Conceptual Hybrid Model for Wearable Cardiac Monitoring System

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Research

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RESEARCH

Conceptual Hybrid Model For Wearable Cardiac Monitoring System

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Abstract

Background: The electrocardiogram is the most convenient and widely used method of cardiac monitoring. The information provided by the ECG has the potential to be used as a means by which cardiac arrhythmia can be detected at an early stage in order to prevent life-threatening complications. Its significance is widely accepted in the medical field so much so that tele-monitoring is being utilized across the world for cardiac activity. To perform cardiac monitoring more efficiently, a mobile application, used in conjunction with a sensor unit, is designed to perform real-time monitoring of the cardiac signal. The device consists of 3-lead EKG patches with an integrated Bluetooth module allowing a point-to-point pairing between the hardware and smartphone application. The hardware can either be placed on humanoid robot arm fingers or connected to a wearable patch placed on the chest. A real-time EKG signal is transmitted to the Android application on which a time vs. voltage plot will be displayed.

Results: The device was tested using the ProSim8 ECG simulator by Fluke Biomedical. The test confirmed the signal quality of the ECG signal with clear P, QRS, and T waves.

Conclusions: This device provides a more cost-effective telemedicine solution for cardiac home care assistance in remote areas which can serve as a viable alternative to conventional monitors as it has the potential to reduce the time for clinical procedures.

Keywords: EKG; telehealth; real-time data transmission; humanoid robotic arm; 3-lead; wearable patch; Bluetooth; Android application

Background

Cardiovascular diseases (CVD) are a major health issue worldwide; they account for 16.7 million deaths per year [1]. The magnitude of adversity is even greater in developing countries (i.e. Pakistan) where CVD are among the top ten causes of deaths; approximately 37 percent of the deaths in Pakistan are due to cardiac diseases [2]. Conventionally, the electrocardiogram is used for early detection in changes of the cardiac rhythm; it is sensitive enough to detect any underlying arrhythmia, such as atrial fibrillation, ventricular tachycardia, and ventricular fibrillation, that may become life-threatening in the near future [3]. Since Pakistan is a poverty-stricken country, the cost of healthcare diagnostics is a major cause of distress for most of the population. In order to increase the accessibility of healthcare diagnostics, high-quality, low-cost, multidisciplinary instruments must be developed for local use in the screening of cardiac arrhythmia within the population of Pakistan.

Traditionally, continuous ECG monitoring systems transmit data to a base station from which the data is uploaded to a user-interface from which the physician can access it. The typical battery life of these monitoring systems is a week which allows patients to follow their daily routine without any interruptions and/or discomfort. Moreover, the sensing units comprised of wearable patches do not require wires and have been proven to significantly reduce motion artifacts. However, a major disadvantage of these devices is that the hardware carried around by the patient is relatively bulky which may disrupt the patient's mobility. [4]

Previously, several research groups have explored different approaches to increase patient comfort and improve the form factor of wearable ECG devices [5, 6]. Available at a fraction of the cost of conventional monitors, the Netguard by Mindray is a small device designed for in-hospital use which takes uses two electrodes placed on the chest and displays a single ECG lead; this device reduces the weight of the apparatus to less than an ounce and has the capability to link with a PC at the nurse's station while it is within the range of the base station [7]. Patients admitted to the hospital are likely to be examined using a 12-lead ECG, thus making the Netguard device inessential. Similarly, Intelesens' V patch also consists of the same specifications with an added feature expanding its use to ambulatory settings [8].

IMEC has announced the release of a wearable chest patch which can measure three ECG leads. The patch has the ability to calculate the heart rate on board and is embedded with a 3-axis accelerometer. In addition, the system-on-a-chip design integrated with a low-energy Bluetooth radio allows the device to run on a 200 mAh battery for as long as a month. [9]. However, the design of this IMEC device prevents it from transmitting raw ECG data. While it does extract important parameters (heart rate and the onset, peak, and offset of the individual waves) from the ECG waveform, it does not allow the physician access to the original morphology of the ECG waveform.

Since the invention of prosthesis, the robotic arm has undergone several noteworthy technological advancements. More recent developments, including force sensor incorporation and sEMG prosthesis [10], have given rise to a range of applications within the field of robotics. For example, the application of robotic arms in diagnosing breast cancer using palpation methods are currently being explored [11]. The idea of using tactile sensors for robotic arms to measure force applied has provided possibilities for other types of sensors, which can be built into the robotic arm itself. This study extends this idea to ECG signal monitoring. The ultimate aim is to incorporate ECG electrodes in the fingers of a humanoid arm from which ECG data can be acquired and shared with an Android application via Bluetooth in real-time.

Since current continuous cardiac monitors do not allow the ECG waveform to be visualized and because prosthetic arms have the potential to detect ECG signals, the concept of this hybrid model is to design and develop a wearable, cardiac monitor which can be embedded into humanoid robot fingers or attached using a wearable patch. The system is used to acquire the EKG signal and transmit the data to the Android application allowing tele-cardiac monitoring of patients from remote areas.

Methods

The purpose of this study is to develop a small, comfortable, portable cardiac monitor for remote ECG monitoring. The device requirements include ECG signal acquisition using wearable electrodes in accordance with the specifications listed in Table 1 [12, 13], transmission of ECG data via Bluetooth connection, and displaying the ECG waveform on an Android-based mobile application in real-time.

Electrodes

Although disposable, Ag/AgCl gel electrodes are the most commonly used electrodes for the measuring of bio-potentials, they are not the best option for continuous remote ECG monitoring due to several reasons. The gel, which is used to improve the electrode-skin contact thereby reducing the skin-electrode contact impedance, has a tendency to dry over time leading to inaccurate ECG signal detection [14]. Moreover, skin irritation and allergic reactions can result from the skin preparation process prior to applying the electrodes and during removal. On the other hand, dry electrodes are more appropriate for this application since there is no skin preparation required. In addition, previous studies conducted have proven dry electrodes to be less subjected to noise, interference, and motion artifacts; upon initial application, these electrodes tend to detect signals more affected by noise, however, after perspiration fills the air gaps within the electrode-skin interface, the noise factor is significantly reduced [15]. Therefore, for the purpose of this study, dry electrodes have been chosen as they can easily be incorporated in robotic arms as well as wearable patches.

Electrode Configurations

Although two electrodes are sufficient to view an ECG lead, a common practice is to add an additional electrode to the configuration as reference to set the body to a common potential [16]. The advantage of a 2-lead implementation is that it minimizes the footprint on the user, while a 3-lead implementation results in a signal less affected by noise while also offering multiple ECG lead options [16]. Both configurations are explored in this thesis. The three-lead configuration is not the most comfortable option for the patient since components of the device may cross over the pectoral muscles and breast tissue. On the other hand, the 2-lead configuration provides more comfort for the user while only producing an acceptable view from Lead II. For both configurations, two possibilities for the placement of electrodes were explored. Using the three-lead system, the most ideal configuration provided the best view of Lead II.However, in the two-lead system, the most ideal configuration provided the best view of Lead I.

Technical Specifications for ECG Signal Acquisition

The requirements of ECG signal bandwidth vary with its application. For the non-diagnostic ECG, a freqeuncy range of 0.5 to 40 Hz is required whereas a diagnostic ECG must have a bandwidth of at least 0.05 to 150 Hz [17]. In the ECG signal, the P wave is characterized by the smallest peak with an amplitude of 0.05 to 0.25 mV [18]. Therefore,200 μVrms is the maximum acceptable value for the input reference noise in order to accurately detect the P wave; usually, a value less than 30 μVrms is practically implemented. A normal QRS complex is the largest in amplitude with magnitudes greater than 2 mV [19]. This value determines the upper constraint on the overall gain of the system. Since the amplitudes of these bio-signals vary from patient-to-patient, a system with adjustable gain is required to consider differences in potential. Gains of a 1000 or greater [20] will result in sufficient amplification for signals ranging from tens of millivolts to hundreds of microvolts. Since the ECG signal amplitude lies in the millivolt range, an amplifier with high differential gain and high CMRR [20] is required to accurately detect the biopotential; the most commonly used amplifier for such purposes is the Instrumentation Amplifier (IA).

System Design of ECG Signal Acquisition Unit

The electrodes are connected to the patient and acquire the raw ECG signals from the body which are pre-processed through an Instrumentation Amplifier. Filters are applied on this resultant signal which omits signal frequencies outside the range of the ECG wave. This filtered ECG signal is converted to digital data via an ADC on the microcontroller, which reads, formats, and writes the ECG data to the serial port connected with the Bluetooth module. The Bluetooth module then relays this data to a paired Android smart device for visualizing the ECG waveform, refer to figure 1.

Mobile Application Workflow

The application first asks user to select a Bluetooth device to pair with. Connecting the ECG device will take the application to initialize its system variables and start reading and parsing the incoming ECG data stored in an array list. Then the ECG graph user interface is initialized, and the stored data is checked for overflow. If data overflow occurs, the oldest data stored is removed to make room for new data. The array list is then plotted in the application screen to observe the ECG wave in real-time, refer to figure 2.

Calculations

Instrumentation Amplifier (IA)

In this project the instrumentation amplifier INA321 is used. The amplifier is rail-to-rail in type, with its gain set by using the following formula:

$$G = 5 + 5(\frac{R2}{R1})$$

Filters

The operational amplifier OPA4340 is used in the design of filters for this device.

Offset Trimming Filter

$$f_c = \frac{1}{2\pi RC}$$

$$R = 1M\Omega, C = 0.1\mu F$$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(1M)(0.1\mu F)} = 1.59Hz$$

Active Low Pass Filter

$$f_c = \frac{1}{2\pi RC}$$

$$A_v = \frac{R2}{R1}$$

$$R1 = 3.3k\Omega, R2 = 1M\Omega, C = 4.7nF$$

$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(3.3k)(4.7nF)} = 10.2kHz$$

$$A_v = \frac{R2}{R1} = \frac{1M}{3.3k} = 303$$

Passive Low Pass Filter

$$f_c = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}}$$

$$R1 = 4.7k\Omega, R2 = 47k\Omega, C1 = 1\mu F, C2 = 0.1\mu F$$

$$f_c = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}} = \frac{1}{2\pi\sqrt{(4.7k)(1\mu)(47k)(0.1\mu)}} = 33.86Hz$$

Results

After testing basic device functionality, the wearable cardiac monitor was tested, refer to figure 3a, using the ProSim8 ECG simulator by Fluke Biomedical, refer to figure 3b. This test was conducted at the eHealth Resource Centre at Aga Khan Development Network to analyze the quality of the ECG signal on the cardiac monitor designed. The results of this test confirm that the cardiac monitor is able to display a high-quality ECG signal as the P, QRS, and T waves were all distinguishable and noiseless, refer to figure 3c. However, while testing with a digital oscilloscope, refer to figure 3d, a clean ECG signal was not acquired with the simulator set at a normal ECG rate of 80 bpm. This difference in reliability may be affected by the length of the wires used for monitoring, the active buffering of the electrode locations, and printing the circuit board with masking which reduces environmental effects on signals.

Discussion

In light of existing research on the use of robotic arms for medical purposes (i.e. breast palpation), this study further builds on the applications of robotics within the healthcare system. The monitoring of ECG using a humanoid robotic arm is a step towards automated healthcare which promises a more efficient workflow within clinics and hospitals. Although this study focuses on ECG monitoring, other physiological parameters measured noninvasively, such as temperature and blood oxygen saturation levels, can be incorporated within a single robotic arm. While the wearable patch supports continuous, real-time ECG monitoring, the robotic arm only supports real-time ECG monitoring for the time period in which the module is on. Also, the application developed is Android-based and can therefore not be accessed by smartphones operating on iOS.

Conclusions

An ECG monitoring module has been proposed which can either be developed into a wearable patch for placement on the chest for continuous ECG monitoring or embedded into a robotic arm for real-time ECG monitoring of patients within a healthcare facility. The use of dry electrodes allows for improved signal quality for short- and long- term uses. Testing of the module validates its accuracy and proves that the module can serve the purpose it was built for. While the module discussed in this study is a concept in its initial stages,it has the potential to revolutionize the manner in which cardiac monitoring is performed in developing countries.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Availability of data materials
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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Author's contributions
HIA mainly contributed to the technical development of the device, DMS and SS were major contributors to concept development, OS supported the development of the technical hardware involved, NS provided assistance in programming for the embedded system of this device, and AT was involved in the technical documentation.

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Figures

Figure 1 Block Diagram of ECG Signal Acquisition System. The ECG electrodes acquire the raw signal from the patient and undergoes a series of signal processing stages before the final waveform is displayed on the Android application.

Figure 2 Block Diagram of Application Workflow. The application requires the smartphone to be connected to the signal acquisiton unit via Bluetooth. Once the connection is established, the application will read data sent from the microcontroller and display the ECG waveform on its graphical user interface.

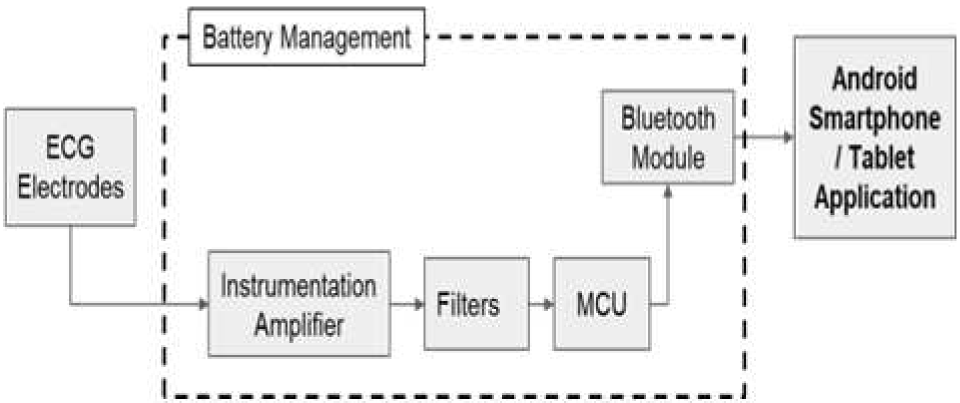
Figure 3 ECG Signal Quality Test and Results. (a) Test Set-up with Oscilloscope (b) Test Set-up with Smartphone (c) Input ECG Waveform from Fluke Biomedical Prosim8 (d) Output ECG Waveform on the Android Smartphone Application (e) Output ECG Waveform on Android Tablet Application (f) Output ECG Waveform on the Digital Oscilloscope

Tables

Table 1 ECG Signal Requirements

Specifications	Minimum	Target
Leads	1	1
Electrodes	2 - 3	3
Bandwidth	0.5 - 40+ Hz	0.5 - 100 Hz
Input Reference Noise	$\leq$ 30V	$\leq$ 20V
Gain	5	5
ADC Resolution	8 bits	12 bits
CMRR (60 Hz)	40+ dB	90+ dB

Figures



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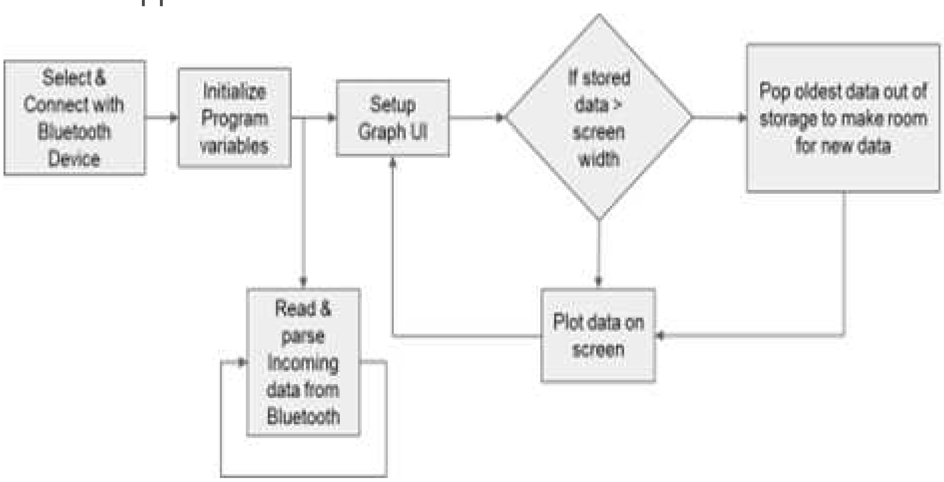

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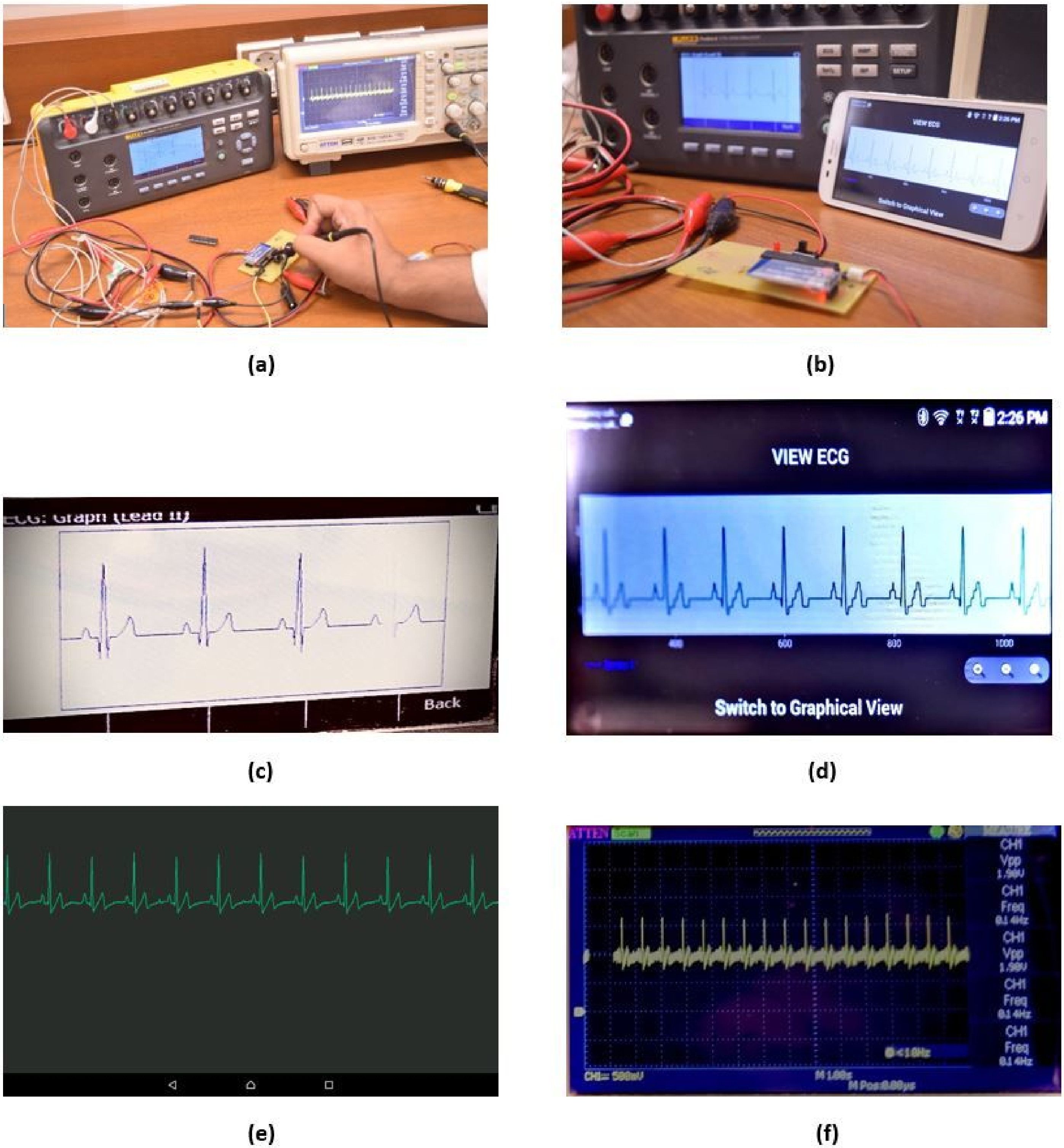

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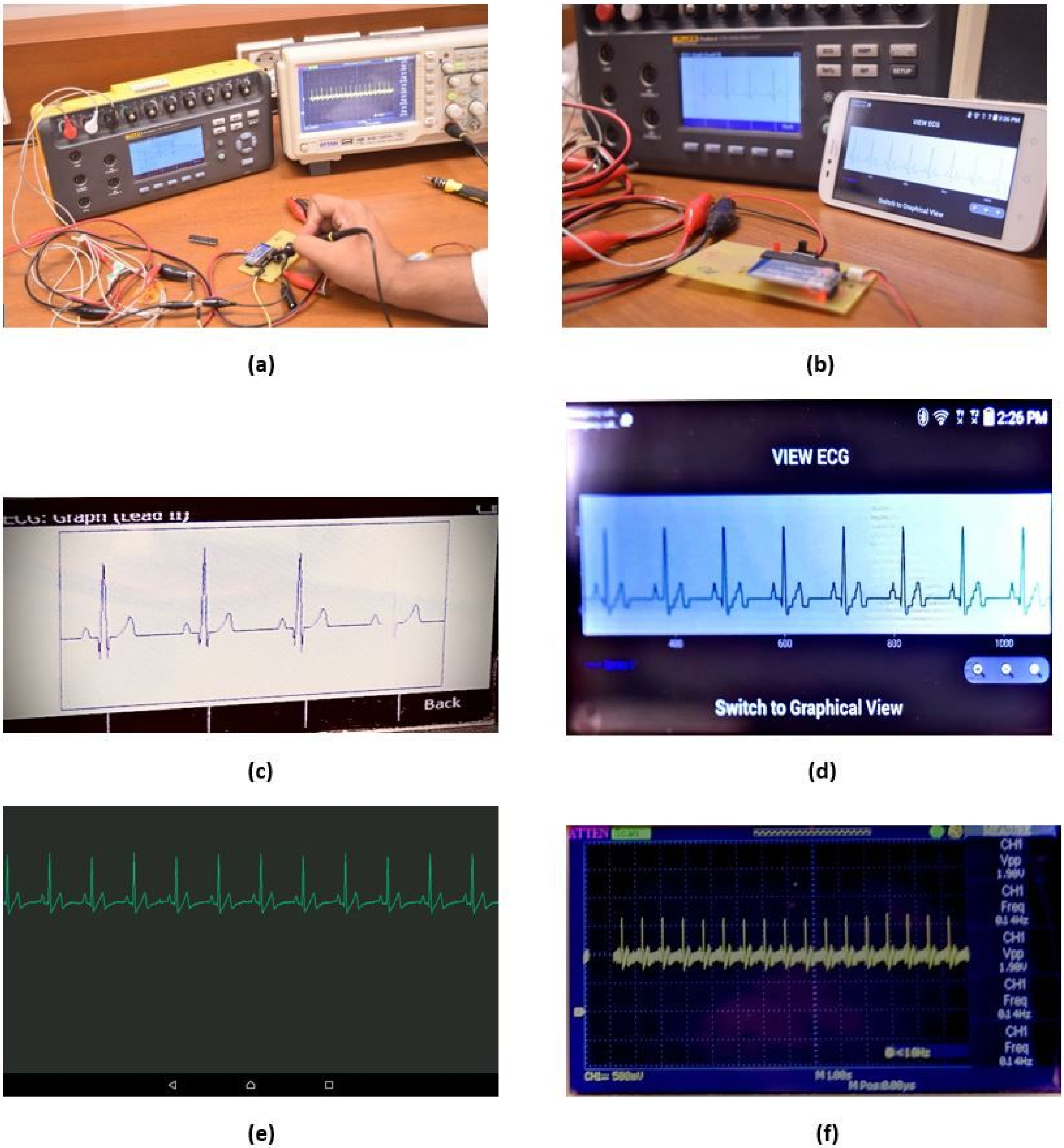

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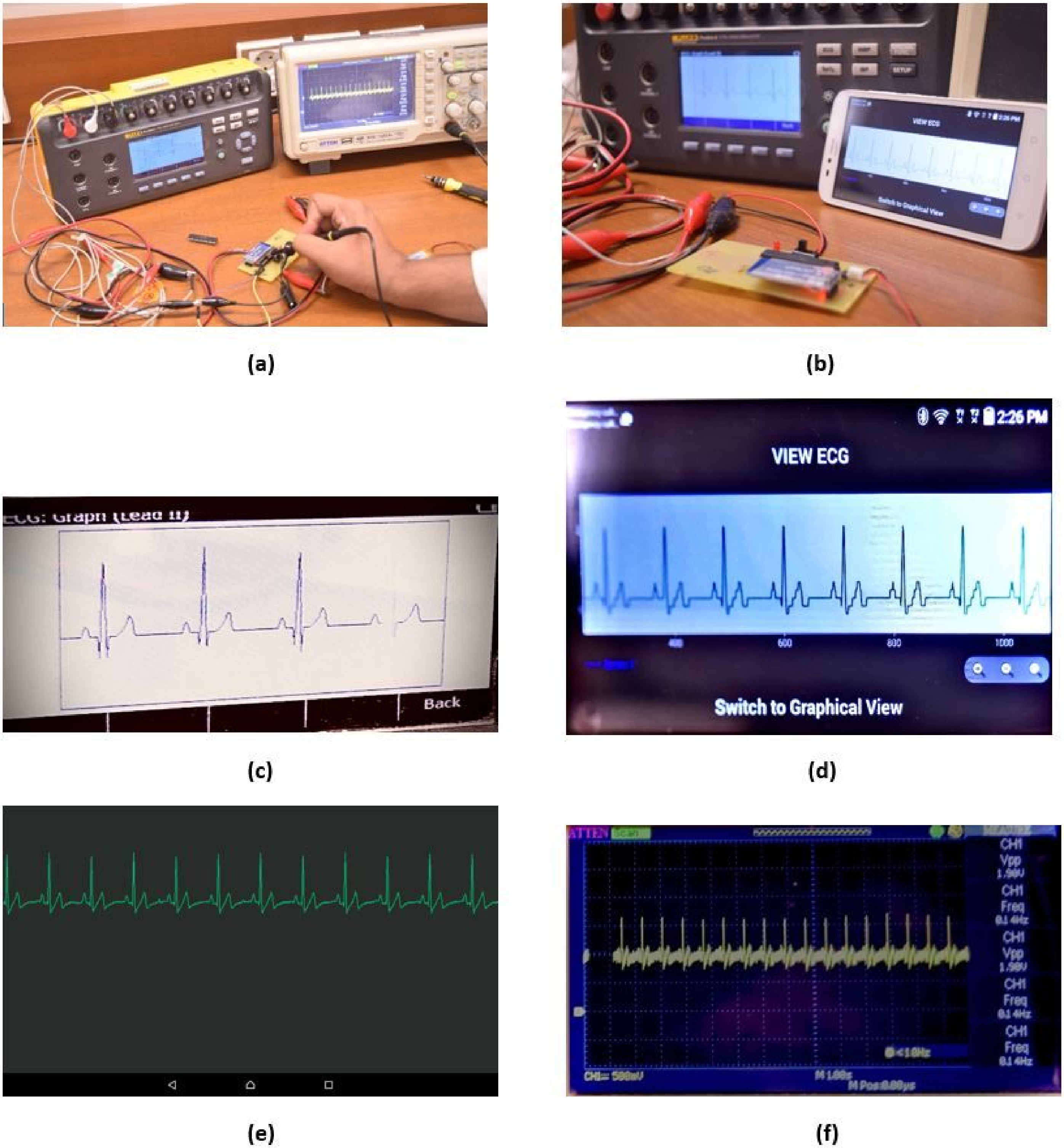

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