission for vital signs such as body temperature, pulse rate/heart rate that might be represented in the form of ECG or PCG signals, respiration rate, and blood pressure to assist healthcare providers and doctors with sophisticated data for analysis, (2) high-speed and secure access to wireless networks that enable real time and periodic transmission, (3) portable, wearable and mobile devices that provide user comfort, (4) intelligent devices that are able to do smart signal processing to offer early diagnostic (prediction) and alert, for example early indication of heart failure.

A typical IMedT cardiac monitoring system comprises of some interconnected components including sensors and signal conditioning, a short range transmission system, a communication gateway, a long range transmission system, data centers and health care providers as displayed in Fig. 1. The term “agent” and “manager” are used in the figure to comply with the existing standard ISO/IEEE 11073 Personal Health Data (PHD). The agent refers to a node that collects and transmits data to its associated manager. On the other hand, the tasks for receiving and collecting data from one or more agent systems and transmits the data to data centers are handled by the manager [15]. Hence, in most cases of cardiac monitoring, one or more sensors as well as clinical devices are attached on agents while providing restricted signal processing before transmitting the signal to the manager through a short range transmission system like USB, Bluetooth, Bluetooth low energy and Zigbee.

The manager is meant to be a multi-protocol device to support for the ubiquitous data collection and global access for the IMedT system. In addition to that, a manager also performs as a gateway for the system to facilitate the transmission of data into the back-end services in the form of storage and data center that might be resided somewhere in the Internet cloud through a long range communication system. An examples of works that clearly explores in detail about integration of information infrastructure and protocols for guaranteeing a pervasive personalized healthcare can be seen in [16].

In terms of future development, the current IMedT system necessitates to adapt with advancement of telecommunication technology and to meet with the standard of the 5G networks which will be expected to provide higher data rate, data bandwidth and fewer latency than the previous generations (3G and 4G). Major characteristics of 5G network may include improved connectivity, cloud-based storage and inter-connected devices and services in order create pervasive IMedT systems [17].

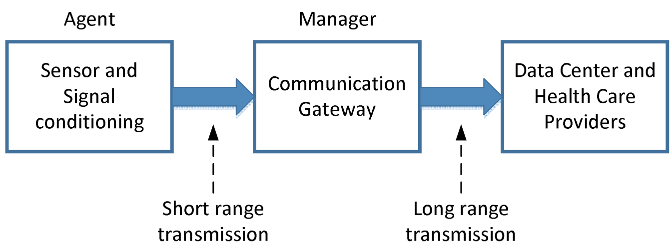

Fig. 1. Typical IMedT for cardiac monitoring system.

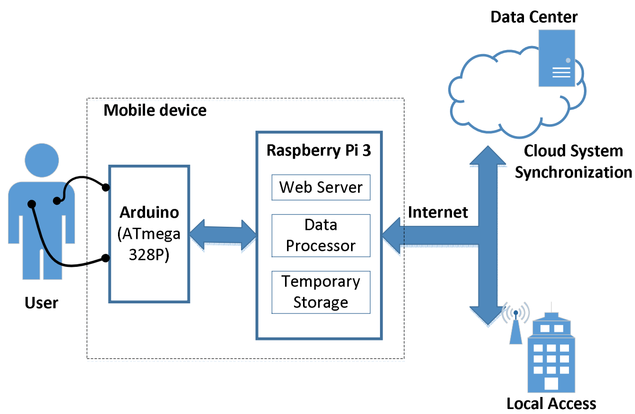

Fig. 2. Block diagram of the IMedT prototype.

III. IMEDT PROTOTYPE FOR CARDIAC MONITORING

We developed an IMedT prototype for storing, processing and monitoring PCG heart sound signal, which comprises of an agent and a manager components. See diagram block of the system that is presented in Fig 2. The goal of this work is to construct an IMedT device that emphasizes on the portability and mobile connectivity around patient's environment and at the same time provides ability to synchronize the heart sound signals data between the local (temporary) storage and the data center at somewhere in the cloud system. Mobility is considered as one of major advantages of IMedT for ubiquitous healthcare solutions. Hence, the work also refers to the terms that are widely used in many literatures, the pervasive cardiac monitoring system.

An agent or a sensor node was built on top of an Arduino microcontroller board that based on ATmega328P. The Arduino microcontroller was chosen to support integration and adaptation of heart sound signal from the cardiac sensors to the manager. It has 14 digital input/output pins (of which 6 pins can be used as pulse-width modulation outputs), 6 analog inputs, 1 UART (the hardware serial ports), a 16 MHz crystal oscillator, 32 KB flash memory, 2 KB SRAM, 1 KB EEPROM, a USB connection, a power jack, an ICSP header, and a reset button. The analog inputs of the Arduino board are operated at voltage of 5V. Each of the analog inputs provide 10 bits of resolution that represents 1024 different values of the digital forms of the signal. In order to accommodate its mobile connectivity, the Arduino can be equipped with one or more Arduino shields to support short range communications using technologies such as Bluetooth, Zigbee or Wifi. In this work, we employed both USB and Bluetooth for short range communications to guarantee the flexibility of the mobile device. The USB connection can be used where the sensor node is in the very close distance from the manager, i.e. both of the sensor node and the manager are situated in the vicinity of users. On the other hand, the Bluetooth connection can be deployed for example in the environment where some sensor nodes, hence there are some patients, are needed to be connected to the manager with maximum distance of 100 meters. This is the theoretical maximum distance that can be attained by Bluetooth technology.

The manager in this work was built utilizing a tiny computer the so called Raspberry Pi version 3 Model B. It is a credit-card sized single board computer. Despite its small size, the Raspberry Pi version 3 capable of doing just about anything a desktop PC does. It has a 1.2GHz 64-bit quad-core ARMv8 CPU, 1GB RAM and a micro SD card slot for loading operating system and storing data. For connectivity support, the Raspberry Pi version 3 added the 802.11 Wireless LAN, Bluetooth 4.1, Bluetooth Low Energy, 4 USB ports and an Ethernet port. With all of its apparatus attach on board, the Raspberry Pi has advantages of having small power consumption of about one tenth of what comparable full size PC box can draw. It also has no noise operation that will benefit its deployment close to user's environment. Furthermore, the Raspberry Pi does not require a heatsink as the chip used in the Raspberry Pi is equivalent that is used in a mobile phone. It is guaranteed that it should not become hot enough to need any special cooling.

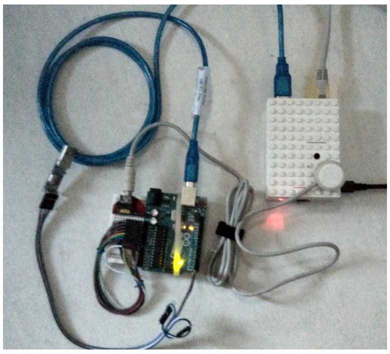

Fig. 3. A set of a sensor node comprises of a Raspberry Pi as a manager and an agent equipped with a heart sound sensor.

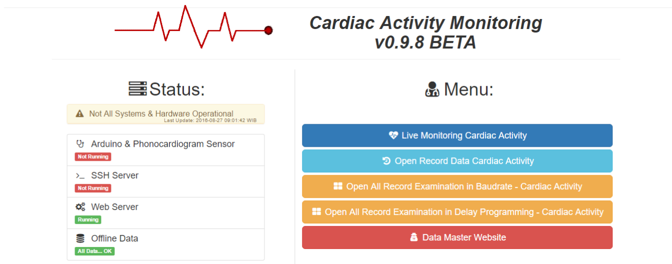

Fig. 4. Cardiac activity monitoring interface.

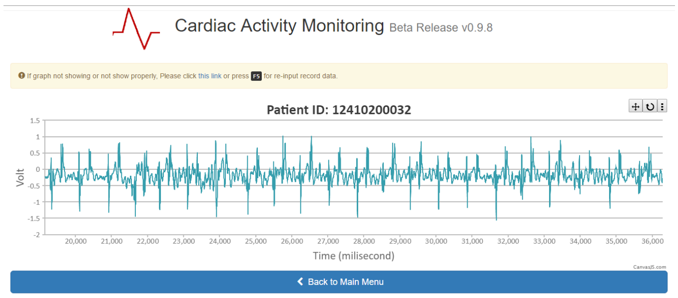

Fig. 5. An example of a page showing PCG activities for a certain user.

In addition to that, the Raspberry Pi that is enclosed in a case, with a palm-sized box, is suitable for mobile activities such as recording PCG signal for some patients in different rooms in one medical facility or patients in remote areas where conveying heavy electrical and medical equipment can be troublesome. A set of our developed sensor node comprises of a Raspberry Pi as a manager and an agent equipped with a heart sound sensor is shown in Fig. 3.

Besides gathering signal from some sensor nodes, the Raspberry Pi has been operated as a web server to make the data available online for doctors and can be accessed anywhere with certain authorization schemes. The cardiac activity monitoring web-based interface is displayed in Fig. 4, while an example of a page showing a PCG activities for a certain user can be seen in Fig. 5. The graph shows that for privacy purposes the user is only identified by its user ID.

The web server can also be accessed locally, for example in a local area network. It is commonly known that the subjectivity due to the physical proximity can affect the interpretation of the diagnosis of heart disease. It can lead to biased heart disease diagnosis, this is primarily due to exposure of patient chest area during the process of measurement. One solution to cope with this problem can be done by allocating doctors and patients in separate rooms. Such a process is known as remote auscultation (tele-auscultation). Hence, the advantages of accessing web server locally can be exercised in such kind of environment.

Our developed manager in this project is equipped with ability to do data mirroring to a data center in the cloud. In this way, the most updated file can be copied to the targeted location to ensure the authorized healthcare providers and doctors anywhere around the globe to get the latest heart sound data.

The most intriguing functionality of the Raspberry Pi in the future is the ability for the manager to do signal processing before the heart sound data resided both in the local storage and in the cloud. Unlike some other mobile devices that only inherit limited computation power, the Raspberry Pi has enough processor speed and memory to perform some signal processing algorithm, such as heart sound signals denoising and feature extraction to support the heart sound signal interpretation. This feature will benefit greatly for the adaptation of the developed IMedT system to the emerging 5G mobile networks, where it requires that high-level computation should be diffused throughout the mobile devices.

IV. Performance Evaluation

In this part we aim to examine the performance of the mobile device box in Fig. 2, i.e. communication between the microcontroller unit and the Raspberry in terms of sampling frequency, baud rate, throughput and bandwidth utilization. Both the sampling frequency and the baud rate are the setting parameters, while both the throughput and the bandwidth utilization are the measured parameters. Bandwidth utilization is defined as comparison between throughput and maximum set up baud rate of a communication channel between the microcontroller unit and the Raspberry.

In this work, we took some PCG signals from seven different people that were categorized to have normal heart sound, each of them was obtained for the duration of 120 seconds. Then we repeated the same procedure for different sampling frequencies and baud rates.

TABLE I. Averaged Throughput and Bandwidth Utilization for Various Baudrates with a Fixed Sampling Frequency at 500 Hz

Baudrate (bps)	Throughput (bps)	Bandwidth Utilization (%)
19,200	15,777.50	82.17
38,400	31,531.86	82.11
57,600	36,077.90	62.64
115,200	35.694.80	30.98

TABLE II. Averaged Throughput and Bandwidth Utilization for Various Sampling Frequencies with a Fixed Baudrate at 115200bps

Sampling Frequency (Hz)	Throughput (bps)	Bandwidth Utilization (%)
1,000	23,295	20.22
500	15,567	13.50
333	11,680	10.14

Table 1 shows that increment of the baud rate approximately twice does not significantly help to increase the averaged throughput of the channel. In fact, the throughput starts to decrease when the baud rate was set to 115,200 bps. As a result, the increment of the baud rate of the communication channel shrinkages the averaged bandwidth utilization. This detrimental behavior of the system performance is probably affected by internal inefficiency of the MCU and its inability to produce high throughput along with the increment of the baud rate. We can see from Table 1 that the most optimum throughput and bandwidth utilization can be achieved at baud rate 38,400 bps. Based on the examination in Table 1, it can be concluded that selecting the most suitable MCU module as well as constructing the most efficient algorithm for processing heart sound signal from the sensor are the most important part in designing the mobile device in order to produce the most optimum system performance.

On the other hand, investigation on Table II reveals that increasing the sampling frequency of the signal can help to leverage the averaged throughput and the averaged bandwidth utilization. Similar observation and results can be seen in [7]. Therefore, it should be noted that enhancement on the averaged throughput and the averaged bandwidth utilization in the mobile device can be achieved by increasing the sampling frequency of the MCU. However, in the design of the IMedT realm, increment of the sampling frequency should be taken carefully as it may increase the power consumption of the mobile device.

V. Future Directions

For future directions there are some issues that need to be addressed to make the IMedT prototype to be fully ready to deploy. We list some of them that are part of the development of the project as follows:

1) *Smart diagnosis capability.* Advancement in diagnostics is an important capability for the IMedT to track vital signs and electronically transmit the information to the healthcare providers and doctors. The IMedT system should be able to provide smart decision support and early warning that help doctors to detect possible problems and deliver medical care in proactive manner.

2) *Security issues.* Heart sound signals are close related to patient's privacy. Therefore, it is necessary for the whole system, all the way from sensor nodes to the data center to be well protected from any intruders for interfering the system. Furthermore, analytics platforms in the cloud that integrate patient information from

variety organization also require strong privacy protection and suitable authorization algorithms.

3) *Deployment using IPv6 protocol*. The IMedT prototype should consider capabilities presented by future Internet with IPv6 protocol. Specifically we should consider extension of the IPv6 over Low Power Wireless Personal Area Network (6LoPAN) protocol to our small devices. The 6LoPAN offers advantages such as ability to transmit data directly without user interactions. This feature will benefit elderly patients who are not accustomed with new technologies.

4) *5G compliant*. Development of mobile network technology to the 5G networks is on its way. Technologies that are deployed based on cellular communication, wireless LAN WiFi and wireless PAN Bluetooth will enable IMedT communications across users and it is envisaged that in the future 5G will become the network that connect all these devices [18]. Hence, it is important for the IMedT system to be compliant with the development of the 5G mobile networks.

VI. Conclusions

In this work we built an Internet of Medical Things (IMedT) system for cardiac monitoring in the form of PCG heart sound signals. The proposed model offers a unique design of a mobile device module compared to the previous works. The prototype of the system comprises of an agent and a manager components. An agent or a sensor node was built on top of an Arduino microcontroller board that based on ATmega328P and a manager was built utilizing a tiny computer the so called Raspberry Pi version 3 Model B. Besides gathering signal from some sensor nodes, the manager has been operated as a web server to make the data available online locally or globally for doctors and can be accessed anywhere with certain authorization schemes. The manager in this project is also equipped with ability to do data mirroring to a data center in the cloud in such a way that the most updated file can be copied to the targeted location to ensure the authorized healthcare providers and doctors anywhere around the globe to get the latest heart sound data.

Performance evaluation on the mobile device module shows that selecting the most suitable MCU module as well as constructing the most efficient algorithm for processing heart sound signal from the sensor are considered the most important phase in designing the mobile device module. It should also be noted that enhancement on the averaged throughput and the averaged bandwidth utilization in the mobile device can be achieved by increasing the sampling frequency of the MCU.

Furthermore, some issues regarding future development of the IMedT system were presented including smart diagnosis capability, security issues, and extension to the 6LoPAN as well as its compliance to the emerging 5G mobile networks.

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