Design and Development of Heart Rate Per Minutes Based on Atmega16 Microcontroller with Alarm Warning

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Abstract. Sport is an activity to train one's body, not only physically but also spiritually, which is useful for maintaining and improving the quality of one's health. The simplest and most cost-effective exercise is jogging, which is usually done in the morning or evening. Sports activities will stimulate the heart to work extra in pumping blood and will expedite blood in the body. So that the benefits achieved are more leverage, it is really recommended to do sports activities with regular and well-structured way, because if you exercise excessively it will be very dangerous if the heart works beyond its normal limits. In this study, a heart rate meter was made which has the principle of controlling and monitoring heart rate per minute, with the hope to make it easier to calculate the heart rate while exercising and provide safety because this tool can inform the normal heart rate when exercising for users. This system is made by using the atmega16 microcontroller as the main module. This monitoring process is carried out by connecting the pulse sensor on the finger whose output is a numeric character on the LCD and the sound of a warning on the buzzer if the heart rate exceeds the normal limit. Based on the results of testing of 20 respondents, the device has been able to calculate heart rate per minute and the buzzer can sound as a warning alarm when detecting heart rate if the heart rate exceeds the normal limit. In addition, the tool designed has a percentage error of 0.72%.

1. Introduction

Sport is an activity to train one's body, not only physically but also spiritually, which is useful for maintaining and improving the quality of one's health. The simplest and most cost-effective exercise is jogging, which is usually done in the morning or evening. Sports activities will stimulate the heart to work extra in pumping blood and will expedite blood in the body. So that the benefits achieved are more leverage, it is really recommended to do sports activities with regular and well-structured way, because if you exercise excessively it will be very dangerous if the heart works beyond its normal limits. Heart rate per minute for normal heart in adults is 60-100 [1]–[4]. If an adult exceeds the normal per minute heart rate this will cause fatal heart disease. The research on heart rate detection that has been previously carried out is titled "Digital heart rate measuring device based on microcontroller ATMega8535". Where in the study heart rate measurements using sensors in the form of electronic circuits such as LEDs and light sensors. Therefore, the research "Design of a Heart Rate
Per Minute Microcontroller-Based Heartbeat Counter with Alarm Warning” was raised so that sports such as jogging can still be done safely and comfortably without worrying about excessive exercise with the presence of this heart rate meter, making it easier to watch - detect heart rate when you exercise. In this research, a device that can calculate heart rate per minute will be made to monitor the heart rate while exercising with a warning sound.

2. Literature Review
2.1 Heart
The heart is a vital organ and is the last defense for life other than the brain. The pulse in the heart cannot be controlled by humans. Cone heart is located in the thoracic cavity (chest) between the two lungs posterior to the sternum (breastbone) [2]. Normally adults beat about 60-100 times per minute. In children the baby beats faster, but emotional and hormonal activity can affect the heart rate so that it changes its beat [3] - [4].

2.2 Mikrokontroler ATMega16
AVR is an 8-bit RISC (Reduce Instruction Set Compute) microcontroller based on Harvard architecture made by the Atmel company [5]–[8]. AVR (Advanced Versatile RISC) or Alf and Veg's Risc Processor derived from the names of two Norwegian Institute of Technology (NTH) students, Alf-Egil Bogen and Vegard Wollan [5]. AVR has an advantage compared to other microcontrollers which has a faster program execution speed because most of the instructions are executed in 1 clock cycle, faster than other types of microcontrollers. AVR microcontroller [9]–[12] has complete features such as internal ADC, internal EEPROM, timer / counter, watchdog timer, PWM (Pulse Width Modulation), I / O port, serial communication, comparator, I2C and other enhancements. In general, the AVR microcontroller is divided into five types of families, namely TinyAVR, MegaAVR, XMEGA AVR, UC3 AVR32, and AVR32 AP7. The difference that is owned by the five types of AVR is a feature that is in each microcontroller, which has advantages and disadvantages of each. ATMega16 [13]–[16] is a MegaAVR type which is a low-power 8 bit CMOS microcontroller and has 32 general purpose registers [6]. Figure 1 is a configuration of the ATMega16 AVR pin [17]–[20].

![ATMega16 AVR pin configuration](image1.jpg)

Figure 1. ATMega16 AVR pin configuration

2.3 Pulse Sensor
The pulse sensor works by utilizing light. When this sensor is placed on the surface of the skin, most of the light is absorbed or reflected by organs and tissues (skin, bones, muscles, blood), but some of the light will pass through body tissue that is quite thin [7]. Figure 2 is the physical form of the pulse sensor.
2.4 Liquid Crystal Display (LCD)
Liquid Crystal Display (LCD) [2], [21]–[23] is a form of liquid crystal that will emulsify if given a voltage. The LCD used is a 16 X 2 LCD with each character formed by 8 pixel rows and 5 pixel columns [8]. Figure 3 is a physical form of LCD 16x2.

2.5 Buzzer
Buzzer [24]–[27] is an electronic component that functions to convert electrical vibrations into sound vibrations. Basically the working principle of the buzzer is almost the same as the loudspeaker, so the buzzer also consists of a coil mounted on the diaphragm and then the coil is flowed so that it becomes electromagnetic, the coil will be attracted into or out, depending on the direction of the current and the magnetic polarity, because the coil is mounted on the diaphragm back and forth so that it makes air vibrate which will produce sound [9]. Figure 4 is the physical form of the buzzer.

3. Methodology
3.1 Literature Review
The stage of conducting a literature review begins by collecting various references in the form of books, journals, theses, online sources related to the final project Designing a Heart Rate Per Minute Counter Based on ATMega16 Microcontroller with a Warning Alarm.

3.2 Needs Analysis
This needs analysis includes hardware and software requirements.

3.3 Research Planning
Research planning includes: a. Hardware design Hardware design is done to get a picture of the design of electronic circuits and patterns of communication between existing hardware. b. Tool work system design The tool work system design phase is carried out after an overview of communication between hardware is obtained.
The working system of this tool includes the design of sensor sensitivity in responding to the heart rate of the input/output device communication with the microcontroller, as well as the algorithm applied to the microcontroller. c. Software design The programming language used in this study is the basic compiler language. The programming algorithm designed refers to the working system of the tool, where this program allows the microcontroller to be able to process signals from input/input devices and provide output/output device measures.

3.4 Integration
In the Integration phase, the results of the planning and needs analysis are processed to be made into a whole system. This stage is carried out in order to realize this tool into real form, by integrating system design, hardware and software.

3.5 Testing
This testing phase involves testing the hardware and software.

3.6 Implementation
This stage is the final stage after a series of testing of the device.

4. System Design
The design that will be carried out in this study includes the design of hardware (hardware) and software design (software). The design of a hardware device begins with designing a block diagram and the working principle of a tool, then continues to design a series of tools by combining the whole device into a controlled system.

4.1 Block Diagram and Tool Working Principle
a. Block diagram
Figure 5 is a block diagram of a minute-based heart rate counting device based on the ATMega16 microcontroller with a warning alarm.

![System Block Diagram](image)

b. The Working Principle of the Tool
This tool will work based on the system as a whole and integrated from each series in which the principle of working the series of tools or systems are as follows: 1) Pulse sensors function to detect heart rate. When this sensor is placed on the surface of the skin, most of the light is absorbed or reflected by organs and tissues (skin, bones, muscles, blood), but most of the light will pass through the body tissue which is quite thin. Heart rate detected through the skin surface by the sensor functions as an input (input) and is still a voltage which is also an analog quantity to be sent to the microcontroller. Furthermore, the microcontroller processes the signal or data from the heart rate using the ADC facility to convert the output voltage into digital data that is recognized by the microcontroller. 2) Microcontroller processes the signal or data from the heart rate by counting the heart rate data continuously every minute, then get the heart rate data per minute. The heart rate data per minute is obtained by multiplying the heart rate calculation results for 15 seconds by 4, because 15 seconds is ¼ minutes. The heart rate data will be compared continuously with the normal heart rate. Furthermore, the microcontroller will send data or signals as output to the buzzer and LCD circuit. 3) This system is equipped with an output device (output) such as an LCD that functions as a medium for displaying heart rate data and a buzzer device that functions as a warning alarm sound when the heart rate data exceeds normal limits.
4.2 Hardware Design

Hardware (hardware) is the main and most important component in making this system [28]–[34]. The hardware design in this study include: a. The Minimum Circuit Design of the ATMega16 System The microcontroller used is the type of AVR ATMega16 which is a single chip that functions as a data processing center and device controller. ATMega16 was chosen because it is easy to get on the market, has a number of pins according to needs and a practical circuit because it is arranged in one module that is very easy to use, simple and does not take place. In order for the microcontroller to work, an additional circuit is needed for the microcontroller called the minimum system circuit, the function of this circuit is almost the same as the motherboard contained in the computer. In this study, the minimum system applied is quite simple, for hardware communication it can be directly connected to the pin in the port of the microcontroller. Figure 6 is the design of the ATMega16 minimum system schematic circuit.

![Figure 6. ATMega System Minimum Schematic Series16](image)

The pin functions on the minimum ATMega16 microcontroller system can generally be used as I / O. The ports on ATMega16 are ports A, B, C and D, where each port consists of 0-7. Examples of ports consist of ports A.0 to portA.7, as well as other ports. In addition to general functions as I / O, each port has its own special function. There are facilities that serve to interrupt, serial communication, generate PWM pulses, and others. In this heart rate / heart counter study, the special function, namely ADC (Analog to Digital Converter), is available on the ATMega16 microcontroller, there are 8 ADCs which happen to be inport, not owned by other ports. Where the maximum ADC on the ATMega16 microcontroller is 10 bits, if it is minimized 1023. The use of ADC facilities in this study because the output of the pulse sensor is still a voltage that is still in the form of an analog quantity. While the microcontroller used can only process input in the form of logic 0 and 1 or can only recognize 0 volts and 5 volts. Therefore ADC is needed to convert the output voltage into digital data that is recognized by the microcontroller. b. LCD Circuit Design The LCD circuit planning aims to make the LCD as a display of the number of heart beats per minute fully controlled by the ATMega16 microcontroller. LCD used type 16x2 which means 16 columns and 2 rows. On the LCD there are 16 pins that will be connected to port B on the ATMega16 microcontroller. Figure 7 is the design of the LCD circuit.

![Figure 7. LCD schematic circuit](image)
In LCD circuit design, RS pin is connected to PortB.0, pin E is connected to PortB.1, DB4 pin is connected to PortB.2, DB5 pin is connected to PortB.3, DB6 pin is connected to PortB.4, and DB7 pin is connected with PortB.5. so not all LCD pins are connected to the pins on the microcontroller, only the 6 pins above are needed to be connected to the microcontroller pin so that it can be controlled by the microcontroller ATMega16.

c. Design of Buzzer Circuits
The buzzer circuit functions as a warning in the form of sound, so that the buzzer circuit can be controlled by a microcontroller it needs to be connected to a specific pin on the microcontroller. Figure 8 is the design of the Buzzer series.

![Figure 8. Buzzer Schematic Series](image)

In the design of the buzzer circuit connected to portD.0 there is no specific reason for the selection of ports because for buzzer control such as the above circuit which has received a positive voltage (VCC) first so that the microcontroller only needs to provide negative voltage, such a circuit is called active low circuit. In controlling it, it only needs the I/O control function, so all ports on the microcontroller can control it.

d. Pulse sensor design
In this pulse sensor circuit planning it aims to control or process the sensor output using a special ADC facility on the ATMega16 microcontroller. Figure 9 is the design of the pulse sensor circuit.

![Figure 9. Pulse Sensor Schematic Circuit](image)

In the design of a pulse sensor circuit connected to ADC 0 which happens to be located in PortA.0. ADC value will change according to the output of the sensor in the form of voltage.

e. Overall Hardware Design
After designing the hardware, the next stage is the design phase for the entire hardware. Hardware such as pulse sensors, buzzers, and LCDs are connected to the microcontroller via predefined ports. At this stage, the entire hardware unit or set of tools is transformed into a prototype so that it can be directly simulated. Figure 10 is a whole schematic set of hardware.
4.3 Software Design
Software is needed as a protocol between the microcontroller and other hardware components. Based on the concept in hardware design, the designed program is expected to be able to process heart rate data to the microcontroller or vice versa. a. The design of microcontroller software flow diagrams

To facilitate the preparation of software on the microcontroller, it is necessary to make a flow diagram (flowchart). Figure 11 is a microcontroller software flow chart.

Figure 11. Flow Chart of Microcontroller Software

When the program starts, the initialization process begins with the registration of the microcontroller and the microcontroller pin configuration that will be used to control the components and input data from the sensor. Consists of configuring to activate the timer, ADC configuration, LCD pin configuration, buzzer configuration and start button configuration. Make the variables needed for processing values, the variables used are time variables, ADC values, heart counts, BPM, and normal limits. The workflow of this system will work when the start button is activated. Previously the on button is activated then the sensor is first mounted by the hand. Then when the start button is activated the sensor will work (counting the number of pulses). If a pulse is detected, the system will automatically calculate the heart rate for 15 seconds, then the timer will stop first and the Beat Per
Minute (BPM) calculation will be carried out. In this process BPM can be calculated by multiplying the heart rate calculation results for 15 seconds by 4, because 15 seconds is \( \frac{1}{4} \) minutes. Then the process continues if the heart rate data per minute exceeds the normal limit, the buzzer will sound, if not the buzzer will turn off. The last process if the device is not turned off then the process to calculate the heart rate will be repeated again. If the device is turned off, the program is finished. b. Design of ATMega Microcontroller Programming Algorithm 16

The design of a program algorithm aims to determine the program flow before the program is written and incorporated into the microcontroller. Algorithm design makes it easier when writing programs and makes writing programs more directed. The program algorithm will define actions to be taken by the microcontroller such as receiving an input signal and giving an output signal to the hardware. This programming algorithm functions to define the variables used for program writing.

Making software algorithms using the AVR Basic Compiler program that functions to write program code and compile it into a hex file. The hex file that is generated after the compilation process will be downloaded into the microcontroller. So the microcontroller will work in accordance with the commands that exist in flash memory.

5. Result and Discussion

After the design and manufacture of tools and programs have been completed, a system test is performed to find out whether the tools that have been designed can run as planned. Tests carried out include testing hardware such as a minimum circuit ATMega16 system, LCD, Pulse sensor, and buzzer. The test for the incorporation of all components used in testing the overall system. The tests are carried out separately on each unit or series block and carried out in an integrated system for the overall testing.

5.1 Overall System Testing

This overall test involves the performance of all components in order to determine whether the device is able to work properly and can detect heart rates or not. Overall testing is done by assembling all components or tools used in an integrated manner. The whole system testing stages are as follows: a. Connects all hardware components such as minimum ATMega16 system, LCD, Pulse sensor, and Buzzer. b. Download the program into the ATMega16 microcontroller. This test aims to determine whether the heart rate calculation process in this system can function as expected. Figure 12 is a display of the overall test results. The monitoring process in the heart rate meter will work in accordance with the sensor response that is read and programmed in the microcontroller. Indicator of success on this tool is in the form of an output number of heartbeats that appear on the LCD.

Figure 12. Display of Overall Testing Results

In the device, if the sensor has responded then the system will run in accordance with the program and produce an output heart rate that will be displayed on the LCD as shown in figure 12. In addition, if the number of heartbeats exceeds the normal limit, the output will be a warning sound on the buzzer. In the picture 12 characters displayed on the LCD are the symbol t for time, N for normal BPM, pulse for input heart rate that is read on the pulse sensor at the time of measurement and BPM for the number of heartbeats detected within 1 minute.

5.2 Testing Analysis

From the overall results of testing the equipment that has been done, it can be explained that the heart rate calculator based on ATMega16 microcontroller with this warning alarm functions in accordance with the previous design. Based on the test, it is known that the heart rate calculation tool per minute can work to respond to the heart rate per minute in accordance with the input read in the system and the number of heartbeats that are read according to a person's condition at the time of measurement. Each hardware component such as the minimum circuit ATMega16 system, Liquid Crystal Display (LCD), Pulse sensor, and buzzer can be connected between devices and can function and work well too.
Table 1. Tool Testing Results

| Name  | BPM Actual | BPM Measured | Sound  | Error (%) |
|-------|------------|--------------|--------|-----------|
| Mia   | 104        | 104          | berbuni| 0.00%     |
| Denia | 95         | 95           | Tidak berbuni| 0.00%    |
| Dena  | 108        | 108          | berbuni| 0.00%     |
| Dini  | 128        | 124          | berbuni| 3.23%     |
| Eduar | 124        | 124          | Berbuni| 0.00%     |
| Emy   | 112        | 108          | Berbuni| 3.70%     |
| Janar | 88         | 88           | Tidak berbuni| 0.00%    |
| Louis | 84         | 84           | Tidak berbuni| 0.00%    |
| Maria | 120        | 120          | Berbuni| 0.00%     |
| Patrissia | 104 | 104          | Berbuni| 0.00%     |
| Peter | 104        | 104          | Berbuni| 0.00%     |
| Prina | 108        | 104          | Berbuni| 3.85%     |
| Raoda | 116        | 112          | Berbuni| 3.57%     |
| Riska | 88         | 88           | Tidak berbuni| 0.00%    |
| Sofia | 140        | 140          | Berbuni| 0.00%     |
| Vina  | 92         | 92           | Tidak berbuni| 0.00%    |
| Willy | 104        | 104          | Berbuni| 0.00%     |
| Yato  | 92         | 92           | Tidak berbuni| 0.00%    |
| Yudi  | 88         | 88           | Tidak berbuni| 0.00%    |
| Yuwono| 116        | 116          | Berbuni| 0.00%     |

Total Error: 14.35%
Rate-rata Percentage Error: 0.72%

Based on the results of tests that have been carried out, the results of data consisting of 20 respondents indicate that each person has a different heart rate depending on conditions during the test such as in a state of calm or in a state of many activities. Factors that differentiate a person's heart rate are also due to a person's different health, different quality of exercise, age, and many more factors that can influence a person's heart rate. In a test consisting of 20 respondents, there were some people whose heart rate exceeded the normal limit, so the buzzer was active (beeping). In addition, it can be seen that the heart rate test results show a relatively small error and the results are almost stable between tool measurements with manual measurements. This shows that the measurement data experienced quite small errors. Comparison of measurement results with manual calculation tools (calculation of the pulse on the wrist) can be seen that the measurement results error of 0.72%. This can be caused by manual calculations performed on the wrist to allow smooth pulses to go undetected. Whereas the measurement of heart rate using this measuring instrument is carried out on the fingers with sensors mounted attached to the fingers. In the heart rate sensor testing that has been done, the resulting output in the form of data or heart rate signals that are more easily detected at the fingertips. The light on the sensor will be able to work effectively if placed on the tip of the finger because this section is thin which makes the blood flow in the body read properly. Proper placement with the location of the sensor on the surface of the fingertips can display data more constant and stable. Placement of the fingers is recommended by the use of this tool to see the results of testing carried out easily and precisely with a very small error. From the results of tests conducted, this tool can be used to calculate heart rates properly.

6. Conclusion

After testing and analyzing the heart rate measuring system per minute based on the ATmega16 microcontroller with this warning alarm, the conclusions can be drawn as follows: 1. The tool can calculate the human heart rate per minute with an average percentage error of 0.72 %. 2. Overall the tools made can work and function as expected. Heart rate measuring devices have given a warning with an alarm when the heart rate per minute exceeds the recommended normal limit of 60-100. 3. This heart monitoring device has a different heart rate input response according to the condition at the time of measurement which is read by the pulse sensor.
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