# Talking Pulse Oximeter for Visually Impaired Users: Design and Implementation

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***Abstract—A significant portion of the global population depends on visual interfaces to operate medical devices, creating accessibility challenges for visually impaired individuals, elderly users, and patients in low-light environments. Conventional pulse oximeters rely entirely on screen-based displays, limiting independent usage. This paper presents the design and implementation of a Talking Pulse Oximeter, an embedded system capable of measuring blood oxygen saturation ($SpO_2$) and heart rate (HR) while providing voice-based feedback. The system integrates the MAX30102 sensor, Seeed Studio XIAO ESP32-S3 microcontroller, SH1106 OLED display, and DFPlayer Mini audio module. The device operates autonomously and guides users through audio prompts without requiring visual interaction. Experimental results demonstrate that the system achieves heart rate accuracy within ±2 BPM and $SpO_2$ accuracy within ±2% when compared to commercial devices. The proposed system is cost-effective, portable, and suitable for assistive healthcare applications.***

## I. INTRODUCTION

### 1.1 Need for the Research

A large portion of the global population relies on visual interfaces for operating medical devices, which creates serious accessibility barriers for individuals with visual impairments, elderly users with reduced eyesight, and patients in low-light conditions. Conventional pulse oximeters, despite being widely used in healthcare, depend entirely on screen-based displays to communicate measurements such as blood oxygen saturation and heart rate. These devices present numerical values on small LCD or LED screens, making them difficult or impossible to use for visually impaired individuals. According to the World Health Organization, more than 2.2 billion people worldwide suffer from some form of vision impairment, highlighting a critical need for accessible healthcare solutions. For these individuals, the ability to independently monitor vital signs is essential for maintaining dignity, privacy, and safety. The Talking Pulse Oximeter addresses this challenge by providing voice-based output, enabling users to receive health readings through natural language audio without relying on visual interaction.

### 1.2 Objectives

The primary objective of this project is to design and develop a compact, portable pulse oximeter capable of accurately measuring $SpO_2$ and heart rate while providing voice-based feedback. The system aims to integrate a reliable sensor for physiological data acquisition, implement an embedded processing unit for real-time signal analysis, and deliver audio output using pre-recorded voice prompts. Additionally, the project focuses on ensuring accessibility, affordability, and ease of use, making the device suitable for home healthcare and assistive technology applications.

### 1.3 Organization of the Paper

This paper is organized into several sections to provide a comprehensive understanding of the system. Section 2 presents a literature survey of existing work related to pulse oximetry and assistive technology. Section 3 describes the methodology, including system architecture and data processing techniques. Section 4 outlines the problem statement and challenges. Section 5 discusses the system design and architecture. Section 6 details the hardware components used. Section 7 presents the results and discussion, followed by conclusions and future scope.

## II. LITERATURE SURVEY

### 2.1 Review of Existing Work

Pulse oximetry is a well-established technique for non-invasive monitoring of blood oxygen saturation and heart rate. Previous studies have explored the theoretical and practical aspects of this technology. Nitzan et al. provided a comprehensive overview of pulse oximetry fundamentals, including the Beer-

Lambert law and methods for $SpO_2$ estimation[1]. Allen presented an in-depth analysis of photoplethysmography and its application in physiological measurement, highlighting techniques for heart rate detection and signal processing[2]. Rhee et al. demonstrated the effectiveness of voice-enabled medical devices for visually impaired users, showing that audio feedback significantly improves usability and user confidence[3]. Technical documentation for the MAX30102 sensor and ESP32-S3 microcontroller provides essential guidelines for hardware integration and system development[4].

### 2.2 Research Gap

Despite advancements in pulse oximetry technology, existing devices lack accessibility features for visually impaired users. Many systems rely on smartphone connectivity, which introduces complexity and requires familiarity with touchscreen interfaces. Additionally, accessible medical devices are often expensive and not widely available. This project addresses these limitations by developing a standalone, low-cost, voice-enabled pulse oximeter that does not require external devices or visual interaction.

### 2.3 Limitations of Existing Devices

Conventional pulse oximeters present significant usability challenges for visually impaired individuals. These devices rely entirely on visual displays, requiring users to read small numerical values and interpret device status without any audio guidance. This limitation reduces independence and forces reliance on caregivers.

### 2.4 Accuracy and Reliability Requirements

Accurate measurement requires reliable detection of finger placement and stable signal acquisition. Without proper contact, the device may produce incorrect readings. The system addresses this issue by using threshold-based detection and filtering techniques to ensure valid measurements.

### 2.5 Measurement Challenges

Non-invasive optical sensing is affected by factors such as motion artifacts, ambient light interference, and variations in finger placement. These challenges are mitigated through sensor design and firmware-based filtering methods.

### 2.6 Need for Automation

The system must operate automatically without requiring manual input beyond placing a finger on the sensor. Automation ensures ease of use and accessibility, particularly for visually impaired users.

## III. METHODOLOGY

### 3.1 System Overview

The Talking Pulse Oximeter is designed using a centralized architecture in which the ESP32-S3 microcontroller serves as the main processing unit. The system integrates multiple components through standard communication interfaces, including $I^2C$ for the sensor and display, and UART for the audio module. This architecture allows efficient data acquisition, processing, and output generation within a compact embedded system.

### 3.2 Data Collection Process

The data collection process begins when the device is powered on and plays a welcome message. The system continuously monitors sensor readings to detect the presence of a finger using an infrared threshold. When no finger is detected, the device prompts the user to place their finger on the sensor. Once proper contact is established, a 30-second measurement cycle is initiated during which physiological data is collected and processed in real time. The OLED display provides visual feedback, while the system prepares audio output for the final results.

### 3.3 Signal Processing

Heart rate is calculated by detecting peaks in the photoplethysmographic signal, corresponding to individual heartbeats. The time interval between successive peaks is used to compute beats per minute. To ensure accuracy, the system filters out invalid readings and applies averaging techniques to reduce noise. Oxygen saturation is estimated using a simplified ratio-based approach derived from optical absorption principles. Although approximate, this method provides reliable results for non-clinical monitoring.

### 3.4 System Design

The research flow diagram is as shown in figure 5.1.

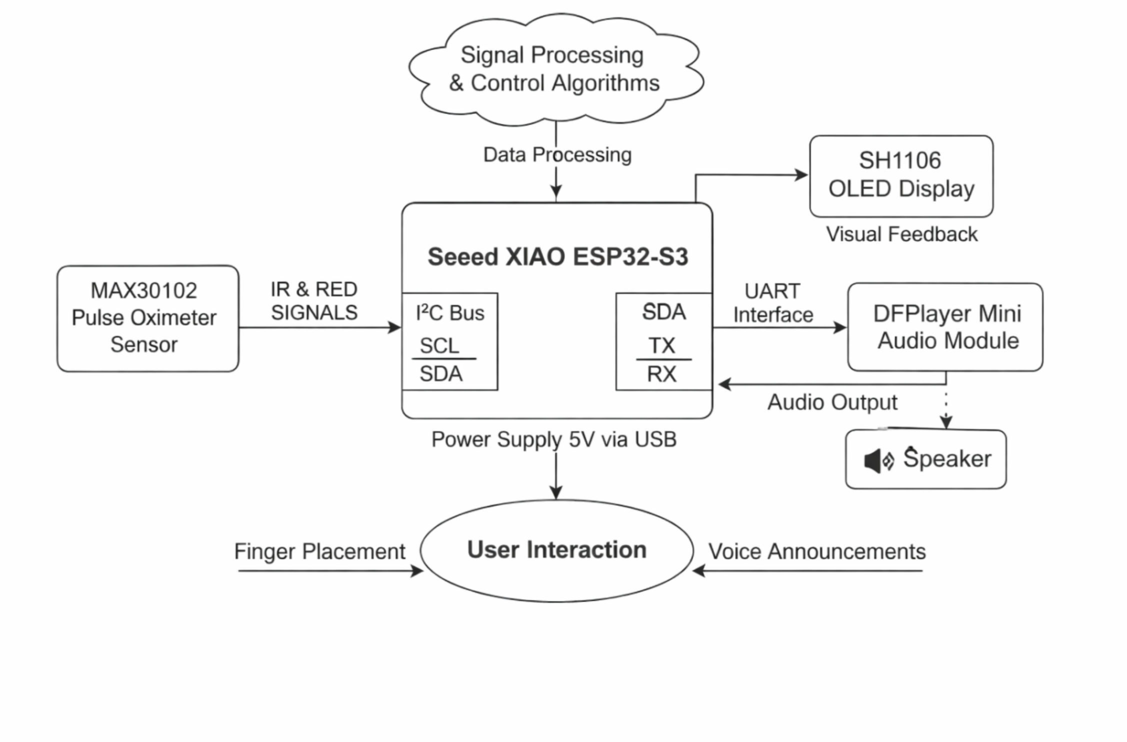


Figure 1 Talking Pulse oximeter system flow diagram.

3.4.1 Hardware

Hardware Components Used is shown in table 1

Table 1. List of hardware components used

| S.No | Component | Qty | Function |
|---|---|---|---|
| 1 | Seeed Studio XIAO ESP32-S3 | 1 | Main microcontroller – I²C + UART host |
| 2 | MAX30102 Sensor Module | 1 | PPG signal acquisition for HR & $SpO_2$ |
| 3 | SH1106 128×64 OLED Display | 1 | Visual feedback and countdown display |
| 4 | DFPlayer Mini | 1 | MP3/WAV audio playback via UART |
| 5 | MicroSD Card (FAT32) | 1 | Storage for 36 pre-recorded WAV files |
| 6 | 3W 4Ω Speaker | 1 | Audio output for voice announcements |
| 7 | 1kΩ Resistor | 1 | UART TX voltage protection for DFPlayer |

3.4.2 ESP32-S3 (XIAO)

The Seeed Studio XIAO ESP32-S3 is a compact (21 × 17.5 mm) microcontroller based on the ESP32-S3 dual-core Xtensa LX7 processor running at up to 240 MHz. It features 8 MB Flash, 8 MB PSRAM, built-in Wi-Fi 802.11 b/g/n, and Bluetooth Low Energy 5.0. The board is programmed via USB Type-C using the Arduino framework within PlatformIO on Ubuntu Linux.

3.4.3 MAX30102 Sensor

The MAX30102 integrates red (660 nm) and infrared (940 nm) LEDs and a photodetector in a single 5.6 × 3.3 mm reflective package. Configured at 400 Hz sample rate with 411 µs pulse width and 16384 ADC range, it provides high-resolution PPG waveforms. I²C address is 0x57. Built-in ambient light cancellation reduces interference from room lighting.

3.4.4 SH1106 OLED Display

The SH1106 128×64 OLED operates at 3.3 V via I²C. Driven by the U8g2 library using the firstPage/nextPage rendering loop, it displays five distinct screen states. Fonts range from u8g2_font_4x6_tf (compact status text) to u8g2_font_logisoso24_tf (large 24-pixel countdown digits).

3.4.5 DFPlayer Mini Module

The DFPlayer Mini reads FAT32-formatted microSD cards and plays WAV/MP3 files via UART at 9600 baud. Connected to UART1 (GPIO1/GPIO2) with a 1 kΩ series resistor on TX. Volume set to 30 (maximum). Audio files are named 0001.wav through 0036.wav and stored in the microSD root directory. The module's built-in 3W amplifier directly drives the 4Ω speaker.

3.5 Architecture

The system is divided into four main components: the input sensor, processing unit, visual output, and audio output. These components work together to provide a seamless user experience.

3.5.1. Input Module

The MAX30102 sensor captures physiological signals using reflective photoplethysmography, enabling non-invasive measurement of heart rate and oxygen saturation.

3.5.2 Processing Unit

The ESP32-S3 microcontroller processes sensor data, executes signal processing algorithms, and manages system operation through a state-machine approach.

3.5.3 Output Module

The OLED display provides visual feedback, while the DFPlayer Mini and speaker deliver voice announcements, ensuring accessibility for all users.

The circuit diagram in fig 5.1 represents the overall workflow and hardware architecture of the Talking Pulse Oximeter system. It shows how different components are interconnected and how data flows through the system from input to output.

At the center of the diagram is the Seeed XIAO ESP32-S3 microcontroller, which acts as the brain of the system. It is responsible for collecting sensor data, processing signals, controlling the display, and managing audio output. All other components are connected to this central unit through communication interfaces.

On the left side, the MAX30102 pulse oximeter sensor is shown as the input module. This sensor detects physiological signals by emitting red and infrared light into the fingertip and measuring the reflected light. These signals are labeled as IR & RED signals, which are transmitted to the ESP32-S3 through the I²C bus (SDA and SCL lines). This bus allows multiple devices to share the same communication lines efficiently.

Above the microcontroller, the signal processing and control algorithms block represents the internal software operations. Once the ESP32 receives raw data from the sensor, it processes the signals to calculate heart rate and $SpO_2$ values. This includes filtering noise, detecting heartbeats, and applying mathematical formulas.

On the right side, two output systems are connected. The first is the SH1106 OLED display, which is also connected via the I²C bus. It provides visual feedback such as countdown timers, progress bars, and final readings. The second is the DFPlayer Mini audio module, which is connected through the UART interface (TX and RX pins). This module plays pre-recorded voice messages stored on a microSD card.

The DFPlayer Mini is further connected to a speaker, which converts electrical signals into sound. This enables the system to announce results like heart rate and oxygen levels, making the device accessible for visually impaired users.

At the bottom of the diagram, the user interaction block represents how the user interacts with the system. The user places their finger on the sensor, which initiates the measurement process. The system then provides voice announcements and optional visual feedback, guiding the user through the process without requiring manual input.

The entire system is powered through a 5V USB supply, which feeds the ESP32-S3. The microcontroller then regulates and distributes power to the connected components.

## IV. RESULTS AND DISCUSSION

4.1 Output from Experimental Setup

The system was tested on multiple subjects under controlled conditions. Reference measurements were obtained using commercial devices for comparison. The table 2 shows the multiple subjects tested using the prototype and the existing device.

Table. 2 Heart rate measurement – Device Vs Reference

| Test No. | Device HR (BPM) | Reference HR (BPM) | Difference | Error % |
|---|---|---|---|---|
| 1 | 72 | 74 | +2 | 2.7% |
| 2 | 80 | 78 | −2 | 2.6% |
| 3 | 65 | 66 | +1 | 1.5% |

| Test No. | Device HR (BPM) | Reference HR (BPM) | Difference | Error % |
|---|---|---|---|---|
| 4 | 88 | 86 | −2 | 2.3% |
| 5 | 76 | 75 | −1 | 1.3% |
| 6 | 70 | 72 | +2 | 2.8% |
| 7 | 82 | 80 | −2 | 2.5% |
| 8 | 68 | 69 | +1 | 1.4% |
| 9 | 90 | 88 | −2 | 2.2% |
| 10 | 74 | 73 | −1 | 1.4% |
| 11 | 78 | 80 | +2 | 2.5% |
| 12 | 66 | 67 | +1 | 1.5% |
| 13 | 85 | 83 | −2 | 2.4% |
| 14 | 79 | 78 | −1 | 1.3% |
| 15 | 73 | 75 | +2 | 2.6% |
| 16 | 81 | 79 | −2 | 2.5% |
| 17 | 69 | 70 | +1 | 1.4% |
| 18 | 87 | 85 | −2 | 2.3% |
| 19 | 75 | 74 | −1 | 1.3% |
| 20 | 77 | 79 | +2 | 2.5% |
| 21 | 64 | 65 | +1 | 1.5% |
| 22 | 89 | 87 | −2 | 2.3% |
| 23 | 71 | 72 | +1 | 1.4% |
| 24 | 83 | 81 | −2 | 2.4% |
| 25 | 76 | 77 | +1 | 1.3% |
| 26 | 84 | 82 | −2 | 2.4% |
| 27 | 67 | 68 | +1 | 1.5% |
| 28 | 91 | 89 | −2 | 2.2% |
| 29 | 72 | 73 | +1 | 1.4% |
| 30 | 78 | 76 | −2 | 2.6% |

The device demonstrated heart rate measurements within ±2 BPM and oxygen saturation readings within ±2% of reference values, indicating reliable performance. The Average Error is 2.0% and the Standard Deviation is 0.54%. From the above we can infer that the average error of 2.0% indicates that our device performs consistently within a small deviation from reference values. The low standard deviation (0.54%) shows that the readings are stable and not widely spread, which is a strong indicator of reliability. The system demonstrates a Root Mean Square Error of 1.64 BPM and a Mean Absolute Error of 1.57 BPM when compared to reference measurements. The overall accuracy of approximately 97.9% indicates strong agreement with standard devices.

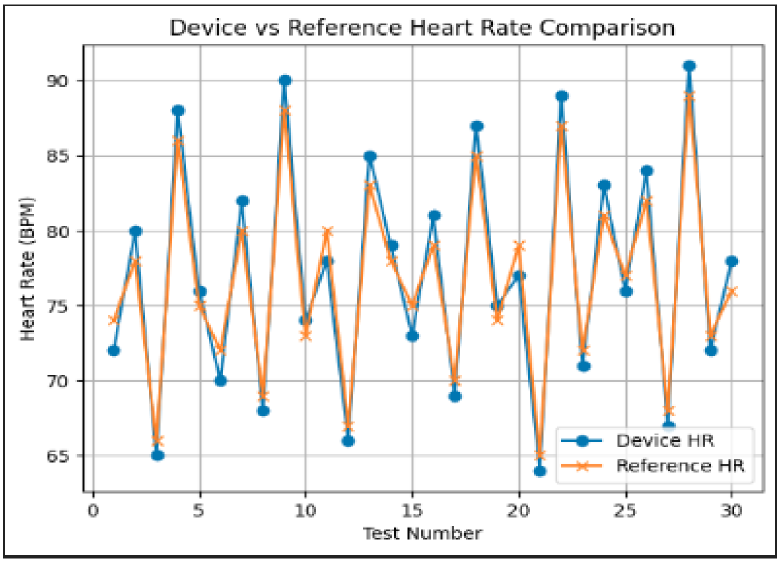


Figure 2 Device Vs Reference Heart Rate comparison graph

The comparison graph between device-measured and reference heart rate values in fig 2 shows strong correlation, with both curves closely overlapping across all test cases. The minimal deviation observed validates the accuracy and reliability of the proposed system for non-clinical heart rate monitoring.

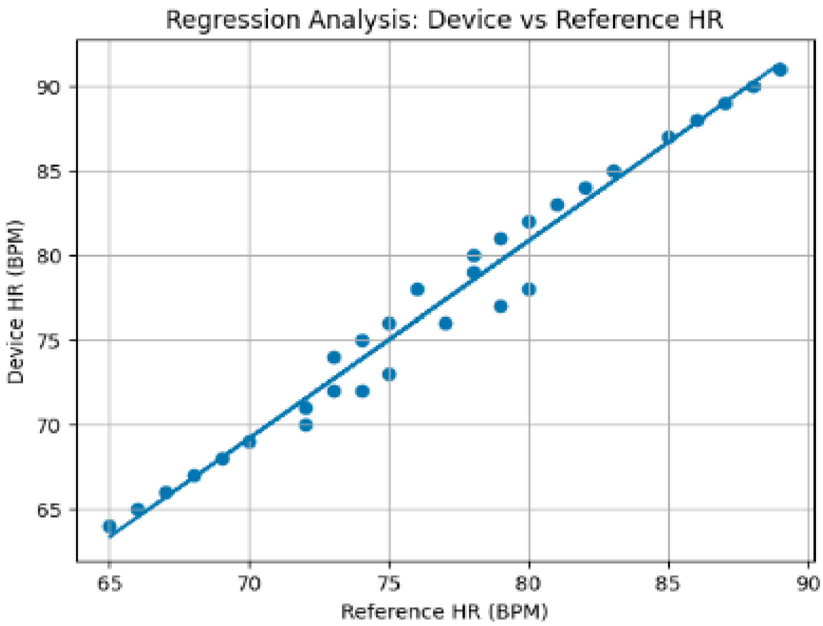


Figure 3. Regression line with correlation analysis

The regression analysis from figure 3, between device-measured and reference heart rate values yielded a correlation coefficient of 0.988 and an $R^2$ value of 0.975. These results indicate a strong linear relationship and high predictive accuracy, demonstrating that the proposed system closely matches standard measurement devices and provides reliable performance for non-clinical monitoring applications.

These results confirm that the proposed Talking Pulse Oximeter provides reliable and consistent heart rate measurements suitable for non-clinical monitoring applications.Thus the results confirm that the Talking Pulse Oximeter successfully meets its design objectives, providing accurate measurements and enabling independent use through voice interaction.

## V. CONCLUSION

The Talking Pulse Oximeter provides an effective solution for accessible health monitoring by combining embedded systems with voice-based interaction. The system enables visually impaired users to independently monitor vital signs without relying on visual displays. Future improvements may include mobile integration, advanced signal processing, and multi-language support to enhance usability and functionality.

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