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An Automatic Wearable Electrocardiographic System

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Abstract: The proliferation and popularity of open source hardware and software has brought the health industry to rapid evolution, creating portable and low-cost medical devices for monitoring vital signals.

Recent technological advances in wireless communications and wireless sensor networks have enabled the design of low-cost, intelligent, tiny, and lightweight medical sensor nodes that can be strategically placed on human body, create a wireless body area network (WBAN) to monitor various physiological vital signs for a long period of time and providing real-time feedback to the user and medical staff.

Electrocardiographic (ECG) equipment plays a vital role for diagnosis of cardiac disease, but the cost of this equipment is huge and the operation is too much complex which cannot offer better services to a large population in developing countries. In this paper, I have designed and implemented a low cost fully portable and wearable ECG monitoring system based on Arduino platform; medical sensors were used to collect physiological data from patients and transmit it to Android smart phone using Bluetooth standard. I introduced priority scheduling and data compression into the system to increase transmission rate of physiological critical signals which improve the bandwidth utilization. The purpose it was to create a mobile and wearable device for remote teleassistance. The results obtained by the device were tested comparing them with those obtained from a traditional ECG used in clinical practice on 85 people.

Keywords: Tele health and Remote Monitoring, Innovative eHealth, Electrocardiographic system, Cardiovascular disease, Wireless Sensor Networks.

I. INTRODUCTION

The Cardiovascular diseases (CVDs) are disorders of the heart and blood vessels and include different disease like: coronary heart, cerebrovascular, rheumatic heart etc.. World Health Organization (WHO) research showed that the most people was dying due to heart illness[1]. Therefore, this disease cannot be taken lightly and need for monitoring systems[2]. The Electrocardiography (ECG or EKG) is one of the most popular medical kits that can measure the heartbeat per unit time[2]. An ECG is a recording of the electrical activity on the body surface generated by the heart muscles, and it is one of the most common heart tests[3]. There are a number of reasons why someone may have an ECG, including an irregular heartbeat, shortness of breath when they exert themselves, significantly high blood pressure, palpitations or a suspected heart valve problem [4]. It can also be an useful way of ruling out problems. It is the best way to monitor and diagnose abnormal rhythms of the heart muscles caused by damage to the conductive tissue that carries electrical signals. It is possible to be in cardiac arrest with a normal ECG signal (a condition known as pulseless electrical activity)[5]. Only Analyzing and monitoring the ECG signal at initial stage, the hearth disease can be prevented [2]. ECG is an high-priced equipment and its use for the measurement of the heart rate only below an economic level. The proliferation and popularity of open source hardware like the Arduino and Raspberry PI platforms, have made it possible to build devices to sense virtually any physical phenomena and display the results on remote display via Bluetooth or wireless connectivity[6].

Remote ECG monitoring systems are becoming commonplace medical devices for remoteand long term physiological monitoring, especially for that of the elderly and frail pa-tients[6]. The systems are consisted of three major components:

- a mobile gateway, deployed on the patient's mobile device, that receives 12-lead ECG signals from any ECG sensor;
- a remote server component that hosts algorithms for accurate annotation and analysis of the ECG signal;
- a point-of-care device for the doctor to receive a diagnostic report from the server based on the analysis of the ECG signals.

The wireless physiological information collection nodes of the wearable network are connected to the patient's portable terminal, such as a personal digital assistant (PDA), smart phone, or other communication device, to send data. At the same time, it is also capable of uploads, backup, analysis, and feedback of data to a remote medical service centre through the internet or mobile communications network[6].

To ensure patients safety and save lives, it is necessary for medical staff to have access to patients' information within short period of time and at the right time. Therefore, providing guaranteed, secured, and low transmission latency for patients vital signs are of great importance for life threatening diseases such as cardio-vascular diseases, temperature, blood pressure etc..

Mehdi Shokoue-inejad et al.[7] proposed a fully operational portable ECG system for training and educational purposes in biomedical engineering (BME) curriculum courses, based on Arduino. The device need for an USB connection with a pc to display the results using a labview software.

Bhimasen K. et al., [8] proposed a prototype ECG generator circuit low cost, battery powered making it portable with wireless connectivity for transferring the signal to the PC and SmartPhone.

R.Harini, et al., [9], presented a study to use handheld tele-electrocardiogram (ECG) to identify heart condition in the rural underserved population where the doctor-patient ratio is low and access to health care is difficult.

Udit Satija (Student Member, IEEE) et al. [10], proposed a novel signal quality aware IoT-enabled ECG telemetry system for continuous cardiac health monitoring applications. The proposed quality-aware ECG monitoring system consists of three modules:

1. ECG signal sensing module;
2. automated signal quality assessment module;
3. and signal-quality aware ECG analysis and transmission module.

Chowdhury et al [11] proposed the development of a wearable system for real-time de-tection and warning of heart attacks in drivers, which could be enormously helpful in reducing road accidents.

All these systems had some design issues and, in particular, cost factor played a very crucial role.

In this study I propose a fully automatic and wearable ECG monitoring system Arduino based. Sensor nodes can be strategically placed on the human body create a cluster that is called wireless body area network (WBAN) that can be used to collect patient's vital signs. The sensors are inserted in a cotton shirt. This smart shirt measures the body's heart rate, the electrocardiogram, respiratory rate and acceleration, and send the data to the smartphone using a Bluetooth protocol. An important part of the research is devoted to the study of the best positions for electrodes. The best position is one that combines good data quality with a comfortable fit. The electrodes used are Ag / AgCl dry electrodes. As a result, no gel is required to make good contact with the body. There is an additional height in the electrode area for better contact with the skin while maintaining a comfortable fit.

The device sends the signals detected on the subject by Ag / Cl sticking to an Android application installed on smartphone. The Android app shows the ECG wave, beats per minutes (BPM), and the principal cardiac parameters: P-Wave, PR interval, PR segment, QRS complex, ST segment, QT interval and T wave. If there are anomalies or values out of normal range, the Android software will highlight the abnormal values and send an emergency call.

The acquired data show results with a high correlation with the reference devices. This study wants to demonstrate how it is possible to realize a portable, intuitive, automatic and low-cost ECG device very affordable to all the lower and middle class family in every countries.

II. MATERIALS AND METHODS

2.1 Hardware

Figure 1 represents the block diagram of the proposed system.

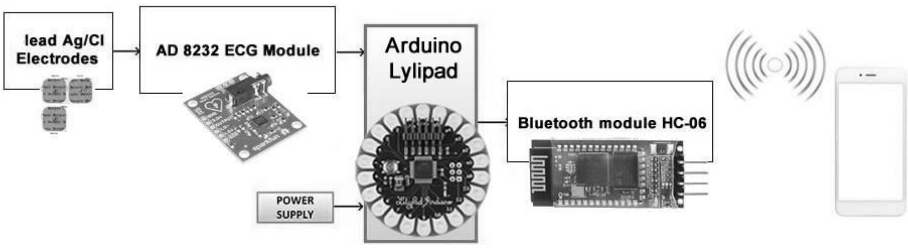

Figure 1 Pictorial representation of the system.

3-lead Ag/Cl electrodes are insertet into a cotton shirt on the Left Arm (LA), Right Arm (RA) and Right Leg (RL) of the patient's body (Fig. 2a). Electrodes of ECG Sensor have 3 pins and it is make ECG sensor easy to connect with controller and placed at the waist or pocket [12-14]. The sensor assembled on an arm pulse and a leg pulse. The signal is taken from the human body and then it is transmitted to ECG module (AD8232 ECG Module).

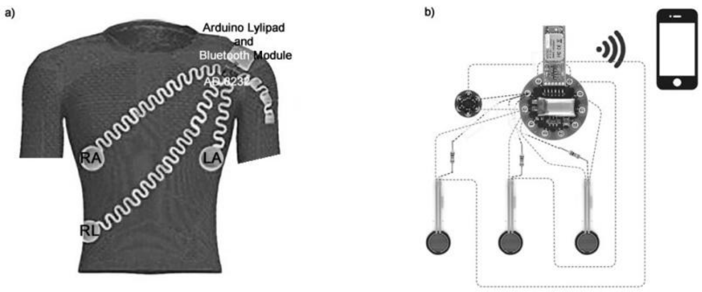

Figure 2 a) The smart shirt takes the signals from the human body and it transmits to ECG module (AD 8232) connected to Arduino Lylipad platform. b) Circuit diagram with LiPo battery and Bluetooth module

The AD8232 is an low cost, high accuracy instrumentation amplifier, integrated signal conditioning block for ECG and other bio-metric measurement applications. It measures the electrical activity of a beating heart through electrodes taped to the skin; it produces the continuous analog values according to the input given by the electrodes, the final measurement results can be displayed as an electrocardiogram. It is designed to pull out, amplify, and filter less energy bio-potential signals in the presence of noisy conditions, such as those created by movement or remote electrode position. The AD8232 module breaks out nine connections from the IC that you can solder pins, wires, or other connectors to. SDN, LO+, LO-, OUTPUT, 3.3V, GND provide essential pins for operating this monitor with an Arduino or other development board. Also provided on this board are RA (Right Arm), LA (Left Arm), and RL (Right Leg) pins to attach and use custom sensors. Additionally, there is an LED indicator light that will pulsate to the rhythm of a heartbeat. The AD8232 can execute a two pole high-pass filter for eliminating motion artificial facts and the electrode half-cell potential. This filter is tightly coupled with the instrumentation amplifier design to allow both large gain and high-pass filtering in a first stage, thereby saving money and space.

LilyPad, Arduino family of boards is especially designed for wearable applications. This board is one of the most popular boards for beginner level projects of Arduino and one of the most important reasons is its spacious layout. It is based on ATMega328 microcontroller. Pin identification is much easier in this board. When it comes to stitching, it has more space for that without the fear of accidently colliding with other pins on board If we talk about built in battery then it's easy and convenient to select LiPo battery (Fig 2b). We can choose any LiPo battery that suits best for our project run time. The best thing about this battery is that we can easily recharge it just by plugging our board into USB port of our computer or by simply using a 5 V wall charger.

2.2 Software

The software implemented on the Microcontroller Arduino Lylipad, is written in assembly C language. Figure 3 depicts a flow chart to ECG measurement. The flow starts from getting inputs from the ECG module (AD8232). The microcontroller checks whether all three inputs are given properly. If someone of the inputs is not detected well, the system send a warning; or else, if all inputs are detected, the software send the signal thought the Bluetooth module HC-06 at the app android.

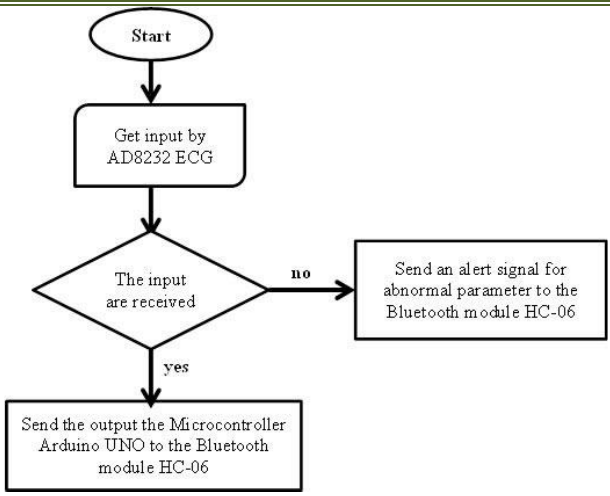

Figure 3 Flow chart Arduino software.

The Android application receives the digitized signals, handles the processing and extrapolation of ECG data for varying degrees of measurement and interpretation and displays all of the data to the user via a custom GUI.

Before the further signal processing, it needs to de-noised the recorded raw. The noise in the ECG signal may come from other physiological signals: electrode contact noise or motion artefacts. These noises could be modelled as white noise [16], which could be de-noised based on Wavelet Transform (WT). The WT of the ECG signal f(x) is defined in Equation (1):

$$Ws(x) = f(x)*\Psi s = (1/s)\int f(t)\Psi\,((x-t)/s)\ dt \quad (1)$$

Where Ψ is the Daubechies wavelet due to similarity of the shape to the QRS wave of ECG signal (Figure 4a). One cycle ECG (Figure 4a), consist of P wave, QRS wave, until T wave. P wave offers benefit information about the propagation time of the impulse to both atria [4].

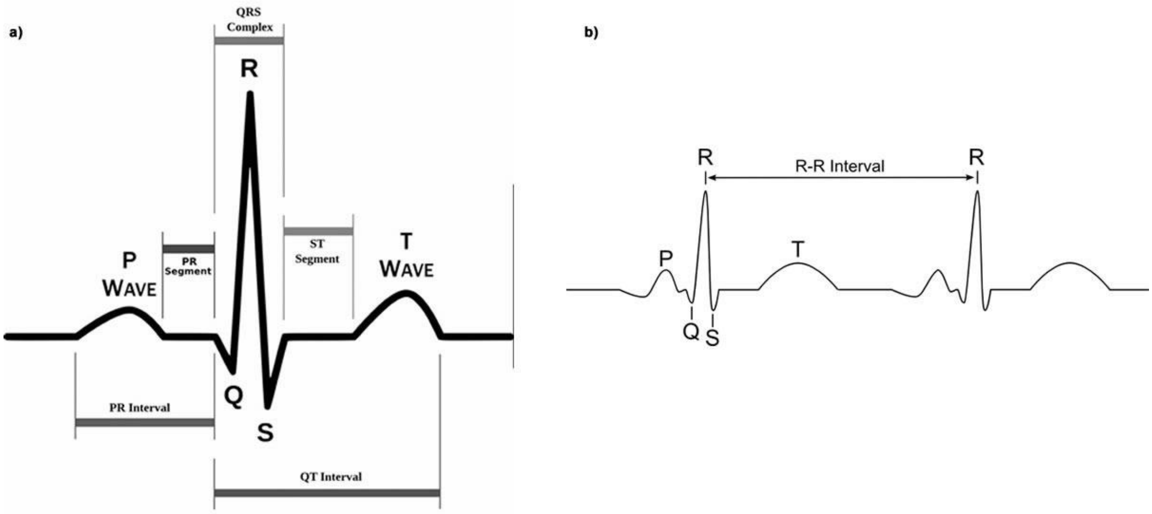

Fig. 4 a) ECG signal from a heartbeat. b) The RR interval is the time between QRS complexes. The instantaneous heart rate can be calculated from the time between any two QRS complexes.

The QRS complex provides information about the ventricular systole in consequence of the impulse propagation to the ventricles (Q wave), whereas the transmission to the whole tissue is caused by the R and S wave[17]. QRS complex can be helpful to analyse heart attacks [13]. The T wave permits to have information about the cardiac hypertrophy, heart attacks, and ischemia [17]. ST interval represents the period during which ventricles are contracting, which is the last stage of the heart cycle [2]. Moreover, others parameters, such as the QT interval, allow specific further pathologies to be characterized. Finally, the ECG signal ended with a small peak.

Part of this QRS complex is the "R" apex point (Figure 4a) which corresponds to the depolarization of the right and left ventricles of the heart.

In the Android App was implemented a real-time QRS detection algorithm based on the Pan-Tompkins Algorithm [18]

The overall detection system is mainly composed of three processing stages:

a moving average-based high-pass filtering (HPF),
a non-linear low-pass filtering (LPF), and
a decision making stage.

An ECG signal is processed by the linear HPF to accentuate the QRS complex, and meanwhile, to suppress the undesired waves of ECG, such as P or T waves. Then, low-amplitude artefacts can be smoothed down to a certain level while the QRS feature can be well preserved; the linear HPF output is then processed by a full-wave rectification and LPF followed by a sliding-window summation; thus resulting in an envelope-like feature waveform. Finally, an adaptive threshold (2) is applied to perform the decision-making for completing a QRS complex detection.

$$treshold = \alpha * \gamma * win\_max + (1 - \gamma) * treshold; \qquad (2)$$

where:

$$0 \leq \alpha \leq 1.$$

The values of γ can be between 0.15 and 0.2. I fixed it empirically: γ=0.175. The win_max is the local maximum newly detected in the feature waveform.

To determine the R wave positions, the algorithm searched for the maximum positive point and minimum negative point pair using the high frequency scale [17,19]. The distance (in milliseconds) between each "R" is defined as the "RR interval" (Figure 4b). A search window was implemented to determine the P wave and T wave at low frequencies.

Further, when registering a heartbeat, we get a simple series of numbers (intervals between every two consecutive heart beats in milliseconds, in average 70 numbers during 1 minute, for example, 720, 735, 814, 701, 798, etc.) these numbers are each characterized by strongly different physiological or psychological conditions. Based on this information, a Heart Rate Variability (HRV) of the ECG signal is implemented like Root Mean Square of the Successive Differences (RMSSD) (3):

$$RMSSD=\sqrt{((〚RR\ interval〛\_1-〚RR\ interval〛\_2)+(〚RR\ interval〛\_2-〚RR\ interval〛\_3)\ldots.)} \qquad (3)$$

Finally, QRS complexes, the BPM, RR interval, PR interval and RT interval are displayed on the Android APP GUI and compared to the normal parameters (Table 1); in this way the system may predict which disease the user potentially suffering from. If one of the values is out of normal range, it is immediately highlighted; at the same time the Android application makes an emergency call and sending an alert message with the parameters out of range to the numbers that the user had preset in the App configuration.

Table I: Normal ECG parameters

Event/Interval/Segment	Normal range	Amplitude
P Wave	0.06-0.11	<0.25 PR
PR Interval	0.12-0.20 sec	-
PR Segment	0.08 sec	-
QRS Complex	<0.12 sec	0.8-1.2
ST Segment	0.12 sec	-
QT Interval	0.36-0.44 sec	-
T Wave	0.16 sec	<0.5
R-R interval	0.6-1 sec	

III. RESULTS AND DISCUSSIONS

The system gets the input bio-metric signals from the human body using 3-lead electrodes. After processing all the three inputs, the ECG module produces the single analog output that was given to the Arduino Microcontroller. It checks whether all the three inputs are received properly and sends the signal to Bluetooth module HC-06 transmitting to a mobile application installable on any Android smartphone. The app Android processes the received data and shows BPM; RR, PR, and RT intervals and the ECG waveform [3] comparing them to the normal parameters (table I). The performance tests were based on the comparison between the results coming from Arduino ECG automatic approach, and those obtained from a certified medical devices (gold standard): OMRON HEART-SCAN HCG-801-E. The results were carried out by a trained cardiologist on a total of 85 healthy subjects (45 Male - 40 Female) with ages 20/70 years old gave their written informed consent to participate in the study. First, it was counted the number of R wave peaks, RR, PR and QT intervals in 60 seconds. All the results were able to identify the 100% of R peaks correctly, and overall, the PR and QR intervals had the same length; the estimated beats per minute (BPM) for each of them had no significant difference (Table 2).

Table II: beats for Average resting hearth rate in minutes (BPM) for men and women
Pulse rate varies by age and sex

Men		
Age	**Gold standard system**	**Proposed automatic system**
20-25	61.52	62.00
26-35	61.87	62.00
36-45	62.05	62.11
46-55	63.00	63.00
56-65	61.75	62.05
>65	61.00	61.08
Women		
Age	**Gold standard system**	**Proposed automatic system**
20-25	65.25	65.00
26-35	64.25	64.10
36-45	64.50	64.00
46-55	65.30	65.20
56-65	64.48	64.35
>65	64.50	64.50

The measurements of average RR intervals between gold standard and automatic device had a correlation coefficient resulted r = 0.993, as graphically reported in Figure5. Thenthe algorithm was tested using 40 one-minute long ECG data sets from the MIT-BIH Arrhythmia Database. The detected beats were compared to the annotated information with each ECG signal. The algorithm implemented in this project was able to achieve a sensitivity of 98.1% and a specificity of 79.73%; the percentage of correctly classified heartbeats varied from 87% to 100% with an average of 97.89%; the average error rate for the detected RR interval was 0.07%;the RMSSD error rate was 0.68%. Finally, the RR50 error rate was 0.72%.

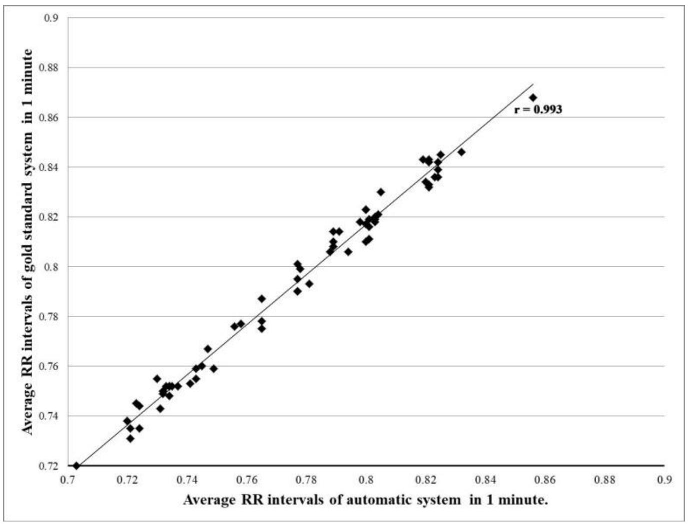

Fig. 5 Scatterplot showing the performed measurements of average RR intervals

IV. CONCLUSION

This paper proposes an automatic wearable low-cost ECG monitoring system for the use in any environment. The role of wireless technology in healthcare applications is expected to become more important with an increase in deployment of mobile devices and wireless networks. The system implements a Bluetooth connectivity to transmit the data to any Android smartphone, where a specific application processes the data and extracts the main hearth parameters. The results are displayed in a user-friendly graphical interface that can be easily understood by the patient and send to the doctor in any location. The specialist doctor will observe the physiological data of the patient diagnose it, prescribe the necessary treatment and drugs for the patient. This information will sent back to the doctor in the remote hospital via the internet.

The Android App also provides feedback instructions to the patient, such as physician's prescribed exercises.

There are different physiological signals that are normally transmitted between the sensor nodes, Android smartphone and the remote doctor via internet. The transmission is divided into four types according to their data rate and latency. They are classified as follow.

- High data rate and low latency traffic
- Low data rate and low latency traffic
- Low data rate and high latency traffic
- High data rate and high latency traffic

High data rate means critical signs that need to be transfer very fast with high reliability while low latency means time delay to the response of transmission of critical signals and should be as much as possible be short.

Priority scheduling method not only reduces the transmission delay for critical physiological signals, but also decreases traffic congestion. The total number of data sent reduced through data compression method. Therefore, the bandwidth utilization is improved thus, reduces total transmission time.

Thus, through this system timely monitoring of the heart condition can be done and the abnormality can be detected early leading to the reduction of the death of patient due to the cardiac diseases. The system is easy wearable, the electronic hardware is implemented in a cotton shirt, so to make the subject constantly monitored 24 hours a day without having any impediment or discomfort in his daily actions.

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