Prototype low-cost portable electrocardiogram (ECG) based on Arduino-Uno with Bluetooth feature

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Prototype Low-cost Portable Electrocardiogram (ECG) Based on Arduino-Uno with Bluetooth Feature

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Abstract. World Health Organization (WHO) data stated that heart diseases cause 37% of deaths in Indonesia. In Indonesia, devices used to monitor the heart's activity or electrocardiogram (ECG) are only owned by some big hospitals. With an Arduino microprocessor, a simple portable ECG with a function to read the heart's condition could be made. The AD8232 sensor is the main device that is used to read the heartbeat by processing the voltage received from the electrodes attached to the body. Combination of Arduino-Uno and HC-05 FC-114 as a Bluetooth antenna, an ECG display could be seen on a smartphone's monitor in real-time. An ECG simulator is used as an artificial heart activity to be used as a trial for the ECG portable's performance from test results. ECG using the simulator can be delivered to the smartphone's monitor by Bluetooth module with an accurate result that draws the real-time condition of the patients.

Keywords: Arduino, Bluetooth, electrocardiogram, low-cost, portable

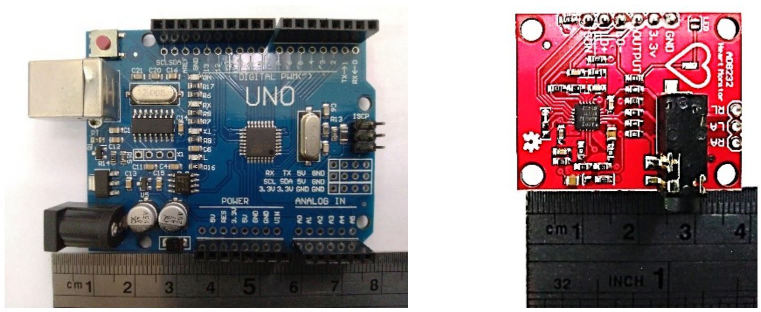
INTRODUCTION

Electrocardiogram (ECG) is a graph created by an electrograph that records the electrical activity of the heart in a certain period. An ECG is a diagnostic test that analyses the cardiac conduction system and gives the clinician insight into the health of the heart and disease process, which the patient may be suffering from. Many patients calling for emergency care will either have an acute cardiac emergency or have a past medical history of cardiac disease. An accurate assessment of the patient increases the accuracy of diagnosis, triage, and management of the patient. This not only allows for timely intervention but also decreases the long-term morbidity and mortality rates of patients [1].

(a) (b)

FIGURE 1. (a) Commercial Patient Monitor ; (b) Display on the Screen Patient Monitor

In figure 1 (a) is an example of a commercial Patient Monitor used in the health sector. Patient Monitor is used to seeing the patient's condition, such as oxygen saturation (Sp02), body temperature, patient's heart rate per time, and ECG chart. One of the most important in seeing cardiac abnormalities is the ECG parameters seen in Figure 1 (b). Figure (1b) shows a screenshot of the display Patient Monitor on a computer monitor that plots a graph of the patient's heart condition. But even with all its components, the use of such Patient Monitors is limited because formal training is needed to operate the device and the price is high. From international statistics, 9.4 million deaths every year are caused by cardiovascular disease, and 45% of the mentioned deaths are caused by coronary disease [2]. In Indonesia, lots of healthcare centers do not own an ECG. By data of Health Ministry, in 2016, only 16.5% of every hospital that has said facility [3].



(a) (b)

FIGURE 2. (a) Arduino-Uno ; (b) AD8232 Module

With advances in technology, especially those that are open-source, we can make ECG independently based on Arduino, especially Arduino-UNO [4]. Figure 2(a) is Arduino-Uno as a microprocessor that will acquire data so that it can be displayed according to user needs. And figure 2(b) is one of the simplest sensors to detect the heart rate, commonly called AD8232 Module [5]. AD8232 sensor is used to catch the heart's electric signal. Lots of ECG research are based on this AD8232 sensor [6]–[8]. In this era, a smartphone is one of the most if not the most used electronic devices by people. The ease given from the application feature of a smartphone makes it popular inside the masses. The main purpose of this research is to make a portable, low-cost ECG based on Arduino-Uno that can be connected to a smartphone by Bluetooth to increase flexibility.

BASIC THEORY

Einthoven's Triangle

Figure 3 describes how three of the most influent point produces an ECG graph. Precordial lead use three main positions, which are RA (Right Arm), LA (Left Arm), and LL (Left Leg). ECG wave moves from the negative electrode to the positive electrode. Wave I uses RA as the negative electrode and LA as the positive electrode. Wave II uses RA as the negative electrode and LL as the positive electrode. Wave III uses LA as the negative electrode and LL as the positive electrode. The three heart waves of I, II, and III are the three original waves used by Einthoven., wave aVR, aVL, and aVF are added to complement those three waves into the mix. aVR uses the average/middle of the LA and LL as the negative electrode and RA as the positive electrode. aVL uses the average/middle of the RA and LL as the negative electrode and LA as the positive electrode. Lastly, aVF uses the average/middle of RA and LA as the negative electrode and LL as the positive electrode.

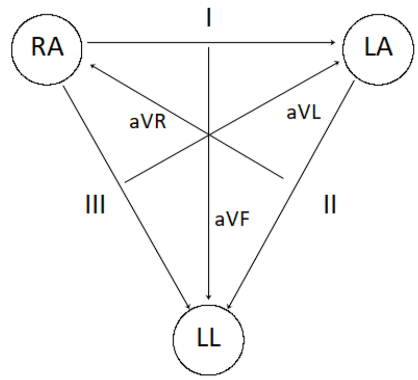


FIGURE 3. Einthoven's Triangle

For data requisition, the II wave, which comes from the original Einthoven's group, will be used. Electrodes will be placed in a position based on figure 4. The positive electrode will be placed on RA, negative electrode on LL, and the ground electrode on LA [9], [10].

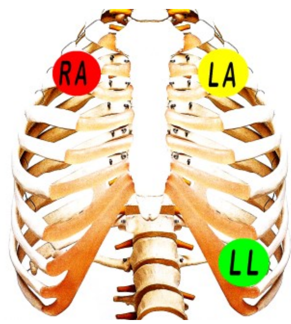


FIGURE 4. 3-Lead Placement

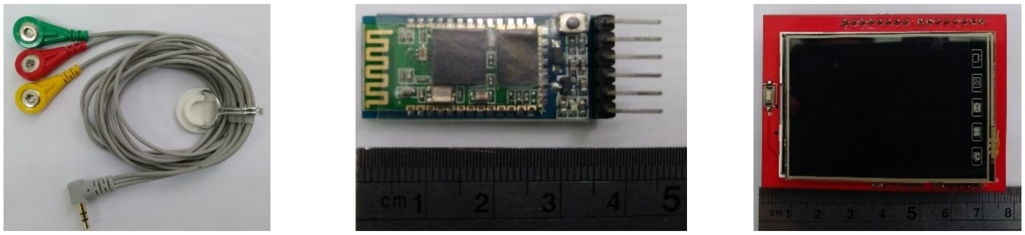
The heart activity signal that is received by the electrode then will be sent to AD8232 to be processed into Analog data. This is done by amplifying the received electric signal, which then will be scaled on 0.3 - 3V voltage. Then, this data will be directed to microprocessor Arduino's recorder. The analog data which took the form of voltage will be scaled again into an integer value of 0-1023. The biggest value is 1023 from the 5V scaling value and the smallest value is 0 from the 0.049V scaling value. Since ECG has the maximum voltage of 3.3V, the possible maximum integer value is 676.

METHODOLOGY

Hardware

Arduino-Uno as a microcontroller purposed as data acquisition. AD8232 was an integrated signal conditioner block for ECG and other bio-potential measurers. AD8232 was designed to extract, amplify, and filter small bio-potential signals inside conditions that are full of noises like muscle movements. AD8232 was an integrated signal block that conditions cardiac bio-potential to monitor heart activity. On the inside, there were Instrumentation Amplifier, an Operational Amplifier, a Right Drive Amplifier, and a Mid-reference Buffer. AD8232 also had Leads-off Detection circuit and Fast Recovery circuit to recover signals after the leads were connected.

Specialized Instrumentation amplifier, amplified ECG signal while rejecting noise potential. This reduced possible "indirect current feedback" architecture, which decreased the size and the power more, compared to the old implementation. This also increased the accuracy of voltage reading. Operation Amplifier was a rail-to-rail device that could use low-pass filtering and increased extra gain to signal. Right Leg Drive (RLD) Amplifier invert common-mode signal inside the Special Instrumentation amplifier's input. When Right Leg Drive's output was inserted inside the subject, the mentioned output will neutralize other common-mode variations. AD8232 operated using a single power supply. To ease the single-supply application, AD8232 used the reference buffer to create a border between the supplied voltage and the ground system. Because of the Low Cut-off frequency that was used in the high-pass filter in ECG application, the signal needs a certain amount of seconds before being ready. This duration of seconds could cause a delay that disturbs data acquisition every time electrodes were connected for the first time. Fast Recovery circuit decreased the duration delay to its milliseconds, making data acquisition easier and faster [11].



(a) (b) (c)

FIGURE 5. (a) 3-Electrodes cable; (b) HC-05 FC-114 Module; (c) TFT LCD 2.4” Arduino

The three electrodes attached to the body used to catch the electrical signal of the heart [12]. A simple monitor named TFT LCD 2.4” was needed as a visual instrument to display ECG graph [13]. HC-05 FC-114 acted as a data sender via Bluetooth to a smartphone [14]. Every of these hardware assembled and a code uploaded inside to control its work

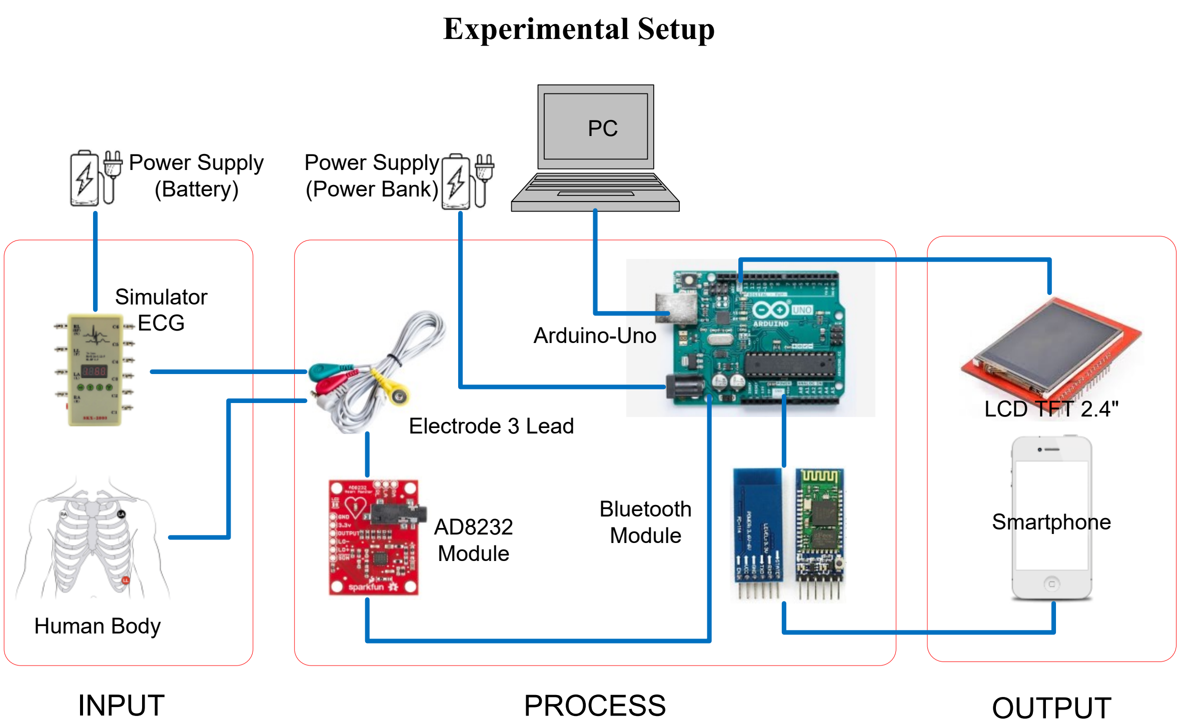


FIGURE 6. Experimental Setup of Portable ECG with Bluetooth feature

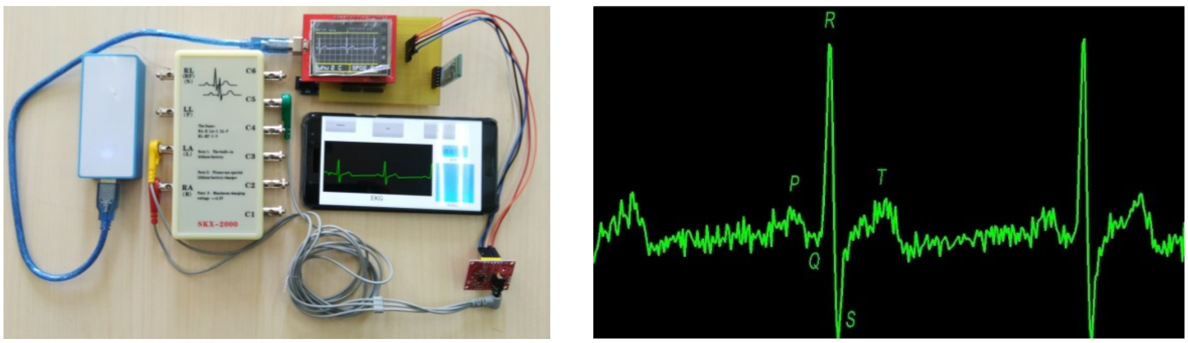
ECG simulator and voluntary patients were sources of analytical data. The three electrodes that were attached to them acquired an electrical signal and sent them to the AD8232 module. The signal was sent from AD8232 to microprocessor Arduino. It did not only processes them into analog value but also sent those data into integer values that were used to display data. A code to display output was already uploaded inside the Arduino microprocessor. The desired output was formed into two displays. One display is through LCD TFT 2.4” which was assembled with

Arduino. The other was through smartphone by Roboremo app [15], which could receive the blue-tooth signal given by Arduino and produced a graph on the smartphone's display.

RESULT AND DISCUSSION

ECG Simulator

Figure 7 shows a trial with ECG Simulator as the reference data, showing a healthy heart wave (Normal Sinus Rhythm). Figure 7(a) shows a full assembly of Portable ECG with Bluetooth feature acquiring data from ECG Simulator. While figure 7(b) is a close-up look on one cycle of a PQRST wave, which was produced by a simulator acting as a healthy heart.



(a) (b)

FIGURE 7. Reading results of Portable ECG with ECG Simulator. (a) Actual experimental setup. (b) Smartphone's screenshot of data

Figure 7(b) explains the result of a healthy heart. Two main values were extracted from the data, one in the form or morphology of the PQRST wave, and the second one was the heart's BPM. Figure 7(b) is an example of an ECG wave caught on the smartphone screen. An ECG wave could be split into three sections, which are P-wave, QRS complex, and T-wave. P-wave was the recording result of the SA Node which was the heart's pacemaker. The QRS complex was the combination of deflection and contraction of the ventricle's muscle. T-wave was the recording when the ventricle's muscle repolarized to be ready for the next heartbeat.

The second value was BPM (Beats per Minute), which was the frequency of heartbeats inside 60 seconds time period. A healthy heart rate is 60 - 100 BPM while in a resting state. When exercising, it will increase to around 110-150 BPM. And while sleeping, the heartbeats will be around 40-60BPM. In making data acquisition on a patient's heart, the said patient must be set on a resting state. If a patient has a heart rate value outside the range of 60 - 100 BPM, then the patient is afflicted by Bradychardia if his heart rate below 60 BPM or tachycardia if it's over 100 BPM.

Data Acquisition Trial on Human Body with ECG

Next, Portable ECG with Bluetooth feature was tested on a real human body that has an unhealthy heart condition. The results which were displayed in figure 8 then interpreted using medical reasonings and a conclusion.

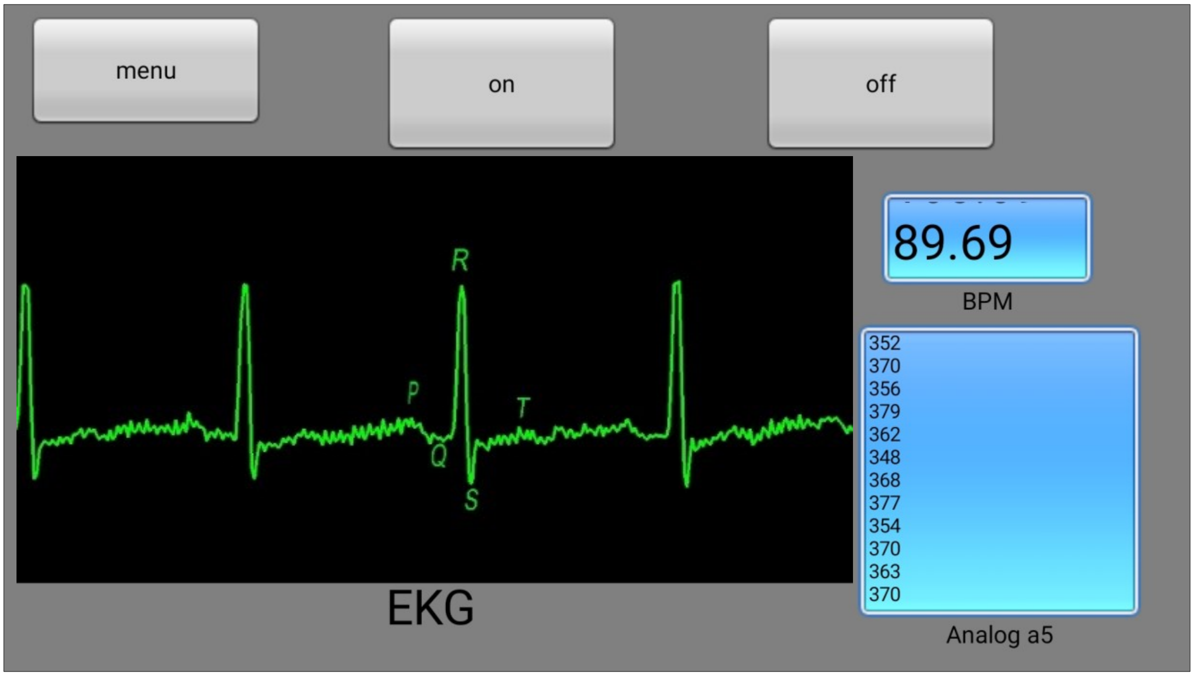


FIGURE 8. ECG's reading results in the human body (smartphone screenshot).

In Figure 8, it can be interpreted that the distance between each of the R wave is similar to others. This result showed that the heart has a normal heart rhythm. The value of Heartrate was 89 BPM, which told that its Heartrate was normal because it was still inside the range value of 60-100 BPM. Seen from the morphology of the ECG waves, we could observe that there were differences between ECG Simulator and Patient's ECG wave. First is that the ECG wave on the patient is not as smooth as ECG Simulator. This caused by "noise" from the patient's muscle movement and the imperfect noises from the place of data acquisition. The P-wave of the patient was a bit less visible compared to ECG Simulator yet still has normal morphology. The QRS complex also had the same shape as the simulator. The T- wave had a very small amplitude, showing signs that there was partial clotting inside the patient's coronary artery. It could be concluded that the patient was afflicted by Myocardial Ischemia (Coronary disease).

CONCLUSION

This ECG hardware has worked with a desirable result. The TFT display was not only able to record the electrical activity of the heart using the AD8232 sensor but also able to plot analog data in the form of a graph on the screen. ECG used the HC-05 Bluetooth module. It can be saved in the JPG file from which it can be inserted into this report and also in an MP4 file to see the real-time process of data acquisition directly. Regretfully, that even though TFT LCD can display a grid, a method to show it on a smartphone app is still not found. We hope that in the future, the method to display a grid will be found to make a more accurate analysis of JPG files, just like an LCD.

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REFERENCE

1. U. Flinders, "3-Lead ECG Acquisition," *University Flinders*, 2019. [Online]. Available: https://flo.flinders.edu.au/pluginfile.php/1488147/mod_folder/content/0/3-Lead ECG Acquisition - Information Sheet.pdf?forcedownload=1. [Accessed: 18-Jun-2019].

2. L. Ghani, M. D. Susilawati, and H. Novriani, “Faktor risiko dominan penyakit jantung koroner di Indonesia,” *Indones. Bull. Heal. Res.*, vol. 44, no. 3, pp. 153–164, 2016.
3. Kemenkes, “Profil Kesehatan Indonesia Tahun 2016,” 2016.
4. Arduino, “ARDUINO UNO REV3 Code: A000066,” 2019. [Online]. Available: https://store.arduino.cc/usa/arduino-uno-rev3. [Accessed: 16-May-2019].
5. C. Therobot, “AD8232 Heart Rate Monitor Hookup Guide,” 2019. [Online]. Available: https://learn.sparkfun.com/tutorials/ad8232-heart-rate-monitor-hookup-guide/all. [Accessed: 18-Jun-2019].
6. M. A. Agung and Basari, “3-lead acquisition using single channel ECG device developed on AD8232 analog front end for wireless ECG application,” in *AIP Conference Proceedings*, 2017, vol. 1817, no. 1, p. 40015.
7. T. C. Lu, P. Liu, X. Gao, and Q. Y. Lu, “A portable ECG monitor with low power consumption and small size based on AD8232 chip,” in *Applied Mechanics and Materials*, 2014, vol. 513, pp. 2884–2887.
8. M. W. Gifari, H. Zakaria, and R. Mengko, “Design of ECG Homecare: 12-lead ECG acquisition using single channel ECG device developed on AD8232 analog front end,” in *2015 International Conference on Electrical Engineering and Informatics (ICEEI)*, 2015, pp. 371–376.
9. Admin, “EINTHOVEN TRIANGLE PDF.” [Online]. Available: http://check-backlink.info/einthoven-triangle-60/. [Accessed: 10-Jul-2019].
10. M. Cadogan, “ECG Lead Positioning.” [Online]. Available: https://litfl.com/ecg-lead-positioning/. [Accessed: 10-Jul-2019].
11. A. Device, “AD8232 Single-Lead, Heart Rate Monitor Front End,” *2018*. [Online]. Available: https://www.analog.com/media/en/technical-documentation/data-sheets/AD8232.pdf. [Accessed: 18-Jun-2019].
12. Y. Ding, “3.5mm Mini Stereo Jack to Medical Snap Cable for ECG Devices,” 2019. [Online]. Available: https://trangjanindustrial.manufacturer.globalsources.com/si/6008848107440/pdtl/ECG-EKG/1167666543/medical-female-snap-ecg-cable.htm. [Accessed: 10-Jul-2019].
13. P. Labs, “2.4" TFT LCD Touch Screen - Arduino Shield,” 2019. [Online]. Available: https://potentiallabs.com/cart/buy-2.4-inch-tft-touchscreen-online-india. [Accessed: 10-Jul-2019].
14. R. Retail, “RG Retail HC05 Bluetooth Module for Arduino,” 2019. [Online]. Available: https://www.amazon.in/RG-Retail-Bluetooth-Module-Arduino/dp/B071LHLLDC. [Accessed: 10-Jul-2019].
15. RoboRemo, “RoboRemoFree Arduino Bluetooth,” 2018. [Online]. Available: https://play.google.com/store/apps/details?id=com.hardcodedjoy.roboremofree. [Accessed: 18-Jun-2019].