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RESEARCH ARTICLE

An Implementation of a Single Board Computer as a Home Vital Sign Monitoring System Using a Raspberry-Pi

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Abstract

Health monitoring technology is currently developing rapidly. Examining vital signs such as heart rate, electrocardiogram, respiratory rate, and body temperature is fundamental in determining the patient's health status. Patients with chronic diseases should monitor and record their health parameters periodically, with or without clinical supervision. It requires relatively large costs and a long time to carry out this inspection. This research aims to develop a prototype capable of monitoring patient health conditions and vital signs efficiently, in real-time, and easily operated from home with or without clinical supervision. This prototype equipped with a display of single lead electrocardiographic parameters (lead II), heart rate (HR), respiratory rate (RR), and temperature. As a type of single-board computer (SBC), Raspberry Pi technology has the advantage of designing prototypes in relatively small dimensions, compact, open source with full computing capabilities, and can be connected with other devices. The research results show that the prototype can work well, all parameters can be displayed on the 7" TFT touch screen, and the operation uses Indonesian language instructions. Qualitative test results show that all parts and functions function well. The quantitative tests show that heart rate accuracy in the 30-200 bpm range is 95%, while temperature accuracy for observation points 32, 34, and 36 shows instability, especially at the setting point 34^0C which is still above the tolerance of 0.1^0C. In the future, this prototype has the potential to be developed into a telemedicine device that allows clinical staff to monitor health services remotely.

Keywords: home vital sign monitor, single board computer, raspberry-Pi, single lead

1. Introduction

Globalization and modernization have significantly impacted people's lives, including changes in lifestyle and socio-economic levels. These changes contributed to the shift from causes of disease to causes of death and from communicable diseases to non-communicable diseases (NCDs). Global, regional, and national evidence shows an alarming number of non-communicable diseases. Cardiovascular disease is a non-communicable disease caused by impaired function of the heart and blood vessels. Cardiovascular disease includes coronary heart disease, heart failure, hypertension, and stroke. Cardiovascular disease occurs due to various factors, such as hypertension, obesity, smoking, diabetes mellitus, and lack of physical activity. This disease causes sufferers to become less or even unproductive.

Examining the vital signs is essential for a team of health workers and health services to detect abnormalities, changes in organ function, and other medical problems to help doctors diagnose. It can be done in hospitals, clinics and from home. The numbers on a physical examination of vital signs can provide important information about the patient's health condition. Routine health checks can identify early signs of health problems, making disease treatment more effective. The frequency of body checks depends on factors such as age, health condition, family history, and lifestyle choices.

Vital sign measurements include electrocardiogram, heart rate, body temperature, blood oxygen saturation, and blood pressure. Checking the body's vital signs requires various health equipment, such as an electronic thermometer to measure body temperature, a pulse oximeter to measure blood oxygen saturation, and electrocardiography to measure the heart's electrical activity and heart rate. Observation of these parameters for those who have a history of heart disease and other chronic diseases should be carried out continuously without being limited by place and time [1]. It means that people not only have to undergo health checks at the health center but can also observe their vital health signs at home. Home-care devices that are reliable, mobile, accurate, and affordable are necessary for sufferers of chronic cardiovascular disease. Through this tool, people can independently monitor their health condition, and upon identifying abnormalities, prevention, and further examination can be carried out immediately at the hospital.

Previous research has developed devices and applications for health vital signs monitoring systems that only focus on ECG monitors [2, 3, 4, 5], and other studies have equipped them with various other sensors [6]. Previously, Oka et al. designed a vital-signs monitor (electrocardiogram, heart rate, and respiratory rate) using Arduino with a graphic display on a TFT LCD [7]. In previous research, a vital sign monitor was controlled either by a microcontroller [8, 9, 10], a Programmable System-on-Chip (PSoC) [11], or a Single Board Computer (SBC) [12]. The main differences between microcontrollers, PSoC (Programmable System-on-Chip), and SBC are their function, complexity, and application. Microcontrollers are integrated devices with more limited capabilities, used to control simple systems, and have low power consumption. On the other hand, PSoC provides greater flexibility in designing and programming custom systems. Single-board computer (SBC) technology makes it possible to create miniature devices with full computing capabilities and the ability to connect with other devices. The advantage of SBC is that it is small but can run an operating system, run applications, and connect to other devices via various I/O or network ports. An SBC consists of the required computer system on a single integrated circuit board, including processor, memory, storage, and other computing functions. SBC is more suitable for general processing applications and running operating systems. We have equipped the SBC with various interfaces that allow users to connect and control additional devices.

The urgency of this research is to design a vital-signs monitor with small and compact dimensions that can be easy to operate from home. It capable of monitoring several parameters simultaneously, such as single lead electrocardiography (lead II), heart rate, temperature, and respiratory rate. This screen has a patient data feature so that users can enter their identity. We designed It involves technological devices that allow individuals to regularly monitor and record their health parameters with or without clinical supervision. We chose the Raspberry Pi SBC because of its small size and low power consumption, making it suitable for integrating into portable devices. An open-source operating system with full computing capabilities is equipped with a GPIO (General Purpose Input/Output) port, enabling connection to various sensors and devices. In the future, this prototype holds the potential for development into a telemedicine device that enables remote health monitoring services, especially for chronic disease patients.

The organization of this paper is as follows: Section II explains the materials and methods. Next, section III presents the results, section IV discusses them, and continues with the conclusion in section V of this paper.

2. Materials and Methods

We conducted the study using a prototype-based design. Performance evaluation is driven by comparing existing measuring instruments with prototypes. It involves a series of steps to compare, test, and determine the quality and performance of a measuring instrument or prototype. Biopotential is an electrical signal (voltage) produced by a process of physiology that occurs in the body. Biopotential is generated by the activity electrochemistry of a type of cell called an excited cell. Excited cells are found in the body's nervous system, muscles, and glands. When the cell is excited and stimulated, it produces an action potential, an essential biopotential source in the body. Electrocardiography (EKG) results show a graph of muscle electrical activity in the heart over time. The heart muscle contracts in response to the electrical depolarization of heart muscle cells. ECG is a measured quantity of this electrical activity over time, as recorded from the electrode connections. In 1908, Willem Einthoven published a description of an ECG recording system as medically beneficial. This ECG system uses a particular lead connection method now known as Einthoven's system as shown in Figure 1. Einthoven's lead vectors are based on the assumption that the heart is in a conductive volume [13]. Einthoven's lead system is in the form of three bipolar lead triangles with the heart in the middle position, better known as Einthoven's Triangle.

The prototype used a single-lead ECG, Lead II. Lead II in electrocardiography (ECG) is one of 12 leads or derivations that record the heart's electrical activity from a specific perspective. Lead II records the potential difference between the positive electrode on the right leg and the negative electrode on the left leg [14]. Lead II is often chosen as the single lead in portable devices because it reasonably represents the heart's electrical activity. It can provide helpful information, especially in short-term or routine monitoring.

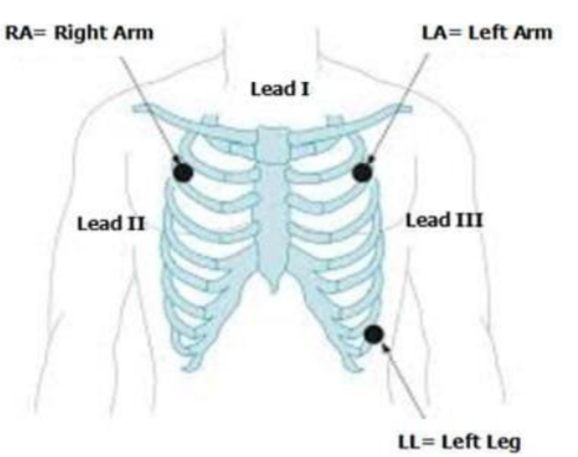

Figure 1. Einthoven's triangle.

2.1 The Diagram Block

The block diagram is depicted and explained in Figure 2. The ECG wave parameters obtained from several leads capture electrical signals from various angles around the heart. Each clue provides a unique perspective on valuable heart rhythm information, assessing heart rate and overall function. If a complete 12-lead ECG is unavailable or deemed unnecessary, one may opt for using a single-lead ECG as an alternative. A single-lead ECG uses only one set of electrodes to record electrical signals.

This study employs a single lead ECG, specifically Lead II, typically selected as a single lead ECG. The MAX30001 is a single-channel biopotential Analog Front-End (AFE) that provides electrocardiogram, heart rate, and respiratory measurements. Electrodes attached to the chest will detect the heart's electrical activity. The placement of these electrodes can also record respiratory rate through electrical activity in the lungs. The heart and lung electrical signals are small, on the order of millivolts, amplified by a series of instrumentation amplifiers so that the output is on the order of volts. We filter the output signal from the amplifier to eliminate noise signals and convert the interference into digital data.

The Raspberry Pi, as a single-board computer (SBC) [15], has several capabilities that make it a versatile platform that can perform most tasks that a standard computer handles. In this study, the device ran the Unix operating system with a graphical user interface. The Raspberry Pi has a set of GPIO pins that allow it to connect and interact with external hardware, such as sensors, motors, LEDs, and more [16]. These pins can be programmed and controlled using various programming languages. The study uses the QT developer software with the C++ programming language. GUIs provide a more intuitive and visual way for users to communicate with programs or systems than text-based or command-line interfaces [17]. Users can perform actions within a GUI, such as clicking buttons, dragging and dropping elements, entering and interacting with software or computer systems, text, selecting menu options, and interacting with other graphical elements. GUIs often provide visual features such as colors, images, and animations to enrich the user experience.

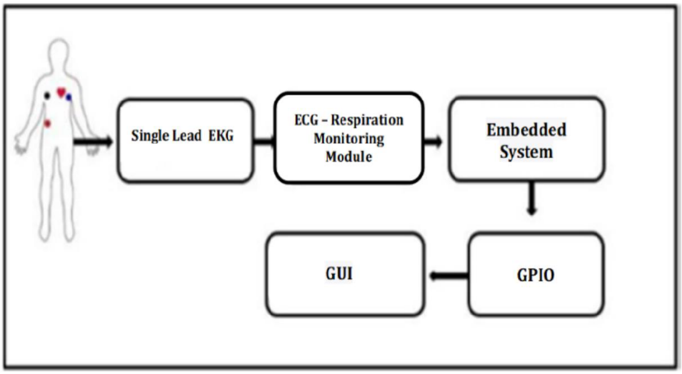

Figure 2. Diagram Block.

2.2 The Material

The tools and materials used in this study include:

- Hardware: Single Board Computer: Raspberry Pi; MAX30003; 7” TFT LCD touchscreen; Patient Cable; Skin Sensor; Adapter Power Supply; Cable Power: Keyboard; and SD card
- Software: Operating System Unix; Software Developer Qt; and language program C++
- Comparison Device: ECG simulator (Fluke); and infant Incubator (GEA-YP100).

2.3 The Flow Chart

Figure 3 displays an explanation of the flow diagram. When the device powers on, a single lead electrode detects the patient’s heart electrical signal, followed by the lung electrical signal. The microcontroller will process the detected signal. The 7" TFT LCD will display the Lead II electrocardiogram, temperature, respiratory waveform, RR, and HR values.

3. Result

The prototype of the vital signs monitor has been completed and is functional and working fine. It incorporates the Raspberry Pi single-board computer and utilizes MAC3001 as a single-channel analog front end. It is more attractive and interactive because the monitor uses a 7" TFT touchscreen. The prototype can display parameters

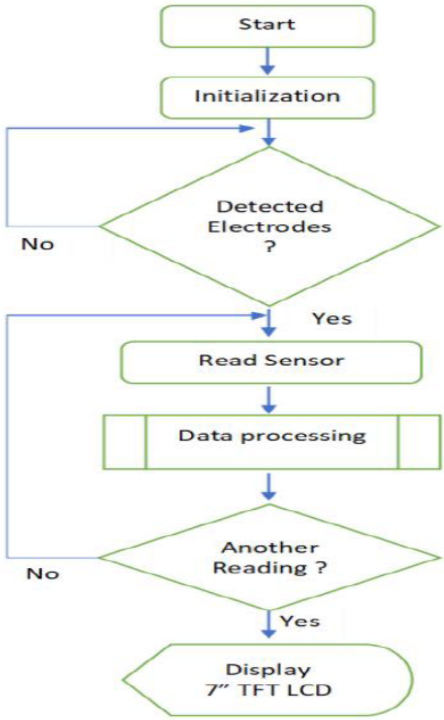

Figure 3. Flow Diagram.

including electrocardiogram, respiratory waveform, HR in beeps per minute, RR, body temperature in degrees Celsius, and a feature with the patient's identity input menu. The prototype of vital signs monitor has been successfully completed functional and working fine as shown in Figure 4. It Equipped with single board computer Raspberry Pi and MAC3001 as single channel analog front end and patient's electrode. SBC is a piece of hardware comprising an entire computer system built onto a single circuit board. This circuit board usually contains all the components needed to run an operating system, such as a processor, memory, storage, and communication interfaces. These SBCs are usually equipped with various interfaces such as HDMI, USB, Ethernet, GPIO (General Purpose Input/Output), and others, which allow users to connect and control additional devices as shown in Figure 4.

We conduct performance tests on the prototype through qualitative and quantitative testing processes. Qualitative testing is a series of procedures to test the function and observe the output of each part of the prototype, such as buttons, electrode functions, and displays. Qualitative testing also applies to respiratory rate by observing changes in signals and values corresponding to variations in the respiratory rate being tested. A single lead ECG installed on the chest must detect variations in the user's breathing rate. Overall, the qualitative test results show that all parts and functions work well as shown in Figure 5.

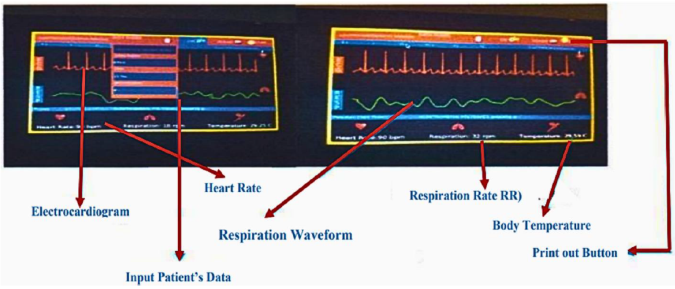

Figure 4. Parameter Display on 7" TFT.

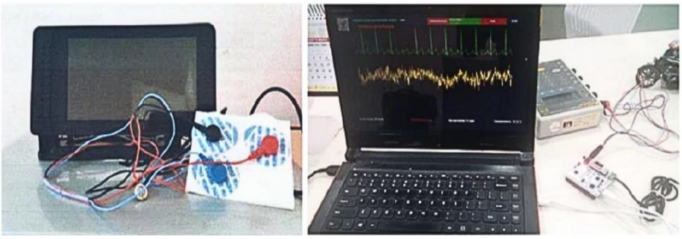

Figure 5. The Main Components of the Prototype.

The quantitative test compares lead II output and heart rate using a standard measuring instrument in the form of an ECG phantom as the gold standard. We conducted Lead II testing using a phantom ECG, as illustrated in Figure 6 and assessed the heart rate (HR) within the same phantom ECG by setting the bpm range on the standard tool between 30, 40, 45, 60, 80, 90, 100, 120, 140, 160, 180 and 200 beep per minute (bpm). Each observation point was repeated up to 5 times to ensure the consistency of the readings. Figure 7 displays the test results. We conducted temperature testing to compare performance by situating the skin sensor within the baby incubator chamber, which was set at 32, 34, and 36^0C, as shown in Table 1.

Table 1. Quantitative Skin Sensor Test Results.

Parameter	Setting Temperature Chamber (^{0}C)	The average value of 3 measurements	Correction
Skin Sensor	32	32.1	0.1
	34	34.3	0.3
	36	36.1	0.1

4. Discussion

The vital signs monitor proposed in this study uses a single lead ECG, Lead II. Lead II records the electrical difference between the left leg's positive electrode and the right arm's negative electrode. The position of the negative electrode from the right

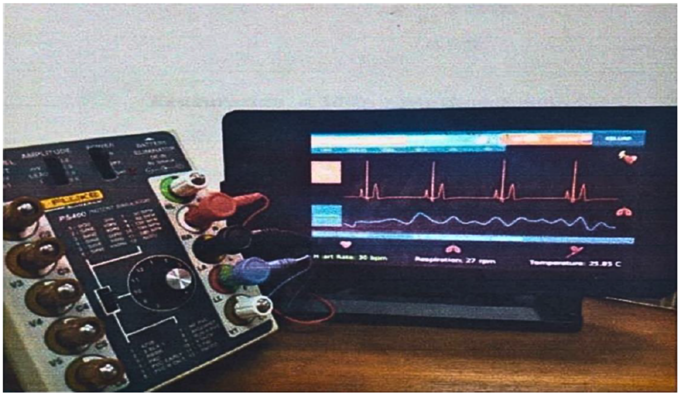

Figure 6. Quantitative Testing Lead II Using the EKG Simulator as Gold Standard.

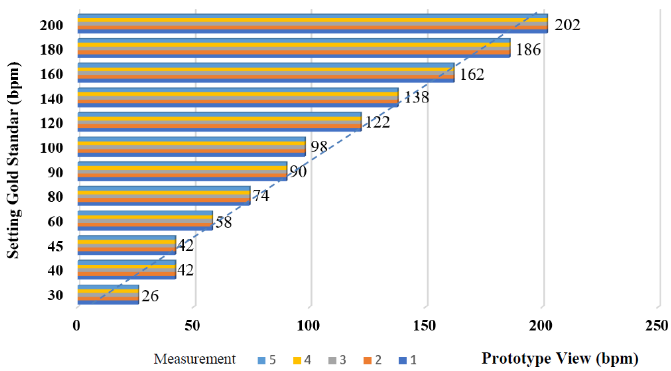

Figure 7. HR quantitative Testing Chart Using ECG Phantom as Gold Standard.

arm and the positive electrode from the left freedom produces an optimal angle for recording a suitable ECG signal. This position of the electrodes allows Lead II to record the electrical activity that occurs vertically through the heart. In Lead II, the P wave (represents atrial depolarization), the QRS complex (represents ventricular depolarization), and The T wave (represents ventricular repolarization) are observable [18]. Lead II is one of the 12 standard leads in the ECG, commonly used in diagnosing and monitoring heart disease. Lead II is generally chosen as the single lead in a single-channel EKG because it provides relatively representative information about the heart's electrical activity. Lead II is one of the leads frequently used in patient monitoring in the hospital or during long-term cardiac monitoring using a Holter monitor or others portable ECG recorder. However, the single-lead EKG has limitations in providing a complete picture of the heart's electrical activity. For a more accurate and comprehensive ECG examination, experts recommend using a multi-lead ECG, which provides a more comprehensive diagnosis [18]. The respiratory rate measures a person's respiratory frequency in one minute. The relationship between a single Lead

II on electrocardiography (ECG) and respiratory rate measurements due to the ECG waveform on Lead II can also provide additional information regarding respiratory activity. Lead II on the ECG is not designed explicitly to measure respiratory rate; ECG waveform changes can provide indirect information about respiratory activity. Figure 6 shows the appearance of the respiration rate signal following variations in heart rate changes measured using an ECG phantom. When a person breathes, the diaphragm's movement and lung volume changes can affect the heart in the chest. It can affect the electrical current in the heart recorded by the ECG electrodes. We choose an SBC Raspberry Pi as central processing unit (CPU). It is a complete computer with all the core components needed to run a system on a single board. SBC is one of the developments in embedded system technology or embedded systems, which also influences the advancement of technology applications in prototype designs of medical devices or equipment. The embedded system is a system-based microprocessor used to perform specific tasks [9-12]. The prototype uses a MAX30001 as a pre-amp. MAC 30001 is compatible with the Arduino platform. The MAC 30001 Single Lead ECG module can acquire ECG signals using only one electrode (lead). MAX30001 is a single biopotential channel that provides electrocardiogram (ECG) waveforms, heart rate, pacemaker edge detection, and one bioimpedance channel capable of measuring respiration [18]. The MAX30001 analog contains a single biopotential channel that transmits the electrocardiogram (ECG) waveform and heartbeat and a single bioimpedance channel capable of recording breathing. We use Qt Software, which produces a GUI with the Unix language as its algorithm. Qt is developer software for this application's user interface, both visually and functionally. A graphical user interface (GUI) is a user interface that uses graphic elements such as icons, buttons, windows, and menus to allow users to interact with software or a computer system. Text, selecting menu options, and interacting with other graphic elements. The GUI also provides visual features such as colors and images, which will be displayed on the value or signal form to make it more attractive. Heart rate performance testing is based on MK 012-18 [19] issued by Direktorat Jenderal Pelayanan Kesehatan Kementerian Kesehatan. Testing consists of physical, functional, and performance testing. Parameters tested in performance testing using ECG phantom include heart rate and standard lead II display. The limitations of the ECG phantom make it impossible to measure respiration rate performance. Respiration rate's testing is carried out by recording changes in chest breathing variations through a single lead. The tolerance value for heart rate testing is 5% or five bpm. Overall, the heart rate performance assessment as shown in Figure 7 is still within the tolerance range. Whereas, temperature accuracy testing is based on MK Number 050-18 [19]. The calibration medium used is a baby incubator whose temperature is stable at 32, 34, and 36 degrees Celsius. The skin sensor is placed in the chamber baby incubator, the temperature read is recorded, and repeated measurements are carried out up to 3 times each. The tolerance value for each test parameter is: temperature 32 - 37 is 0.1 degrees while 38-39 is 0.2 degrees Celsius. The quantitative results in Table 1 show that the temperature values read are still above tolerance, especially at 34^0C. This instability may be related to the calibration media used and the quality of the sensor.

5. Conclusion

Overall, the vital body signs monitor prototype with lead II electrocardiogram parameters, respiration waveforms, HR (heart rate), Respiration Rate (RR), and body temperature can work properly and be displayed on a 7" TFT touch screen. Qualitative test results indicate that all buttons and sensors are operational and functioning correctly. The standard display includes the Lead II electrocardiogram signal and respiration signal. Quantitative tests show that heart rate accuracy in the 30–200 bpm range is 95%, while temperature accuracy for observation points 32, 34, and 36 shows instability, especially at the 34^0C setting point, which is still above the tolerance of 0.1^0C. In the future work, the prototype can be developed more fully by adding a transmission mode finger sensor to measure oxygen levels in the blood. The transmission mode enables the execution of quantitative tests using a pulse oximeter simulator. In addition, this prototype has the potential to be integrated with other medical devices so that the design becomes compact. Adding parameters allows the prototype to be used for home telemonitoring, utilizing the features available on the Raspberry Pi single-board computer and combining them with IoT technology.

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