Miniaturized and Wearable Electrocardiogram (ECG) Device with Wireless Transmission

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***Abstract*—ECG Holter is a device used to acquire and monitor the user heart rhythm. However, it is available only in a major healthcare facility as it is very costly. The objective of this work is to develop a portable ECG monitoring device with wireless transmission for early arrhythmia detection and personal monitoring. The heart of the device is based on Atmel ATmega328p processor, which acquires user ECG data through Analog Devices AD8232 ECG analog front-end chip. Data captured is stored offline in memory card before it is transmitted wirelessly to a cloud server for analysis purpose. Experiments indicate that the device able to sample the ECG data up to 1000 samples per second and Wi-Fi based transmission serves the best for data transfer to the cloud server. User and physician can easily access the data for viewing and analysis, eliminating the needs for users to travel to the hospital for ECG acquisition.**

***Index Terms*—ECG Monitoring; Holter; Wearable; Wireless Transmission.**

I. INTRODUCTION

Cardiovascular disease (CVD) is described as a disease of the heart or blood vessel and is the leading cause of death globally [1]. Government hospitals mortality rate report indicates that there is an increase in death cause by heart related problems and expected to continue in the next decade. There are many symptoms of CVD, including chest pain and irregular heart rhythms. In order to assess and diagnose cardiovascular problems, electrocardiogram (ECG) data are captured and analyzed. However, ECG data interpretation is highly dependent on trained experts and highly specialized medical instrument, hampering early detection and treatment. Moreover, current ECG recording and monitoring devices are very expensive with limited availability and accessibility. Existing portable Holter monitoring systems and cardiac event recorder requires ECG electrodes to be connected to the recording units with a cable which is prone to be heavily affected by noise especially due to user movement. Additionally, current industry guideline for ECG monitoring systems, the event recorder, on numerous occasions fails to identify critical cardiac arrhythmias, which results in a wasted chance for therapeutic intervention for patients that are at risk of stroke and sudden cardiac fatality [2]. Thus, there is a great need for an affordable and easily available device for the masses, capable of providing ECG monitoring and analysis [3]. With the advancement of mobile health (mHealth) technology, this can be made possible.

II. LITERATURE REVIEW

Many technologies and diagnostic tools have been developed to assist medical practitioners in diagnosis of CVD such as electrocardiogram (ECG) machine, Holter, cardiac event monitor and loop recorder [3]. Nonetheless, these medical instruments are available only in large hospitals and inaccessible to people who live in the rural area. ECG Holter is a portable heart rhythm monitoring device that used to capture and record user heart rhythm while they conduct their daily routines. It is capable of monitoring the wearer’s heart rhythm continuously for more than 24 hours [3]. Electrodes are attached to the patient’s chest when monitoring their heart rhythm using ECG Holter. Then, the ECG data is captured, recorded, and stored in the built-in memory of the device or cassette for further diagnosis. However, the memory spaces are limited, so the patient has to replace it with a new one or transfer the data via fixed telephone line to clear the storage whenever it is full. Furthermore, the patient also needs to report their data to the cardiologist, which could be troublesome and inconvenient for people that do not have the time or mean of transportation. Figure 1 shows an example of a twelve leads ECG machine commonly used in hospitals.

Figure 1: 12-Lead ECG machine

Commercially available Holters in the market include Omron HCG-801 Portable ECG Monitor [4], SEER T [5], DL 800 Braemar [6] and many others. Most Holters are considerably heavy and may become a burden to the patients having to carry this load on their neck or around their waist for days. Moreover, ECG Holter is very expensive, thus patients typically rent the unit from hospitals. However, there is a limited quantity available and not all hospitals provide this service. Patients who get hold of a unit could only rent them for limited time and may have to pay rental fee to the hospitals. For example, in Institut Jantung Negara Malaysia, the rental fee is rated between RM 200 to RM 300 per day per unit. Patients that could not rent the device cannot be properly diagnosed. Nevertheless, patients who managed to get an access to the unit may not be successful in detecting or recording the symptoms during the rental period as cardiac events occur unpredictably. By owning a personal unit of ECG recording device, it is not only more hygienic but patients can record symptoms anytime they felt it to obtain a more accurate diagnosis. Most importantly, more people can be screened early and precautionary measures can be taken.

There are several researches for portable ECG recording system. A wireless ECG monitoring system based on novel 3-Lead electrode placements have been developed by Wang *et al.* [7]. The wearable device detects, amplify, filter and transmit the ECG data wirelessly to the PC through the integrated data coordinator. Then, the signals are displayed on the GUI. The system has been evaluated under user in motion, such as walking and running and the results show that a promising performance is achieved even under body motion. Cao developed a three-pad ECG system [8]. Three sensor nodes were worn around the heart to detect the signals from three dimensions, which were transmitted respectively to PC by using ZigBee. 12-lead signals were reconstructed from the 3 dimension signals which are completely based on the wireless system. However, time synchronization was really complex and requires lots of effort. Furthermore, work done by both Wang and Cao respectively sends the data to a PC which is not a portable device compared to mobile phone and consumes lots of power.

Mahmud *et al*. [9] has introduced and developed a low cost and ultra-low power system for measuring ECG and heart rate both in contact and contactless manners. The prototype uses dry electrodes based on Electric Potential Integrated Circuit (EPIC) PS25000 sensor to measure ECG data that converts variable capacitance into voltage. Other than that, another prototype based on EAITRCA8 infrared sensor also has been tested. The sensor claimed to be usable with pants and diapers for infants. Both sensors are interfaced with an Arduino microcontroller which then transmits the collected data via and RF transceiver module NRF24L01+. The central processing unit is based on Arduino Nano coupled with NRF24L01+ as the data receiver. Results show that the device was able to measure user ECG data successfully using the infrared sensor module attached to fingertip, ear, lower belly, wrist and forehead. Whereas, the EPIC sensor based system shows a noisy ECG data. In terms of power consumption in miliampere, the device uses 46.95mA in operating mode while 15mA in hibernation mode. However, the system does not have internet connection and central server for data storage, hence provide difficulties for physician to access the data.

Wang *et al.* [10] proposed a solution for long-term ECG monitoring by introducing a wearable mobile electrocardiogram system. The device was integrated with dry foam electrodes and the ECG acquisition module was designed for long-term ECG monitoring in daily life. The developed ECG acquisition module is small in size with wireless capability that has low power consumption. However, the overall system has a drawback that it has to use large capacity battery in order to maintain long time monitoring. Figure 2 shows the device overview developed by Wang.

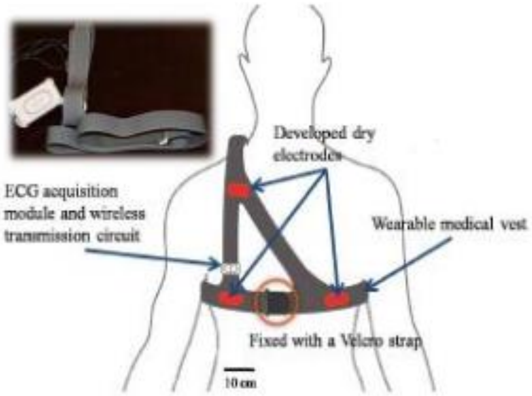

Figure 2: Wang's device overview [9].

III. HARDWARE OVERVIEW

Figure 3 shows the block diagram of the portable ECG monitor developed, mainly includes the following three parts: analog front-end, microcontroller, storage and timestamp, and transmission module.

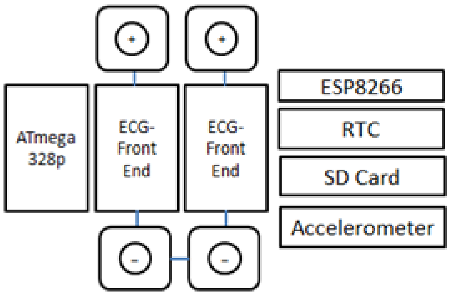

Figure 3: Device hardware component

A. Analog front-end

AD8232 is a single-channel analog front-end for ECG which designed to acquire, amplify, and filter small biopotential signals in the presence of noise either created by motion or remote electrode placement. It also can implement a two-pole high-pass filter for eliminating motion artifacts and electrode half-cell potential. AD8232 is much smaller in term of size with lower power consumption than discrete component. Furthermore, as the communication between the chip and microcontroller is through ADC, it reduces the complexity and CPU cycle needed compared to the other analog front-end which usually I2C or SPI interfaced that consumes a huge amount of CPU cycle. This project employs two AD8232 modules to acquire Lead-1 and Lead-2 ECG of the user heart structure. Lead-3 is derivate from the two lead difference. Thus, the developed ECG device is able to give three different views of the user heart rhythm.

B. Microprocessor

ATmega328p is a high-performance 8-bit microcontroller that combines 32KB ISP flash memory with read-while-write capabilities, 1KB EEPROM, 2KB SRAM, three flexible timer, 6-channel 10-bit ADC converter and five software selectable power saving modes. It has low power consumption and operates between 1.8 to 5.5 volts. The output of the two AD8232 modules is directly feed into the ADC channel of the microcontroller and sampled with 10-bits resolution.

C. Storage, timestamp, power supply

The developed ECG device utilized micro-SD breakout for data storage purpose which interfaced with the ATmega328p through a serial peripheral interface (SPI) communication protocol. Real-time clock module is employed to keep track of the current time and date the ECG data are acquired. The ECG device operates between 3.7 to 5 volts and powered by li-po battery.

D. Transmission module

The ESP8266-12E microcontroller is used to transfer the data from the SD storage to the cloud server through Wi-Fi connection. The processor is an 80 MHz microcontroller with full Wi-Fi front-end and TCP/IP stack with DNS support. It has 4MB flash chip and onboard antenna. The SD breakout module is interfaced through SPI communication to the ESP8266-12E module.

IV. WIRELESS TRANSMISSION COMPARISON

Experiments on three types of wireless protocol radio frequency (RF), Bluetooth, and Wi-Fi have been done in order to investigate the reliability in terms of data transfer. Setup of the experiment as of Figure 4:

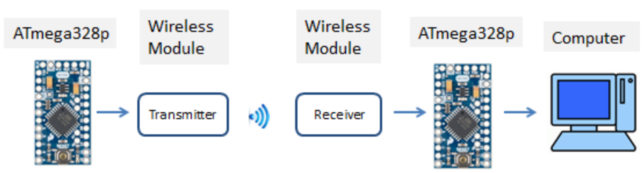

Figure 4: Experiment setup

A pair of each of the wireless module was connected to a microcontroller in which one module set to be the transmitter while the other as a receiver. A sample file programmed on the ATmega328p was streamed from the transmitter to the receiver side which connected to a computer to analyze the data received. Table 1 shows the similarity percentage of the data received on the computer compared to the actual data.

Table 1
Wireless protocol transmission reliability

Protocol	RF (NRF2l01+)	Bluetooth (HC-05)	Wi-Fi (ES8266-12E)
Packet received (%)	95.04	100	100

According to Table 1, Bluetooth and Wi-Fi protocol able to send the data without packet loss meanwhile, RF has packet loss during the transmission of the file. It shows that data transmission reliability through RF is unstable, whereas Bluetooth and Wi-Fi have good transmission reliability. Table 2 shows the comparison between the three wireless protocols: radio frequency (RF), Bluetooth, and Wi-Fi.

Table 2
Wireless protocol comparison

Protocol / Characteristic	RF	Bluetooth	Wi-Fi
Bandwidth (KB/s)	20 – 250	720	11,000+
Transmission Range (meter)	1 – 100+	1 - 10	1 - 100
Success Metrics	Power, Cost	Cost, Convenience	Speed, Flexibility

From the table, Wi-Fi has the highest bandwidth than the other two protocols. ECG data acquired and stored in ECG device are large in size, thus, Wi-Fi suit the needs of large data transfer in the shortest amount of time possible. In terms of connection range, Wi-Fi is superior compared to the other protocol as it can transfer data up to 100 meter distance. Experiment on the three types of wireless protocol indicates that Wi-Fi suit the application of ECG data transfer better than Bluetooth and RF in terms of transmission reliability. Hence, ESP8266-12E has been employed in the developed ECG device.

V. SYSTEM PIPELINE

Figure 5 shows the system pipeline for the ECG acquisition, which begin with ECG acquisition and end with the ECG analysis on the cloud followed by result displayed in a user's smartphone.

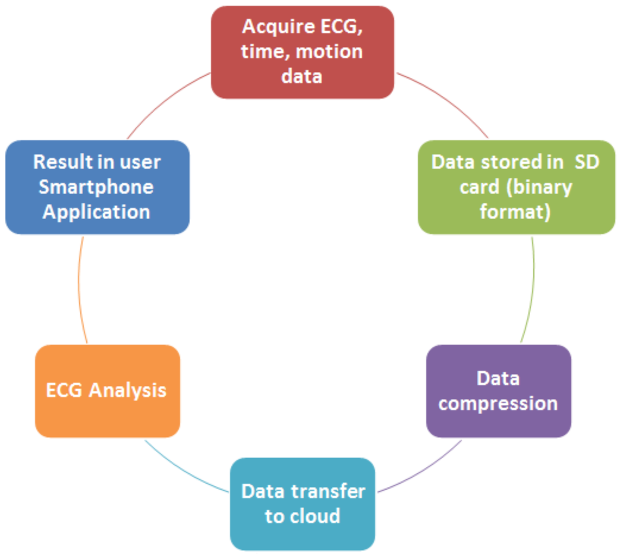

Figure 5: System pipeline

Firstly, user ECG data is acquired through the developed device. Current time and date of the ECG acquired are stored together with the ECG captured into the SD card in binary format. Compression is then performed to the binary file to reduce the file size. Next, the user decides whenever to transfer the data from the SD card to the cloud by connecting to a Wi-Fi Hotspot with a data connectivity. Data received in the cloud are processed and analyzed for abnormalities. Physician and the user are grant access to the data bank. The analysis result displayed to the user through a smartphone application.

VI. TEST AND RESULT

Figure 6 shows the prototype of the developed wireless ECG device. The developed portable device has been tested with a user by setting the parameter as of the following: 1000 Hz sampling rate, and 30 minutes ECG recording with user seated in relax position. Figure 7 shows the lead configuration attached to the user body while Figure 8 illustrates the resultant ECG data acquired.

Based on the result, the user ECG data has been successfully acquired, recorded and transferred to the local server through Wi-Fi connection. Figure 9 shows the ideal waveform for respective ECG leads [11]. Based on observation and comparison of the P, Q, R, S and T wave of the acquired ECG and ideal ECG waveform, the characteristic are similar for the respective leads. There is a slight distortion that could result from the different electrode lead placement and use of different test subject. Lead 3 Derivate (difference between Lead-2 and Lead-1) shows similarities in terms of waveform pattern with the actual Lead-3 acquired however, the amplitude were shifted. Experiments also show that the stability of the developed ECG device was good; it is usable for long-term ECG monitoring.

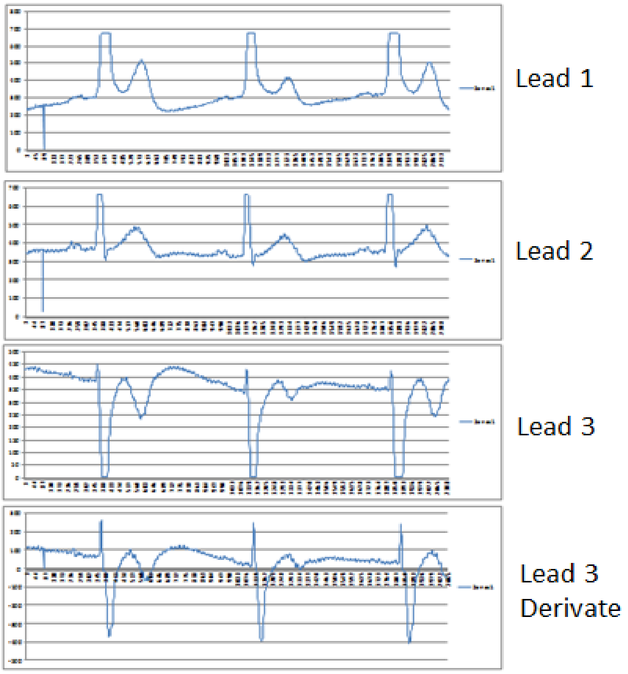

Figure 8: ECG data recorded

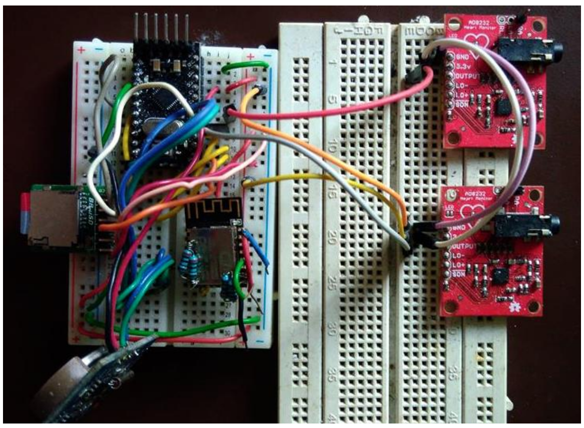

Figure 6: Wireless ECG device prototype

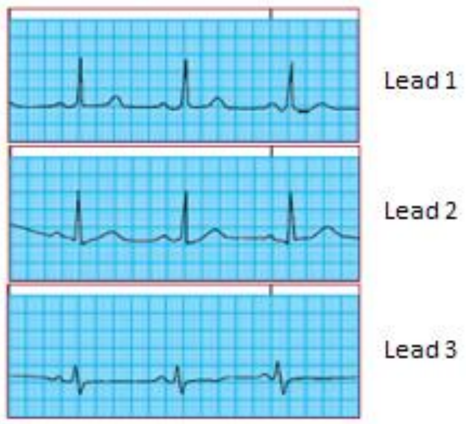

Figure 9: Ideal ECG waveform

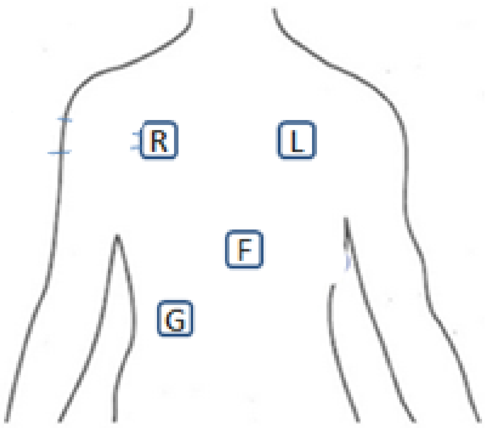

Figure 7: Lead configuration (R: Right Arm, L: Left Arm, F: Right Leg, G: Ground)

VII. CONCLUSION

The designed wireless ECG monitoring device has the advantage over non-wireless device due to its higher data analysis frequency which can result in early arrhythmia detection. It also tackles the limitation of the current Holter device in terms of portability and accessibility. The total cost for developing the device prototype is less than RM 300 which is affordable. It is hoped that the cloud platform implementation with the ECG data processing capability ensures that effective healthcare can be delivered to a large segment of the population including the rural areas.

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