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IOP Conference Series: Materials Science and Engineering PAPER • OPEN ACCESS A low-cost Holter monitor design equipped with external memory and Bluetooth connection To cite this article: D Nofitasari et al 2020 IOP Conf. Ser. Mater. Sci. Eng. 850 012020 View the article online for updates and enhancements. This content was downloaded from IP address 182. 1.125.55 on 10/04/2021 at 06:02 A low-cost Holter monitor design equipped with external memory and Bluetooth connection D Nofitasari\*, I D G H Wisana, T Triwiyanto, E D Setioningsih, M R Mak'ruf and P C Nugraha Department of Electromedical Engineering, Poltekkes Kemenkes, Jl. Pucang Jajar Timur No. 10, Surabaya, 60245. \*dewinofita51@gmail.com Abstract. Monitoring the heart activity is critical for a patient with heart disease. Twentyhour detecting of the ECG signal will help the clinician to diagnose the hearth. This device is usually called a Holter monitor. However, the price of this device is very expensive, therefore the development of a Holter is required. The purpose of this study is to develop a portable and low- cost Holter system to record the ECG signal in twenty-four hours. The mainboard is composed of a pre-amplifier, bandpass filter, notch filter, summing amplifier, Arduino microcontroller, SD Card Memory, and a Bluetooth transmitter. ECG signal is collected from the body based on the standard measurement of LEAD II. The ECG signal is sampled with a frequency sampling of 200 Hz. To record the raw data of the ECG signal, the SD Card Memory was used to save the data for further data analysis. Calibration was conducted by using an ECG phantom. The calibration was performed in order to make this design to be a standard ECG machine. The design was also equipped with a Bluetooth transmitter to transmit the data to the computer. The total price to develop this device is 460,000 IDR. After the evaluation, the BPM error of this Holter is ±0.0273% and the Holter able to operate in 24 hours. The developed ECG Holter is portable in dimension and low cost to be fabricated for mass production to help people with heart disease. 1. Introduction Holter Monitor, or sometimes also referred to as an ambulatory electrocardiographic (ECG) device, is a portable device used to monitor various activities on the cardiovascular system continuously for 24 hours [1]. The principal work of this device is by attaching electrodes to the patient's chest while an instrument records the ECG [2]. This device usually works with the battery. This Holter can be used as an ECG recorder that can be bagged or carried everywhere with a belt or straps on the shoulder [3]. Holter monitor works by tapping the ECG's electrical signal on the heart and is reinforced so that the signal can be read and diagnosed by the medical doctor. Holter monitor function is to analyze and monitor a person's heart activity caused by abnormalities or abnormal changes in the heart [4]. However, the use of this device is only limited to the area in the hospital or medical institution, while the need for this Holter is also essential for monitoring ECG signals at home or in areas that far from the hospital. The function of this device is as early prevention of heart problems in a person, and it is critical to always monitor the heart health regularly by examining the heart signal recordings independently [5].

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Therefore, this is very much needed a portable and practical Holter (easy to carry and easy to use) for a patient with heart disease. By adding a wireless monitoring system and utilizing a computer as a visualization of the ECG signal, the Holter can be used effectively to monitor ECG signals wherever they are without having Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI. Published under licence by IOP Publishing Ltd 1 to look at the ECG record in the treatment room [5]. Holter monitors are vital for checking the heart abnormalities. In cases of arrhythmia, the use of the Holter monitor is very emphasized because this device can record ECG signal activity for 24 hours and is portable [6]. Tai et al. [7] proposed an ECG recorder with an adaptive sampling algorithm and has been evaluated using the MIT / BIH database, but from this study, it can use a simpler method so that it can improve signal reconstruction better. Related research was also developed by Luciani et al. [8]; they made a portable ECG monitoring device with Bluetooth and the Holter that has the capability for telemedicine applications for remote monitoring. In this study, the data obtained can be stored on a flash memory card (FAT16) or sent via Bluetooth or USB to a local station or Access Point. The research can operate in two modes: Holter and on-line transmission. Jin and Miao [9] developed ECG Holter using the MSP430 microcontroller and USB flash. ECG signals are recorded and sent to the monitoring center via a USB flash disk using the SL811HS USB controller, but in this study monitoring still uses serial USB. Further research was developed by Carrasco et al. [10] with the title of design and  $\hbox{development of Holter Prototype with Bluetooth Transmission, in this study using Bluetooth technology as wireless}$ communication, using data storage and user interfaces with Lab View Software but the signal obtained still has noise. Lee et al. [11] develop Holter with noise artifact reduction using the Empirical Decomposition Mode and Statistical Approach. In this study, it has also been designed with a real-time method for detecting artifact and noise (MN) that often disrupts the rhythm of specific ECG signals. But from this research, there is still noise from the signal and PPG signal. Furthermore, the development of the Holter monitor was also has been developed by Putra et al. who modified the EKG into a Holter with a display on the computer, however, in those studies, the data could not be sent directly to the Computer. Furthermore, the Holter was also developed by Ananta Faxia, the Holter Monitor, which can be used as an Electrocardiograph (ECG) monitoring device that can be monitored the ECG signal via a computer screen using wireless system, but the weakness of those study is that the noise still exists and unstable when there is a movement of the subject [11,12]. Based on those problems, the objective of this study is to develop a Holter monitoring based on Arduino microcontroller equipped with SD card memory and Bluetooth connection [13]. The salient feature of this design is that the recorded ECG data can be sent wireless through the Bluetooth connection to the computer host. Furthermore, the Holter can be used as a standard electrocardiograph (ECG) monitoring device and portable ECG recorder. As a conventional ECG device, this proposed design can monitor the ECG signal wirelessly to display on the computer using Bluetooth communication [14]. The second option, the proposed model can be used to record the ECG signal for 24 hours, and the ECG data was saved to the SD card memory. In this study, a marker, in which to assign when a heart attack happens, was also equipped. Hence the system can measure the number of abnormalities [1]. This study implies that the design can be used personally at home for further diagnosed by a doctor and can be built at a low cost. 2. Materials and methods 2.1. Experimental setup This study used ten normal subjects with the criteria the ages ranged between 22 and 27 years old and the weight is between 45 to 50 kg. The subjects were randomly sampled and the data collection is repeated 5 times. 2.1.1. Materials and tool. This study is used a disposable electrodes ECG (OneMed, Jayamas Medical Industri, Indonesia). The electrodes were attached to the right and left a hand on the human. The instrumentation amplifier was built based on TL084 OP-AMP [15]. The Arduino Nano microcontroller was used for ECG data acquisition and communication to the computer unit using Bluetooth module HC-05. SD Card Memory with a 16 Mbyte was used to save the ECG data in real-time. A digital storage Oscilloscope (Textronic, DPO2012 Taiwan) was used to test the analog circuit. An ECG phantom (Fluke, PS320, USA) was used to calibrate the analog circuit. 2.1.2. Experiment. In this study, after the design was completed then the frequency response of this device was tested using a function generator according to the specification of the ECG signal. In the calibration stage, the Holter ECG was tested using an ECG simulator (phantom) with all ranges (30, 60, 120, 180, and 240 BPM). Each setting, the output of the Holter was calculated to validate the result of this study. Then the Holter was tested on the human body [3]. 3. The diagram blocks In this research, the ECG recording was performed based on the placement of the three electrodes for LEAD II combination as shown in Figure 1. The ECG signal was then amplified using instrumentation amplifier, filtered using a bandpass filter, notch filter, non-inverting amplifier, and summing amplifier or adder for offset adjustment. A built-in analog to digital converter (A/D) in Arduino Nano was used to convert the analog ECG signal into digital [16]. The ECG recording was saved to the SD card memory for further data analysis. The ECG data was also can be delivered to the computer unit via the Bluetooth module. Figure 1. The diagram block of the Holter monitor. 3.1. The flowchart The Arduino program was built based on the flowchart as shown in Figure 2. After the initialization of the Arduino, the program asks the Bluetooth whether the connection is active or not. If the Bluetooth is active, then the data was ready to send to the computer. The other option is the data can be directly saved to the SD card memory. The computer program was built based on the flowchart as shown in Figure 3. The menu divided into 2 namely readings from Bluetooth serial and from SD card memory [17]. The data from Bluetooth connection active, the data is ready to send to the computer and then read ECG Signals from the Delphi program. While reading the data from SD Card Memory is initialization and then received data, Conversion data from SD card memory and final reading of the ECG signal. Figure 2. The Flowchart of the Arduino program. Figure 3. The flowchart of for the Delphi programming. 3.2. The analog circuit The important part of this development is the analog circuit which describes in Figure 4 (instrumentation amplifier), Figure 5 (bandpass filter), Figure 6 (notch filter), and Figure 7 (summing amplifier). The circuit is used to process the ECG signal. Hence it will ready for digital processing using Arduino microcontroller. 3.2.1. Preamplifier. An Instrumentation amplifier circuit as shown in Figure 4 was the pre amplifier for the ECG amplifier which takes an important part for analog processing. This circuit is composed of three OP-AMP and one additional OP-AMP for buffering the signal. The overall gain was adjusted by R1 (560 Ohms). The two leads of electrodes were connected to J16 and J17 as shown in Figure 4. 4 U9D TL084 12 - + 14 13 - R32 22k 11 U9A 11 R26 2 - TL084 22k J16 1 1 3 + R20 2 22k 11 U9C TL084 9 - CON2 4 R1 8 560 10 + + R22 22k 4 R25 R27 22k 22k 11 U9B TL084 J17 6 - 1 7 2 5 + CON2 4 Figure 4. Instrumentation amplifier. 3.2.2. Bandpass filter. The bandpass filter is to limit the frequency of the signal; hence the processed ECG signal is only by characteristics of the ECG signal. The bandpass filter was designed for the cut off frequency of 0.05 to 100 Hz. The gain and the cut off value were calculated based on equation (1) and equation 2, respectively. In this study, the gain of the bandpass filter was 101 times. R7 100k R6 R8 1k 1k - 11 U11A TL084 J7 1 2 3 R30 - + 1 R18 47K TP1 C7 10uF 330K 4 + C3 U11B 33n 11 TL084 R19 6 - 7 5 + 47K C8 33n 4 Figure 5. Bandpass filter. Gain = 1+2(Rf/R6) (1) where Rf is the feedback gain, R6 is the divider resistance and the Gain is the amplification of the circuit fc=1/(2nRC) (2) where R is the resistance value, C is the capacitance value, and fc indicated the cut off frequency. 3.2.3. Notch filter. The notch <u>filter was designed to eliminate the</u> line power interference from the environment in which the frequency of the bandstop filter is 50 Hz. This interference could dominate the main signal (ECG) due to the small amplitude of the ECG signal. The input of this circuit was connected to the output of the bandpass filter. The notch filter was designed as shown in Figure 6. U11C R28 C10  $^{\circ}$ C14 R31 4 TL084 J2 68k 47n 47n 68k TP4 10 + 8 1 C15 9 - J1 47n 1 11 R33 R35 TP3 C16 68k 68k 47n U11D TL084 1 4 R34 + 12 2 100k 14 - 13 11 3 Figure 6. Notch filter 50 Hz. 3.2.4. Summing amplifier. The summing amplifier was composed of two operational amplifiers (Buffer and Inverting Amplifier). This circuit is to offset the level of the ECG signal so that the signal is fit to the digital part of Arduino Microcontroller which is the A/D converter. The ECG signal was added with a setpoint voltage from a variable resistor (R4) as shown in Figure 6. According to Figure 7, the buffer circuit is used to maintain the signal voltage. + U12A 4 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 1k R11 11 TP6 U12B 1k J6 11 TL084 1 + 3 J4 - 2 1 R2 + 3 J4 - 2 1 R2 + 3 J4 - 3 J 2 1 - 6 R10 R4 - 2 7 1k 100k + 5 D1 2 3 1 Output C1 3.1V 4 100nF 1 R15 R23 100k 1k Figure 7. Summing amplifier. 3.2.5. Bluetooth module. The Bluetooth (BT) module used in this design was HC-05. This Bluetooth module was used to transmit the ECG signal from Holter monitor to the computer unit. For the communication between the Arduino board and the Bluetooth module, it needs two pins which are Tx (to transmit the ECG Data, and The Rx is to receive the information between the microcontroller and computer unit). The connection between the BT and Arduino module was shown in Figure 8. Arduino Tx Nano Rx Tx Rx BT HC-05 GND GND Figure 8. Bluetooth Connection. 4. Results <u>In this</u>

study, the Holter has been tested using an ECG phantom (Fluke, SP2002, USA) and ECG from the human body. The result shows that the recording is feasible to record the ECG signal from the human body [17]. Figure 9. The Holter monitor Figure 10. The Holter monitor electrode placement (front view). electrode placement (side view). Figure 9 and Figure 10 are examples of the placement of disposable electrodes that are affixed to RL, RA, LL. Holter Monitor can be attached to the respondent's waist area and can be taken anywhere by recording the respondent's heart rate results [5]. 4.1. The Holter ECG design The photograph of the analog and digital part of the Holter ECG was shown in Figure 11 and Figure 12, respectively. The analog part consisted of three of TL084 (OP-AMP) which each unit composed of four OP-AMP [6]. Some variable resistors were used to adjust the gain and offset of the ECG signal. The main part of the digital circuit is Arduino microcontroller, SD card memory, Bluetooth HC-05, and RTC DS1307. Figure 11. The Holter ECG design Figure 12. The Digital part of the Holter ECG 4.2. The listing program for Arduino Holter monitor The <u>listing program for Arduino</u> was <u>shown in the Listing Program 1</u>. The program <u>consisted of the program to send the data to</u> the computer and to save the data into the SD card memory in which it can be chosen in the initial program. The ECG data was sent to the computer host using Bluetooth communication. Listing program 1. Program to send the ECG data Serial.print(" d"); } statebutton=true; } } 4.3. ECG Holter with the input from ECG simulator Before the ECG Holter was tested on the human, the device was calibrated using artificial ECG generated from ECG Simulator. Figure 13 and Figure 14 were the examples of the recorded ECG signal from ECG simulator for 30 and 60 BPM, respectively. Figure 13. The recorded ECG signal from the ECG simulator (BPM 30). Figure 14. The recorded ECG signal from the ECG simulator (BPM 60). 4.4. The recorded ECG signal from the human body by LEAD II In this study, the ECG Holter was also tested using the human body by attaching the three electrodes on the left hand, right hand and right leg as shown in Figure 15 to Figure 16. Figure 15. The recorded ECG signal from the Figure 16. The recorded ECG signal from the human body (subject 1). human body (subject 2). 4 .5. The error of BPM (beats per minutes) The validation of the BPM value <u>shown in the</u> Delphi programming <u>was compared with the</u> Pulse Oximetry device. The <u>error of measurement for BPM</u> parameter between the design and calibrator, for different BPM setting, was showed in Table 1. Table 1. The error of measurement for BPM parameter between the design and calibrator for various BPM. Rate Setting (BPM) Error (%) 30 0.00 60 0. 00 120 0. 00 180 0. 01 240 0. 01 240 0. 00 Table 2. The error of measurement for the BPM parameter between the design and calibrator (Pulse Oximetry) for various subject. Subject Error (%) P1 ±0.0024 P2 ±0.0000 P3 ±0.0026 P4 ±0.0044 P5 ±0.0273 P6 ±0.0084 P7 ±0.0024 The measurement of BPM value in which the ECG signal is from the human body was also compared in this study, between the Holter design and Pulse Oximetry. The result was shown in Table 2. 4.6. Component prices list Table 3 is the price to build the Holter monitor with a total price of IDR. 460,000. Mostly, all of the electronics components can be found in the local market. Further, at a low price, the public can build the Holter monitor by themselves in order to record the heart activities. Table 3. The List of components price. No. Components Vol. Price (IDR) The Totals (IDR) 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 Arduino Nano SD Card Modul SD Card Memory Bluetooth Modul RTC Modul IC TL084 IC 7660 Resistor Capasitor Multitune Jumper Cables PCB Elektrode ECG Cables Box Belt 1 1 1 1 1 3 2 100 10 5 1 4 1 1 1 1 30,000 20,000 30,000 60,000 20,000 5,000 10,000 250 1,000 5,000 5,000 15,000 60,000 20,000 40,000 20,000 30,000 20,000 30,000 60,000 20,000 15,000 20,000 25,000 10,000 25,000 5,000 60,000 60,000 20,000 40,000 20,000 460,000 The Total 5. Discussion The Holter design has been examined and test <u>completely in this study. Based on the measurement of the</u> Holter <u>output,</u> the resulted ECG signal when using the input from ECG simulator showed the right pattern of ECG signal which consisted of P, Q, R, S, and T waveform with the amplitude of 1 mV, for various BPM (30, 60, 120, 180 dan 240), and sensitivity of 1 mV. By comparing the output of the Holter between the input using the ECG simulator and the human body, it was shown that there is a different pattern on the PQRST waveform. Each ECG recording for each subject showed a different amplitude. This is reasonable because each subject has different characteristics of the heart. The error of BPM between the design and the input from the ECG simulator showed a value of 0.01. The error of BPM (from the seven subjects) is ±0.0273%. This error value indicated that the Holter is feasible to be used as a medical device. The main feature of this design is that the ECG data can be sent directly to the computer host by using Bluetooth communication. In this situation, one of the Bluetooth modules has to be configured as a master or slave. In the experiment, we have tested the communication as far as 3 m away between Holter and computer host. In communication, it was proved that there was no corruption in the ECG data. The performance of this work was also compared to other works. In order the Holter able to work in 24 hours then this design needs a battery with high capacity. Carrasco found that his Holter is able to operate in 16 hours without the intervention of the users [10,13]. Jin and Miao claimed that their Holter able to work stable more than 24 hours [9]. In the future work, some issues need to be implemented by using better technology, such as using a Bluetooth module with low power energy and increase the battery capacity but still with compact size. 6. Conclusion This study has demonstrated the development of the Holter to monitoring the ECG signal from a subject in real-time. This project was built based on an Arduino microcontroller and some analog circuit and a Bluetooth transmitterreceiver to connect to the computer unit. The result has proofed that the accuracy is feasible to be used to monitor the ECG signal in real-time and the data recording can be read from the SD card memory. In the future, we may develop to fabricate and use it in the small clinic in the villages at a low cost. References [1] Tanaka S, Motoi K, Nogawa M and Yamakoshi K 2004 A New Portable Device for Ambulatory Monitoring of Human Posture and Walking Velocity Using Miniature Accelerometers and Gyroscope . 2283-6 [2] Gonzalez L, Walker K, Challa S and Bent B 2016 Monitoring a Skipped Heartbeat : [3] Carozzi L, Carrara M, Moss T J, Cerutti S, Ferrario M, Lake D E and Moorman J R 2014 Heart Rate Dynamics Predict 2-Year Mortality Risk in Ambulatory Patients Undergoing Holter Monitoring UVa Holter database 89-90 [4] Dian Permana, Mada Sanjaya W.S. 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