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ECG Simulator Based on Microcontroller Equipped with Arrhythmia Signal

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ABSTRACT Electrocardiograph (ECG) is one of the diagnostic sciences that is often studied in modern medicine and used to detect damage to the heart components or disorders of the heart rhythm called arrhythmias. The purpose of this research is to develop an Electrocardiograph simulator that is equipped with arrhythmia. The main design consists of an Arduino Mega 2560 microcontroller, MCP4921 DAC (Digital to Analog Converter) circuit, a network resistor, and a sensitivity selection circuit. The MCP4921 type DAC converts the digital signal data into analog data which will then be forwarded to the resistor network circuit as a signal formation for each lead. The basic signal image data used for the formation of normal Electrocardiograph and arrhythmias were taken from the Electrocardiograph recorder using Phantom Electrocardiograph. Based on the readings on the Beat Per Minute setting of the module to the Beat Per Minute printout on the Electrocardiograph recorder, the error rate value for the Normal Sine Rhythm parameter is 0.790% for 30 Beats Per Minute, 0.383% for 60 Beats Per Minute, 0.535% for 120 Beats Per Minute, 0.515% for 180 Beats Per Minute, and 0.593% for 240 Beats Per Minute. Meanwhile, the error rate for the Arrhythmia parameter is 2.076% for ventricular tachycardia of 160 Beats Per Minute and 0.494% for Supraventricular Tachycardia of 200 Beats Per Minute. The design of the Electrocardiograph simulator can simulate the signals of the human body and it can be used as a medium in the learning process in the field of health.

INDEX TERMS Arrhytmia, Arduino Mega 2560, DAC MCP4921, Resistor Network.

I. INTRODUCTION

Heart disease has been the first common cause of death for more than 10 years [1]. Every year, 7.2 million people die from heart disease [2]. Electrocardiogram (ECG) is a method for measuring and recording various electrical potentials of the heart, which further can be used to identify heart rate abnormalities or arrhythmias [3]. According to Paul J. Michalek, ECG is a class II medical device that requires special controls beyond general control to guarantee safety and effectiveness [4]. Accurate interpretation of the ECG signal will increase the success rate of heart disease diagnosis [5]. For this reason, it is very important for doctors or students studying medicine and biomedical engineering to train themselves on the interpretation of ECG signals [6]. Damage to each component of the heart will cause different heart diseases. One of them is called Arrhythmia. Arrhythmia is a disturbance or abnormality in the transmission of electrical impulses to the myocardium [7]. The cardiac conduction system starts from the automaticity of P cells in the SA node, atrial depolarization, atrioventricular (AV) node depolarization, impulse propagation along with the bundle, and Purkinje system to ventricular depolarization, that is an orderly and precise impulse conduction sequence [8]. Broadly speaking, arrhythmias are divided into two major groups, namely Brady arrhythmias, which are characterized by a too slow heart rate (less than 60 beats per minute) and tachyarrhythmias, which are characterized by a too fast heart rate (more than 100 bpm). Each group consisted of different types of arrhythmias [9][10].

The electrocardiograph (ECG) was first invented by Einthoven (1904) [11]. An electrocardiogram (ECG) is a diagnostic device that can record the electrical activity of the heart [12]. By analyzing the waveforms generated from the recording of the electrical activity of the heart, various information can be obtained including rhythm abnormalities, the effect of drugs on the heart, heart muscle abnormalities, and estimation of the enlargement of the heart rate for the pacemaker function [2]. Therefore, every recording made with the ECG must be precise, because if an error occurs in the diagnostic results, it will lead to an error in reading the results which will also lead to an error in determining the diagnosis of the disease [13].

A previous study has been conducted by Willa Olivia and Arfian Ahmad in 2017 with the title of the Design of an Electrocardiogram Calibrator using the AT89S51 microcontroller with 0800 Series DAC to form a heart signal. However, the device only has a heart rate of 30.60 and 120 Beats Per Minute [14]. Gregory Mario Tani in 2017 further carried out research entitled ECG Simulator (Phantom Electrocardiograph) using a Digital To Analog IC (DAC) type MCP4921 to form the desired heart signal but the device only has a heart rate value in the range of 30-110 Beats Per Minute [15]. Furthermore, Ni Nyoman Sri Malini also made an ECG Simulator device in 2017 using the formation of an ECG signal with a 4017 IC counter and a NE555 clock. Unlike the DAC IC which can be formed by plotting the original image of the heart signal, the 4017 IC counter has a weakness in the use of capacitors, causing an imperfect ECG waveform in the ST segment and the large capacitor value affects the segment width and interval on the PQRST wave [16]. In this case, the ECG Simulator has a BPM range of 30 – 240. In addition to this, related to BPM, there are also weaknesses in the frequency issued by the microcontroller which changes so that the BPM is not stable [17]. In 2018, M. Ziko Alamanda also created ECG Simulator through his study with the title of Phantom ECG. The method used is a Digital to Analog IC (DAC) type MCP4921 to form the desired heart signal. The ECG Simulator has a BPM range of 30 – 240 but the sensitivity selection is only 0.5 and 1.0 mV and the device is not equipped with arrhythmia parameters. In 2019, I Dewa Gede Budi Whinangun also conducted a study with the title of Microcontroller-Based ECG Simulator. The ECG Simulator made is a 12 channel ECG device that includes Lead I, Lead II, Lead III, aVR, aVF, aVL, V1, V2, V3, V4, V5, and V6 which are displayed on the ECG paper. In addition, it is completed with sensitivity selection selector and BPM as well as using the method of forming cardiac signals through the DAC type MCP 4921 but the device is not equipped with arrhythmia parameters. Finally, I Made Saryastana developed an ECG simulator in 2020 through his research entitled the Design of an ECG simulator with arrhythmia parameters. The ECG simulator made is equipped with arrhythmias with a sensitivity selection selector and BPM as well as uses the method of forming heart signals through the MCP 4921 type DAC, but the tool only includes leads I, leads II, and leads III [17].

The purpose of this study is to make an "ECG Simulator Equipped with Arrhythmia-Based Microcontroller" with 6 channels including Lead I, Lead II, and Lead III, aVR, aVL, and aVF as well as sensitivity selection of 0.5 mV and 1.0 mV. In addition, the method of forming a heart signal on the DAC type MCP 4921 was also expected to be used. Therefore, it is expected that through this research, a learning model considering the importance of studying ECG signals and carrying out the functions of the ECG test kit can be developed [18].

II. MATERIALS AND METHOD

A. EXPERIMENTAL SETUP

In this study, cardiac signaling has a 4-lead output (RA, LA, LL, RL). Outputs lead I, lead II, lead III, aVR, and aVL signals with sensitivity 0.5mV and 1mV and BPM ranges of 30, 60, 120, 180, 240, and 160 for Ventricular Tachycardia and 200 for Supraventricular Tachycardia when recorded with an ECG Recorder [19].

1) MATERIALS AND TOOL

In this study, we used a 12-bit MCP 4921 DAC IC as a digital data processor into an analog signal. In addition, we also employed Arduino Mega 2560 microcontroller module as a control center and array data storage. The buttons used for BPM and sensitivity settings are push on-types. As for the display, a 16x2 Character LCD was used and controlled via I2C. The battery used is a Li-ion battery with rechargeable capability.

2) EXPERIMENT

After the design was complete, the results of this device were compared with the Phantom ECG comparison [20]. In the comparison stage, the ECG Simulator was tested using a Phantom ECG comparison in all ranges (30, 60, 120, 180, 240, 160, and 200 BPM) [21].

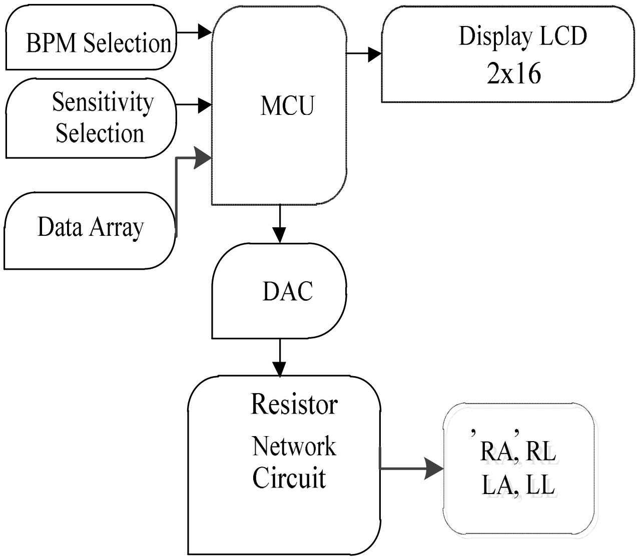

FIGURE 1. The Diagram Block Concept of ECG Simulator Using a Microcontroller

B. THE DIAGRAM BLOCK

When the device is turned on, the MCU or microcontroller will wait for a command from the control to select the selected wave type of Normal or Arrhythmia in the database that has been embedded in the microcontroller [22]. In addition, the display will display the BPM on the BPM selection which is immediately activated when the device is turned on, causing the MCU to output the first signal form even without touching the control to be issued to the Digital to Analog Converter or DAC circuit in Digital form. The selection of the signal form by selecting BPM will have a different BPM range and a different signal form between normal or arrhythmic. In addition, it will also be displayed on a 2x16 LCD display. Meanwhile, the LA, RA, LL, RL blocks will receive the form of the signal issued by the DAC in the form of Analog which has previously been processed in the Resistor Network Circuit block as shown in FIGURE 1. This Resistor Network Circuit block serves to provide a difference in the impedance of each Lead.

C. THE FLOWCHART

The flow chart shows the flow of the program reading journey on the ECG Simulator. After setting the BPM and sensitivity accordingly, the microcontroller will output data to the Digital to Analog Converter (DAC) circuit as shown in FIGURE 2. The DAC circuit will further convert the digital data into analog data form, which are then conditioned by the Resistor Network Circuit into ten outputs

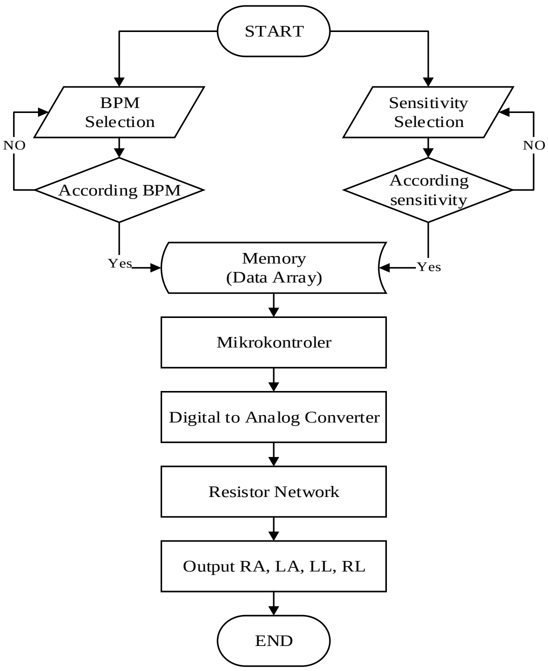

FIGURE 2. The Flowchart of ECG Simulator Using a Microcontroller

D. CIRCUIT OF ECG SIMULATOR

In this study, there are important parts that become the basic circuit of the ECG simulator, those are:

1) MICROCONTROLLER AND DISPLAY CIRCUIT

The control set, namely the Arduino Mega 2560 circuit, is the control center. There are 2 push button settings for BPM and sensitivity selection that connects or disconnects between GND and inputs on pin9 and pin10 on ArduinoMega 2560. There is also a sensitivity selection push button that disconnects or connects GND with pin11 on ArduinoMega 2560. The character LCD serves as a display to show the BPM selection and sensitivity controlled by I2C module.

2) DAC Circuit

DAC circuit is a series used for microcontrollers to communicate with DAC MCP4921 through PIN CS, SCK and SDI. The microcontroller will provide a form of digital signal through the program and dac MCP4921 will translate it into analog data with 12-bit resolution.

3) NETWORK RESISTOR CIRCUIT

The resistor circuit is used to divide the value of the ECG signal according to the impedance of the body. Here are the pin contextor details: pin1 = LL, pin2 = LA, pin3 = RA, pin4 = RL. Next, the signal value in each pin was calculated by the following formula, according to FIGURE 3 and FIGURE 4.

RESISTOR_NETWORK = INPUT:

$$V(p \quad 1) = \frac{R7}{R6+R7} \times \text{INPUT} \tag{1}$$

$$V\ (p \quad 2) = \frac{R9}{R8+R9} \times \text{INPUT} \tag{2}$$

$$V(p \quad 3) = \frac{R1}{R1 \ +R1} \times \text{INPUT} \tag{3}$$

$$V(p \quad 4) = \text{GND} \tag{4}$$

Note: R1-R11 is Resistor and GND is Ground, as described in the FIGURE 3.

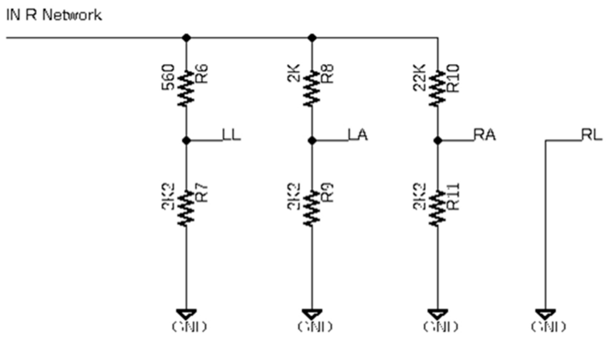

FIGURE 3. NSR and SVT Network Resistors Circuit

Network Resistor Circuit in FIGURE 3 is used to divide the ECG signal value according to the impedance of the body. Here is a breakdown of the contextor pins: pin1 = LL, pin2 = LA, pin3 = RA, pin4 = RL Furthermore the signal value in each pin was calculated by the following formula if it is IN_RESISTOR_NETWORK = INPUT

$$V(p \quad 1) = \frac{R1}{R1 \ +R1} \times \text{INPUT} \tag{1}$$

$$V\ (p\quad 2) = \frac{R1}{R1\ \ +R1} \times \text{INPUT} \qquad (2)$$

$$V(p\quad 3) = \frac{R1}{R1\ \ +R1} \times \text{INPUT} \qquad (3)$$

$$V(p\quad 4) = \text{GND} \qquad (4)$$

Note: R1-R11 is Resistor and GND is Ground, as described in the FIGURE 4.

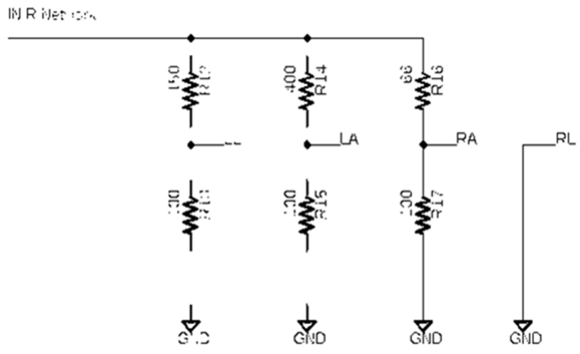

FIGURE 4. Network Ventricular Takikardia Resistor Circuit

FIGURE 6. Hardware Modul

III. RESULTS

Measurement of data on the module with sensitivity values uses an ECG recorder (Digital Electrocardiograph, Model: ECG-9012A, SN: ECG-9012A120435) and an ECG simulator comparison tool (Fluke Biomedical, Model: MPS450, PN: 3789865). The comparison was done by adjusting the sensitivity of the module from the print through the measuring instrument with ECG simulator sensitivity value as a comparison tool.

A. DESIGN OF ECG SIMULATOR

Photos of the display and parts of the ECG Simulator module are shown in FIGURE 5 and FIGURE 6. The display section consists of a character LCD, push on buttons, and 4 output connectors. Meanwhile, the parts consist of a 16x2 character LCD, I2C, push-on button connector, resistor network circuit, DAC, battery, and ArduinoMega 2560.

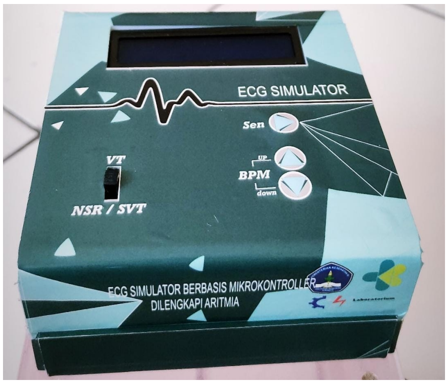

FIGURE 5. The design of ECG simulator

B. THE PROCEDURE LISTING PROGRAM FOR ARDUINO

In this study, the program procedures can be divided into 10 parts, including, SPI Interface Set Up Program, Timer2 Interrupt Program, Sensitivity Setup Program, BPM Program Setup Sampled Data Signals ECG, Program Setting Total Sample Data, Calculation Period of Sample Data Program with Silent Period, Interrupt Function Program, DTOA Send Program, and LCD Display Program as shown in FIGURE 7. The procedure can be explained in the following stages. (1) First, the SPI interface Set Up program is carried out via pin 53, pin 52, and pin 51. In this case, pin 53 is used for the selection of the D/A converter chip, pin 51 is used to send SDI data, and pin 52 is used for hours. 2). Second, timer2 Interrupt Program is used by the author to count exactly 1,000 milliseconds before interrupting. Timer2 has 8 bits and counts up, where when it reaches 255, the timer will "overflow" and return to zero. Selecting the 128 pre-scaled hours to split gives a count rate of 8 uses per count for Timer2. So, it takes 125 ticks of Timer2's clock to get 1000 msec (.000008 * 125 = 0.001 seconds). Therefore, it is necessary to load the Timer2 counter with (256 - 125 = 131) TCNT=131 as the start of the calculation to get a repeat in every 1000 ms. In this case, the measurement of the BPM value of the 1 mV Sensitivity Module is based on the printout. 3). Third is the Program Sensitivity Setting Program. Author used pin11 as input for sensitivity settings. In the above program, there are initials "change=1" which is used for looping the 0.5mV sensitivity program and "change=2" which is used for looping the 1mV sensitivity program. 4). Fourth is programming the BPM Setting

Program. The author used pin 10 to increase the BPM and pin 9 to decrease the BPM value.

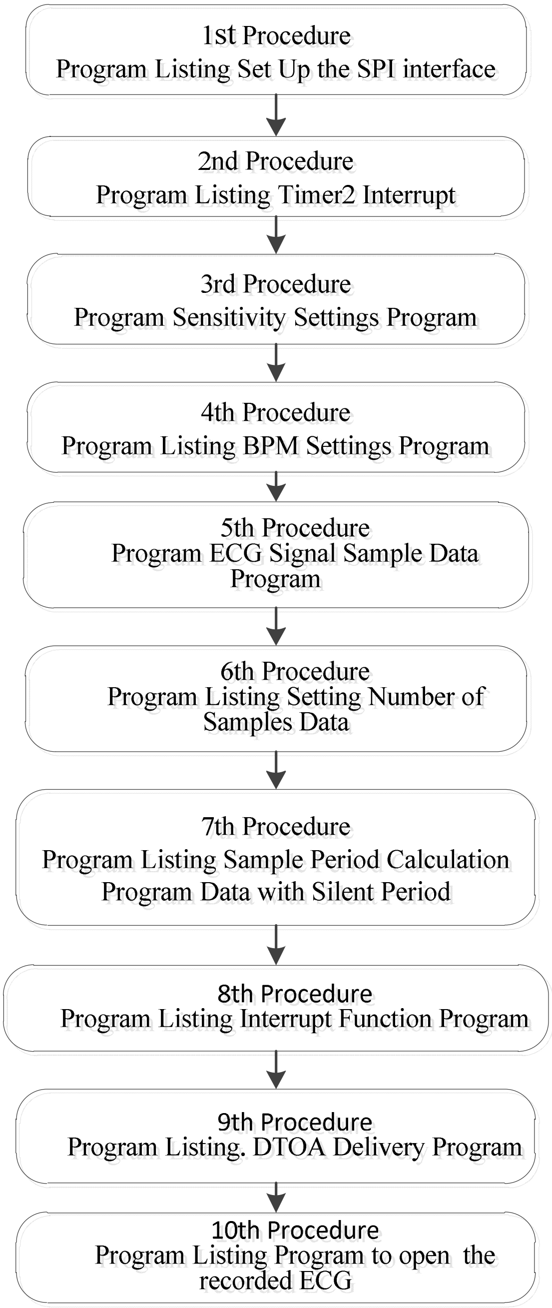

FIGURE 7. The procedures to implement the software

The pin is connected to the pushbutton and sets the initial "moveBPM" value. 5). Fifth is the ECG Signal Sample Data Program. There is a loop requirement with the initials "SG" to change the waveform and "change" to change the sensitivity value. There are 5 wave array data in the program used by the author which is set by increasing or decreasing the "SG" value. 6). Six is the List of Programs for Setting the Number of Data Samples. The number of data samples set at those issued. There are 500 data points entered. Meanwhile, each distance between points based on the program is worth 1 ms. Therefore, among the 500 data, there is a period of 500 ms or a frequency of 2 Hz. So, if the “divisor = 0” factor is a 2Hz signal, only the largest BPM will be formed with a value of 120 Beats per Minute. To have a higher BPM, it is possible to add a divisor variable. The greater the value of the divisor variable, the greater the BPM value (maximum value 200 with BPM 240). The author used programmed timer2 to count exactly 1,000 milliseconds before interrupting. Timer2 has 8 bits and counts up, where when it reaches 255 the timer will "overflow" and return to zero. Selecting the 128 pre-scaled hours to split gives a count rate of 8 uses per count for Timer2. So it takes 125 ticks of Timer2's clock to get 1000 msec (.000008 * 125 = 0.001 seconds). Therefore, it is necessary to load the Timer2 counter with (256 - 125 = 131) TCNT=131 as the start of the calculation to get a repeat every 1000 ms. Measurement of the BPM value of the 1 mV Sensitivity Module based on the printout. 7). Seventh is the Data Period Calculation Program using Program with Silent Period. The value of the IdlePeriod variable will affect the value of the pause or period from the exit of the 1st ECG signal form to the next ECG signal form. For low BPM, the value of IdlePeriod will be even greater. For example, at BPM 60, this IdlePeriod value will be 500 ms. For the BPM value of 60 itself, the signal form will have a period of 500 ms for the DAC output and the pause will be worth 500 ms. So, total for BPM 60 is 1000ms from ECG signal to next ECG signal. 8). Eighth, the Program Interrupt Function Program was used to set the interrupt output signal. The output is divided into two conditions, namely the condition when the NumSamples are calculated and the condition when the IdlePeriod is calculated. 9). Nineth, the DTOA Delivery Program pin 53 was used to execute commands. The function of this program is to set D/A so that it can send 12bit to the MCP4921 DAC via the SPI interface. 10). Tenth, the program for opening ECG records how many things are displayed on the 16x2 character LCD, including the BPM value obtained from "Bpmmap/10" and the sensitivity value that changes according to the change in the "change" value.

TABLE 1
Comparison of error value on ECG module simulator and standard simulator with sensitive value of 0.5 mv.

Setting Value	Error (%)	
	ECG Module	ECG Simulator
30	0.76	0.622
60	0.478	0.589
120	0.177	0.464
160	0.754	0.529
180	0.121	0.371
200	0.588	0.301
240	0.239	0.386

C. COMPARISON BETWEEN MODULES ECG BPM SIMULATOR WITH THE COMPARATOR

Before testing the power consumption value, first the BPM of the ECG simulator module was compared with a comparison tool to match the standard. Based on the results of the comparison of the BPM values between the ECG simulator modules before being compared with a comparison tool, the error value (%) was obtained as shown in the graphs of FIGURE 8 and FIGURE 9 below [23]

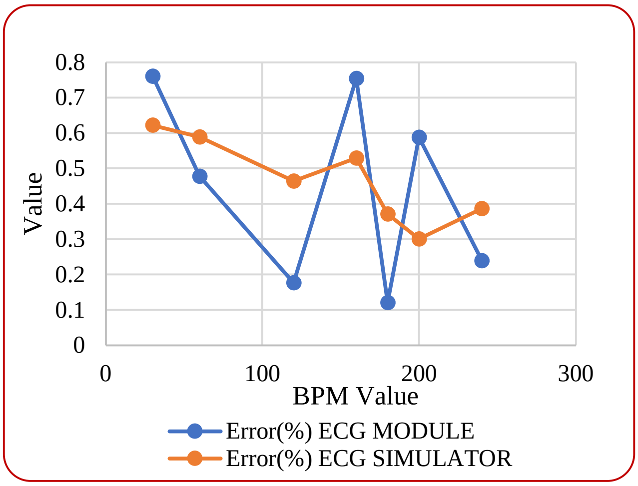

FIGURE 8. Comparison of Error Card Values in ECG Module Simulator and Standard with a Sensitive Value of 0.5 Mv.

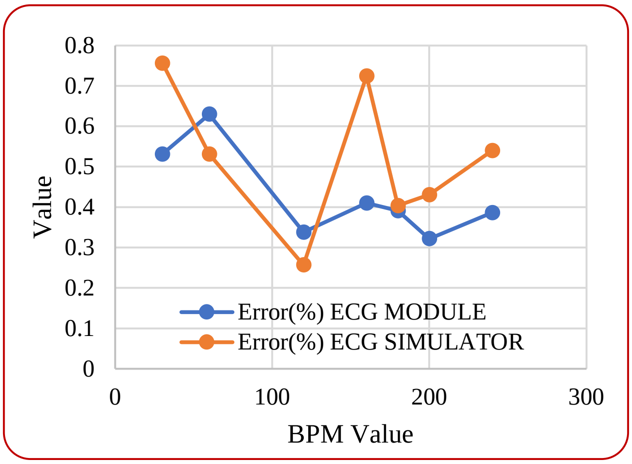

FIGURE 9. Comparison of Error Card Values in ECG Module Simulator and Standard with a Sensitive Value of 1 Mv.

IV. DISCUSSION

After measuring the Fluke MPS450 ECG comparison tool with 6 tests, the error results are 0.756% for 30 BPM, 0.531% for 60 BPM, 0.257% for 120 BPM, 0.404% for 180 BPM, and 0.540% for 240 BPM at sensitivity setting of 0.5mv as shown in TABLE 1. The error rate for the Arrhythmia parameter is 0.410% for Ventricular Tachycardia of 160 BPM and 0.322% for Supraventricular Tachycardia of 200 BPM at a sensitivity setting of 0.5 mv. Meanwhile, the error rate values for the Normal Sine Rhythm parameter are 0.832% for BPM 30, 0.785% for 60 BPM, 0.350% for 120 BPM, 0.154% for 180 BPM, and 0.575% for 240 BPM at a sensitivity setting of 1.0 mv as shown in TABLE 2. The error rate for the Arrhythmia parameter was 0.628% for Ventricular Tachycardia of 160 BPM and 0.455% for Supraventricular Tachycardia of 200 BPM at a sensitivity setting of 1.0 mv. In this study, it has been equipped with aVL, aVF, aVR outputs, and is equipped with Ventricular Tachycardia and Supraventricular Tachycardia arrhythmia parameters [24]. By knowing the parameter values for Ventricular Tachycardia and Supraventricular Tachycardia, the symptoms of heart disease can be detected as early as possible. However, this study still has a drawback in the form of not being equipped with V1, V2, V3, V4, V5, V6 and for sensitivity is still limited to only 0.5mv and 1.0mv.

TABLE 2

Comparison of error value on ECG module simulator and standard simulator with sensitive value of 1 mv.

Setting Value	Error (%)	
	ECG MODULE	ECG SIMULATOR
30	0.531	0.756
60	0.63	0.531
120	0.338	0.257
160	0.41	0.724
180	0.391	0.404
200	0.322	0.431
240	0.386	0.54

V. CONCLUSION

Based on the results of this study, it can be concluded that the ECG Simulator module using a microcontroller can be used for BPM measurements with settings between 30-240. This BPM is equipped with arrhythmia waveforms, namely ventricular tachycardia of 160 BPM and supraventricular tachycardia of 200 BPM with a sensitivity setting of 1mV. The Arduino Atmega 2560 boot loader microcontroller system uses a 2x16 LCD display, readings on the Bpm module setting for the ECG recorder results at an error rate for the Arrhythmia parameter of 0.628% for ventricular tachycardia at 160 BPM and 0.455% for Supraventricular Tachycardia at 200 BPM at a sensitivity setting of 1.0 mv. Therefore, the quality of this design research can be improved in the future for the sensitivity approaching 90%, so that the research design can be used to measure the BPM value as a module for student learning. Furthermore, in the future, outputs in the form of V1, V2, V3, V4, V5, and V6 can also be added, so that the ECG simulator readings are more complex.

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ATTACHMENT:

a. Schematic+Board: https://docs.google.com/document/d/1qw9Q2WdAgGqXAdGWjqqCF1XWrqMIZwWX_kdhIGrL8s8/edit?usp=sharing
b. Listing Program : https://drive.google.com/folderview?id=12dt1LVCwlkUmEihzYLIULjR3VwnBnkxS