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DESIGN AND IMPLEMENTATION OF AN AFFORDABLE PATIENT MONITORING SYSTEM

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Abstract: Heart attacks and strokes are becoming the leading causes of death worldwide. According to a 2012 World Health Organization (WHO) report, approximately 15 million people suffer from strokes each year, with 5 million fatalities and another 5 million left permanently disabled. The consequences of strokes extend beyond physical health, impacting families and societies both economically and socially by depriving them of productive members. To address this issue, this research focuses on developing a device capable of monitoring an individual's health in real-time. The device detects sudden physiological changes and displays the results on a mobile smartphone. It also allows the data to be stored and transmitted to hospitals or concerned individuals via SMS or email. Additionally, the system is designed to periodically monitor the health status of elderly individuals. Since the human body exhibits certain abnormalities such as temperature fluctuations and high blood pressure before a stroke occurs, this research emphasizes signal conditioning and data acquisition for six vital signs: Temperature sensor to monitor body temperature; Pulse sensor to measure heart rate; Electrocardiogram (ECG) sensor to track heart activity; Blood oxygen sensor to determine oxygen saturation levels; Airflow sensor to measure respiration rate and Position sensor to track patient posture (e.g., sitting, standing, supine, or prone). The primary objective of this research is to design and implement a portable, cost-effective, non-invasive wireless device that enhances healthcare, reduces mortality rates, and minimizes disability. The study was successfully executed, ensuring affordability for the general public.

Keywords: Electrocardiogram (ECG), Heartbeat, Stroke, Temperature, IOIO-OTG development board.

Introduction

A stroke occurs when there is a sudden interruption of blood flow to the brain, while paralysis refers to the loss of sensation and function in certain parts of the body. Strokes are primarily caused by a blockage in the arteries supplying blood to the brain (ischemic stroke). In some cases, a stroke results from bleeding into brain tissue due to a ruptured blood vessel (hemorrhagic stroke). Since strokes develop suddenly and require immediate medical intervention, they are often referred to as brain attacks. If stroke symptoms last for a short duration typically less than an hour, it is classified as a transient ischemic attack (TIA) or mini stroke (The Internet Stroke Center, n.d.2025; World Heart Federation, 2014).

The need for continuous patient monitoring in critical care settings is essential. A bedside monitoring system can alert healthcare providers about sudden changes in a patient's condition, enabling timely intervention. Early detection improves patient care, reduces complications, and prevents disabilities or minimizes their severity.

Several approaches have been proposed for vital sign monitoring devices. (Jovanov et al 2005). developed a Wireless Body Area Network (WBAN) for monitoring physical activity and health status. Their system incorporated ZigBee-compliant wireless communication, a low-power microcontroller, an accelerometer, and a bio-amplifier for ECG monitoring. (Anliker et al. 2004). designed a wearable multi-parameter medical monitoring system. This wrist-worn device measured ECG, oxygen saturation, temperature, and blood pressure, transmitting data to a remote medical control station via GSM communication. Amr Abd EL-Aty (2013) developed a wireless wearable body area network (WWBAN) for long-term health monitoring of elderly individuals. His design used heart rate and blood oxygen sensors to track heartbeat and oxygen saturation, interfacing with an Android smartphone via Bluetooth using an IOIO board as the microcontroller unit

This study aims to develop a cost-effective, non-invasive, and portable biomedical sensor system for monitoring vital signs (heart rate, respiratory rate, blood oxygenation, temperature, and ECG) remotely and in real-time. The system will transmit data to hospitals and medical personnel via a smartphone, tablet, or custom-built wireless device. Additionally, a patient monitoring software system will be implemented to automatically alert healthcare professionals if a patient's physiological state changes. The work was designed for individuals aged 25 and above, as they are at a higher risk of heart attacks and strokes. This age restriction ensures the accuracy and effectiveness of the system's components while simplifying the design and implementation process.

Methodology

The system design is primarily composed of hardware and software components.

Hardware Design

The hardware architecture of this system includes sensors, a microcontroller unit, a power source, a Bluetooth module, and an Android smartphone.

1. Sensors: These are responsible for capturing raw physiological signals from the human body and transmitting them to the microcontroller unit.
2. Microcontroller Unit: It processes the sensor data and sends it to the smartphone via a Bluetooth dongle.

3. Smartphone (Android): Displays the collected data graphically or numerically. The recorded data can be stored on the phone's SD card and shared with hospitals or relatives.

Both analog and digital sensors can be used in this design, but analog sensors are preferred due to their ease of programming for seamless communication with the microcontroller, additionally analog sensors are more cost-effective than digital ones.

The system is powered by two lithium batteries, each rated at 3.7V, connected in series to produce 7.4V as shown in figure 1. The IOIO board, which acts as the microcontroller interface, supports an input voltage range of 5V to 15V and provides 3.3V and 5V outputs. To maintain a steady 5V output, the input voltage must be at least above 5V.

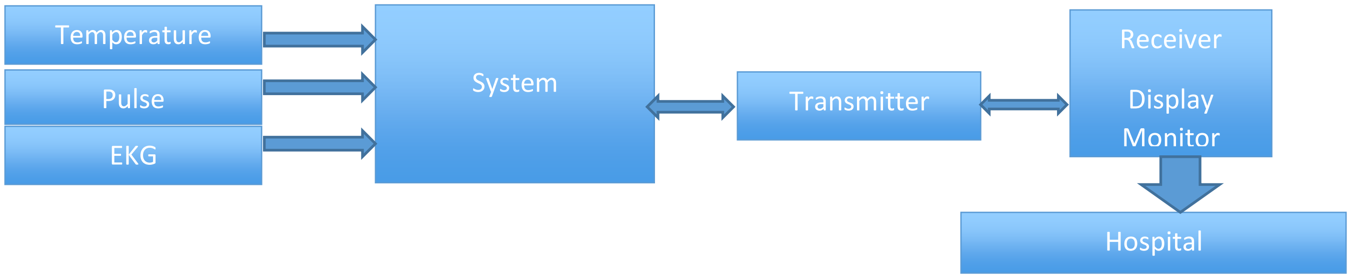


Figure1. System block diagram

Electrocardiogram (ECG) Sensor

An electrocardiogram (ECG) measures the electrical activity of the heart. Each heartbeat is accompanied by depolarization of heart cells, during which positively and negatively charged ions (Na^+, Ca^{2+}, K^+, and Cl^-) move in and out of the cells. This movement generates electrical charges on the surface of each cell. When summed across all the heart's cells, this creates a total electrical charge, which can be detected from the skin as an ECG reading.

The ECG sensor is an analog device that monitors heart activity. The sensor produces an output voltage that fluctuates over time, which can be represented graphically. To measure electrical activity, at least two electrodes (positive and negative) are required to form a circuit. One electrode observes the electrical activity relative to the other, and adjusting their positions alters the viewing angle of the heart's activity as shown in figure 2.

In this system, a three-lead ECG sensor is used. Unlike the standard twelve-lead ECG, the number of electrodes has been reduced for simplicity. Proper placement of the three leads is essential for accurate readings. The bipolar leads measure and display the difference in electrical potential between two points on the body. The three standard leads include: Lead I: Measures potential between the right arm and left arm, Lead II: Measures potential between the right arm and left leg, Lead III: Measures potential between the left arm and left leg. Among the three leads, two are active, while the third serves as an inactive (earth) lead, which can be placed anywhere on the body.

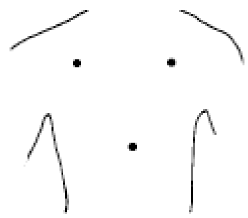
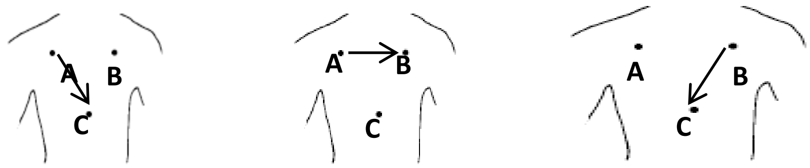


Figure 2. Electrode placement on the body. (Waechter, J. 2012).

Two electrodes are placed on the chest, and one is positioned at the lower left side of the abdomen. These three points generate three leads, each representing an electrical comparison between two points on the chest. Figure 3 below illustrates where each lead is measured. The three bipolar leads together form Einthoven's Triangle. When an action potential begins on the right and moves toward the left side of the heart, a positive deflection appears in Lead I. This principle applies to all leads—whenever electrical activity moves toward a positive electrode, an upward deflection is recorded on the EKG. Lead I records the electrical potential between the right arm (-) and left arm (+), Lead II measures the potential between the right arm (-) and left leg (+), and Lead III records the potential between the left arm (-) and left leg (+). (Renjukumar, B.C., 2010; Kumar, S.A., 2009).



Lead I Lead II Lead III

Figure 3. Locations for lead measurements (Waechter, J., 2012).

Pulse Sensor

The Heartbeat Sensor offers a straightforward method for analyzing heart function. It tracks blood flow through the fingertip or earlobe. As the heart pumps blood through the vessels in these areas, the blood volume fluctuates over time. The sensor emits a small incandescent light through the fingertip or earlobe and measures the transmitted light. A built-in circuit amplifies, inverts, and filters the signal. By graphing this signal, heart rate can be determined, along with insights into the heart's pumping action.

This pulse sensor is based on a photoplethysmograph, a widely used medical device for non-invasive heart rate monitoring. The photoplethysmograph outputs an analog voltage fluctuation with a predictable wave pattern, known as a photoplethysmogram (PPG), as illustrated in Figure 4. The latest version, Pulse Sensor Amped, enhances the raw signal of its predecessor by amplifying it and centering the pulse wave around V/2 (the midpoint of voltage).

Pulse Sensor Amped reacts to changes in light intensity. If the incident light remains steady, the signal stabilizes around 512, the midpoint of the ADC range. An increase in light raises the signal, while a decrease lowers it. The green LED's reflected light changes with each pulse, influencing the sensor's readings.

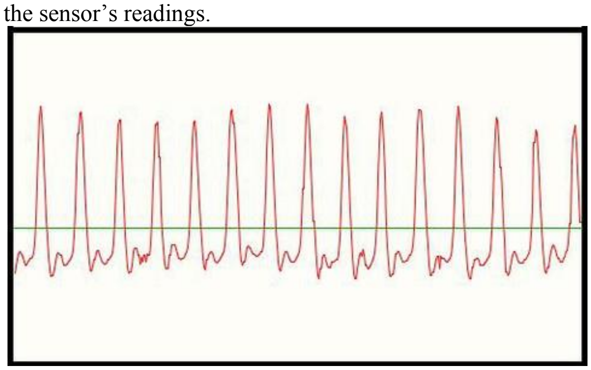


Figure 4. Analog signal voltage along with peak percentage. (Murphy, J. and Gitman, Y., 2014.)

Temperature Sensor

The TMP36 is an integrated circuit temperature sensor that provides an electrical output proportional to the measured temperature. It is a low-voltage, high-precision centigrade sensor that delivers a voltage output directly corresponding to the temperature in Celsius. The TMP36 requires no calibration and offers typical accuracy of ±1℃ at 25℃ and ±2℃ over a temperature range of -40℃ to +125℃. (Sparkfun Electronics US, n.d.2025).

This sensor has three pins: V_{in} (input voltage), V_{out} (analog output voltage), and GND (ground). Measuring temperature with the TMP36 is straightforward simply connect the left pin to a power source (2.7V–5.5V) and the right pin to the ground. The middle pin then provides an analog voltage that is linearly proportional to the temperature. The output voltage remains unaffected by variations in the power supply.

To convert the output voltage to temperature, the following formula is used:

$$\text{Temp in } ℃ = (Vout\ in\ mV) - 500/10 \qquad (1)$$

So for example, if the output voltage is 1V that means the temperature is

$(1000mV - 500)/10 = 50℃$

IOIO-OTG Board

To read sensor data, an input/output (I/O) capability is necessary since different sensors use various output protocols, even though most simply require analog voltage sensing. The sensor interface must support multiple communication methods, such as Pulse Width Modulation (PWM), Serial Peripheral Interface (SPI), and Universal Asynchronous Receiver Transmitter (UART). Additionally, an Analog-to-Digital Converter (ADC) with high resolution and general-purpose I/O is needed for interacting with digital inputs. For these reasons, the IOIO board was selected as the interface, as its API provides support for most of these functionalities. The IOIO board is compatible with both USB cable and Bluetooth modules. In terms of power consumption, it is more energy-efficient compared to other boards. It serves as the central component of the entire system, responsible for executing processes, monitoring, and controlling all connected components and peripherals. The intelligence of the project is embedded in the software running on the IOIO board. (Sparkfun Electronics US, n.d.2025).

The software is written in Java and runs as an application on a smartphone. It is then installed on the IOIO board by connecting the board to the phone via USB cable or Bluetooth dongle. The Bluetooth adapter facilitates wireless communication between the microcontroller and the smartphone. Factors such as operating range, frequency band, maximum data transfer rate, and sensitivity are considered when selecting a Bluetooth adapter, though not all Bluetooth modules are compatible with the IOIO board.

The IOIO-OTG is an I/O prototyping board designed for Android devices running OS version 1.5 or later. It features a PIC24FJ256GB210 microcontroller, which functions as a USB host and processes commands from an Android application. (Sparkfun Electronics US, n.d.2025).

Software Design

To develop mobile applications for smartphones, the Android platform's software capabilities are required. The Android API, which includes various operating system versions, can be downloaded from Google's official sources. Eclipse is the preferred integrated development environment (IDE) for this compilation due to its compatibility with the Android IOIO user guide manual.

Before programming the IOIO board, essential software libraries must be downloaded. The IOIOLib software package contains a collection of libraries for both Android and PC, allowing applications to control the IOIO board. These libraries provide a set of Java interfaces that cover the board's functionalities. When building an application, IOIOLib is packaged into the target .jar or .apk file, making the application self-contained without requiring additional installations. The IOIOLib package includes the following libraries:

1. IOIOLibPC: This library, located in ioiolib/target/pc, contains Eclipse project files and enables interfacing with the IOIO board from a PC.
2. IOIOLib Android: Found in ioiolib/target/android, this library allows users to interface the IOIO board with an Android device.

Additionally, two complementary libraries enhance the IOIOLib Android functionality:

1. IOIOLib BT: Adds Bluetooth connectivity support for the IOIO board.
2. IOIOLib Accessory: Enables Android Open Accessory functionality for connecting to the IOIO board.

These two additional libraries are kept separate because IOIOLib Android is compatible with all Android versions from 1.5 onward, whereas Bluetooth support was introduced in Android 2.x, and Open Accessory is only available on Android 2.3.4 and later. By linking any of these libraries (or both) to the application, the IOIO connection is automatically established through the available communication channel, provided the application is built using Android utility classes as shown in figure 5.

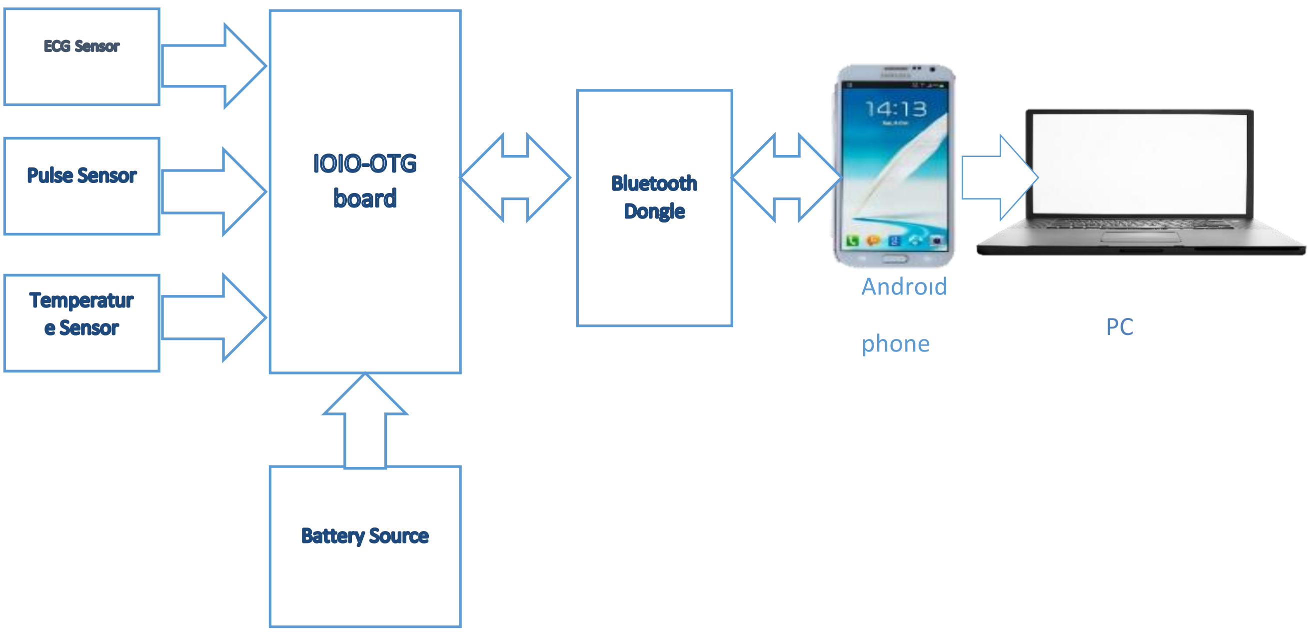


Figure.5. Block diagram of the system

The Android SDK, provided by Google, is a collection of tools designed for accessing Android phone hardware (such as the camera, vibration, and Bluetooth) and includes libraries for Android development. It comes with an Eclipse plug-in called ADT (Android Development Tool), which enhances the Eclipse environment by adding features such as an emulator for testing applications and debugging tools to help developers improve and fix their apps.

To access data transmitted via USB or Bluetooth, specific protocols are required for communication with USB devices. These protocols enable access to registers within a microcontroller that is connected to a host PC via a USB cable. When developing such protocols, variables are assigned to store the addresses of microcontroller registers, using a high-level programming language like Java, as done in the IOIO protocol.

Testing and Results

The patient monitoring device is capable of measuring body temperature and displaying heartbeat data both graphically and numerically, as shown in Figure 6. A screenshot was captured during testing to illustrate this functionality.

Additionally, ECG readings can be used to calculate the heart rate. During testing, multiple data samples were recorded and sent to a PC via email. These data sets were then filtered using MATLAB programming, ensuring accurate heart rate detection within the normal range of 60 bpm to 100 bpm.

Furthermore, the collected data can be analyzed to extract key ECG parameters, such as the PR interval, QRS complex, and QT interval. There are three primary methods for determining heart rate from ECG rhythm: Rule of 300, RR Interval Method,10-Second Rule

The first two methods are used for regular ECG rhythm patterns, while the 10-second rule is applied for irregular rhythms. Figure 7 presents sample data obtained during the testing process.

Figure 6. Screenshot taken during the testing of temperature and heartbeat on an Android phone.

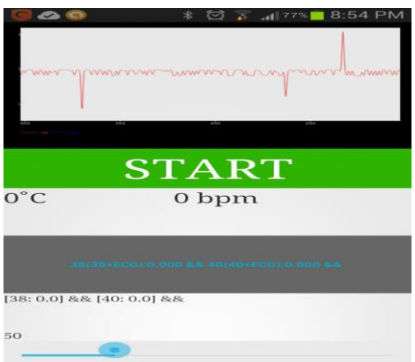


Figure 7. Screenshot of the ECG rhythm recorded during testing.

Conclusion

The primary objective of developing this patient monitoring system was to enhance healthcare by improving the monitoring of vital signs. Early detection of conditions such as heart attacks and strokes are crucial in reducing mortality rates. In regions where medical facilities for treating these conditions are limited, this device can play a significant role by enabling early diagnosis. Additionally, it can serve as a preventive tool for individuals to monitor their health.

In areas where internet access is expensive or unavailable in medical centers, this system remains useful. If an individual notices that their health parameters fall outside the normal range, they can seek medical attention promptly.

As demonstrated in the results, temperature and heartbeat data, along with waveforms, can be recorded and analyzed without the need for supervision. Furthermore, patients can conveniently send their health data via email to their doctors using their smartphones, allowing for remote diagnosis without leaving their homes.

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