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The Performance of the STM32 Microcontroller and MAX30102 for Remote Health Monitoring Device Design

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ABSTRACT

The STM32 microcontroller and MAX30102 in a remote health monitoring device were evaluated, and the results are presented in this study. RHM technology enables doctors to consult with patients who have cardiac conditions, analyse their vital signs, and prescribe medication all without ever leaving their offices. Patients who are being watched for cardiovascular disease will no longer have to worry about making frequent trips to the hospital because they can work and monitor their health in one convenient location. The MAXhigh2 high-sensitivity pulse oximeter and heart rate sensor specifications are given, along with information on the heart rate and maximum SPO2 algorithms, observations, and tests that go along with them. The circuit included the MAX30102 SPO2 and heart rate sensors as well as the STM32F4 microcontroller, with the VDD pin connected to the 3.3V power pin and the GND pin connected to the ground pin. The MAX30102 sensor's ground pins are connected to the GND power pins on the PCB. The MAX30102 sensor's SCL (serial clock) pin is linked to PA6 on the microcontroller. In contrast, the serial data (SDA) line is attached to the microcontroller's pin PA7. The PB5 pin of the microcontroller is wired to the INT pin of the MAX30102 sensor. The different readings clearly show that the heart rate data is not stable and that it improves with increasing sampling rate, with the largest data peak occurring as a result of increasing sampling rate and time. More SP02 data can be recorded when the sample time and rate are increased.

Keywords: *pulse oximeter, heart rate, sensors, microcontroller, cardiovascular*

1. INTRODUCTION

The development of healthcare electronics has enabled a plethora of digital data acquisition devices to monitor a patient's vital signs and send alerts if anything appears amiss. Tracking multiple bodily vital signs simultaneously, however, requires the use of a variety of data acquisition tools. It is evident from the above that a system enabling individuals to set up their own digital data acquisition equipment for real-time tracking of health indicators is required.

The hospital's medical infrastructure development has facilitated the use of sensors and microcontrollers to enhance human life in varied contexts. A remote patient monitoring (RPM) device is a tool that lets doctors check on their patients' acute or chronic conditions, report on them, and analyse them when they are not in the hospital or clinic. So, providers can make clinical decisions based on what they know about a patient's disease state right now. A remote patient health monitoring system keeps an eye on a patient's vital signs from a distance. It was once commonplace to find detection systems in medical facilities. A number of systems have been developed in recent years to address the issue of distance healthcare. Wireless patient monitoring systems have been developed, which wirelessly transmit sensor data to a central server. Some businesses have even implemented subscription-based business models. People in developing countries have difficulty accessing these devices because they cannot afford them. There is also the issue of internet access, as some systems require a constant, high-speed connection to function properly. Internet access remains a problem in developing countries.

Healthcare costs continue to rise daily. With the advancements and innovations in the healthcare electronics industry, there is a significant opportunity to provide affordable, high-quality healthcare. The rise of telemedicine, which allows doctors to remotely diagnose and monitor their patients, plays a significant role in this tele-health system, according to Lepage et al. (2014) and Gonnot et al (2014). In this paper, we discuss several scenarios in which a tele-health monitoring device can be developed and utilised effectively. The development of various dependable and affordable technologies has enabled researchers to develop a number of systems that can enable tele-health. The majority of available solutions, however, are based on specific physiological parameters such as electrocardiography, pulse rate, and so forth. According to Sarkar et al. (2014), Gonnot et al. (2014), and Sarkar et al. (2015). This paper presents a modular and reconfigurable platform that can be customized and configured to meet a patient's health needs. The main focus of this paper is on the MAX30102 High-sensitivity Pulse Oximeter and heart rate sensor, specifically its maximum SPO2 and heart rate algorithms, and the observations and experiments that have been performed on these features. The STM32F411CEU6 microcontroller and the MAX30102 oxygen saturation and heart rate sensor are used in the experiment.

2. LITERATURE REVIEW

A number of systems have been developed by different authors over the years to address the issue of distance, personnel and cost in healthcare delivery. (Wei, 2017) developed an STM32-powered smart monitoring system. The STM32F405 microchip and the Beidou satellite positioning system are utilised by the transportable system. It is able to track the user's location and collect vital signs in real time. The MT2511 is used to record vital signs like BP, HR, and EKG. The coordinate positioning chip is the anti-jamming UC6225 (which uses Beidou navigation). The MPU6050 sensor can measure various human attributes. The mobile phone receives all information via from the developed device.

A smartwatch that tracks numerous health indicators is currently being developed by Fang et al., (2017). In this article, they discussed the development of a watch that can simultaneously record electrocardiography (ECG), photo plethysmography (PPG), and several other derived parameters. The PPG and ECG signals could be used to calculate the pulse and heart rate. The pulse transmits time (PTT), the final component needed to calculate the patient's blood pressure, could be obtained by combining PPG and ECG (BP). (Akhbari et al., 2016) A survey of Internet of Health

Things environments for online heart monitoring systems: a reference model and a forecast wishing to improve their quality of life by utilising this technology have also employed this strategy. In this paper, they conducted a survey with the purpose of presenting and analysing the latest developments in medical care and assisted living studies. Wearable Internet of Things-Based Smart Health Monitoring System (Taştan, 2018). In this research, an Android app was created to track vital signs like heart rate (HR), heart rate variability (HRV), and cardiac output (CT) for patients with cardiovascular disease who need constant monitoring. The sensors worn by the patient provide continuous monitoring data. The data from the measured signals is then transmitted wirelessly to the Android user interface.

(Pernice et al., 2019) used a photo plethysmography, a portable multisensor system measures cardiorespiratory interactions. They developed a portable multisensor system to acquire electrocardiographic (ECG), photoplethysmographic (PPG), and respiration airflow signals in real time and in sync. Using time- and frequency-domain Granger Causality measures, they analyzed cardiorespiratory interactions between heart rate and respiratory time series derived from either the combined ECG and breathing signals (taken as the reference) or the PPG signal alone. According to their findings, linear interaction measures act in the same way regardless of whether they are derived from an electrocardiogram (ECG) or photoplethysmogram (PPG) reading of the respiratory airflow signal. Tough and dependable PPG and ECG integrated biosensors were developed by Ferroukhi et al. (2019). In this paper, they propose three significant obstacles to overcome when designing embedded systems. An inexpensive and reliable system that can acquire electrocardiogram (ECG) and photo plethysmography (PPG) signals simultaneously to measure PTT would be very helpful in outpatient medicine, but these challenges have not yet been met.

(Using Optical Plethysmography based on speckle and intensity, Beat-to-Beat Intervals were developed (Olazábal et al., 2021). analogous to an EKG or electrocardiogram in this investigation, video recordings obtained via remote camera-derived Speckle plethysmography (rSPG) were compared to established clinical parameters (PPG & ECG). (Kuwalek et al., 2021) investigated methods for detecting respiratory rate from photoplethysmographic signals. The paper discusses the specifics of the problem under consideration and proposes a solution that includes photoplethysmographic signal registration (PPG). This signal is used to calculate the heart rate, oxygen saturation, and respiration rate (RR). The primary goal of this paper is to improve and assess RR estimation using the PPG signal. Although some of the algorithms for this estimation are known, sensor placement and poor measuring conditions in the case of detainees affect the algorithms' accuracy.

Mahajan & Kaul, (2022) developed a portable, Arduino-based ECG acquisition system The Arduino Uno and the Arduino Due have been evaluated and contrasted. Parameters such as blood oxygen saturation, heart rate, etc. were calculated from the signals and displayed alongside the signals for easy monitoring. Volpes and colleagues (2022) developed a non-invasive multisensor real-time acquisition system for evaluating cardiorespiratory and skin conductance parameters. In this context, they designed and built a portable biomedical device that can acquire electrocardiographic (ECG), photoplethysmographic (PPG), breathing, and galvanic skin response (GSR) signals in real time for non-invasive monitoring of multiple physiological parameters. This paper depicts the system's architecture, which includes a Bluetooth module for wireless communication with the central computer and novel analogue sensors capable of measuring breathing and GSR.

2.1 The Design of a Health Monitoring Device

A Remote Wearable-Health monitoring system is classified according to its design three stages are involved: Biometric Data Acquisition; Biometric Data Processing; and Biometric Data Storage Communication and Notification Panel.

2.2 Sensor Description

Pulse oximetry and heart rate monitoring are combined into a single biosensor module, MAX30102 (figure 1.0). LEDs, photodetectors, optical elements, and low-noise electronics are built into the device to block out outside light. MAX30102 is a comprehensive system solution that streamlines the design process for mobile and wearable devices.

The MAX30102 only requires a single 1.8V power supply, but the built-in LEDs require their own dedicated 3.3V power supply. The I2C bus is used for communication. There is no standby power consumption when the module is turned off in software. Therefore, the power rails can remain constantly on.

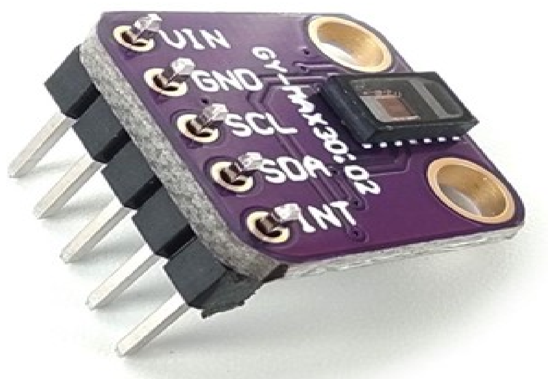

Fig.1.0 MAX30102 for integrated pulse oximetry and heart rate monitoring

2.3 Microcontroller Description

STM32F411xC/xE chips use 100 MHz Arm® Cortex®-M4 32-bit RISC cores (fig.2.0). All data and instructions for Arm's single-precision floating-point unit (FPU) are compatible with the Cortex®-M4 FPU. The STM32 Dynamic Efficiency product family, of which the STM32F411xC/xE is a part, introduces a new feature called Batch Acquisition Mode (BAM) that further reduces power consumption during data batching. Two APB buses, two AHB buses, and a 32-bit multi-AHB bus matrix connect the various enhanced I/Os and peripherals to the high-speed embedded memories (up to 512 Kbytes of Flash memory and 128 Kbytes of SRAM) present in the chip.

Each device has a 12-bit analog-to-digital converter (ADC), a low-power real-time clock (RTC), six 16-bit general-purpose timers, a pulse-width modulation (PWM) timer for motor control, and two 32-bit GPTs. With a power supply range of 1.7 V (PDR OFF) to 3.6 V, the STM32F411xC/xE can function in temperatures between -40 and +125 °C. A wide variety of power-saving modes are available and can be used in the development of low-power applications. These features make the STM32F411xC/xE microcontrollers useful in a variety of settings.

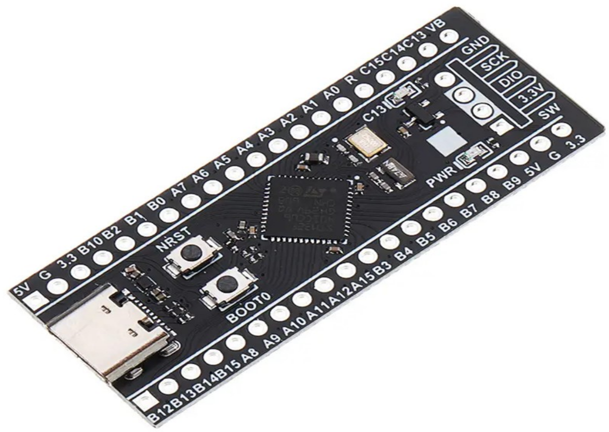

Fig.2.0 STM32F411xC/xE microcontroller for Data Acquisition

2.3.1 Experimental setup (Schematic)

Using the MAX30102 SPO2 and heart rate sensors, the STM32F4 microcontroller was connected to the experimental setup (fig.3.0b). With the MAX30102 sensor, the VDD pin is connected to the 3.3V power pin and the GND pin is connected to the ground pin in the circuit shown below (fig.3.0a).The MAX30102 sensor's ground pins are wired to the GND power pins on the PCB. The MAX30102 sensor's SCL (serial clock) pin is wired to the microcontroller's PA6. In contrast, the microcontroller's pin PA7 is connected to the serial data (SDA) line. The MAX30102 sensor's INT
pin is wired to the microcontroller's PB5 pin.

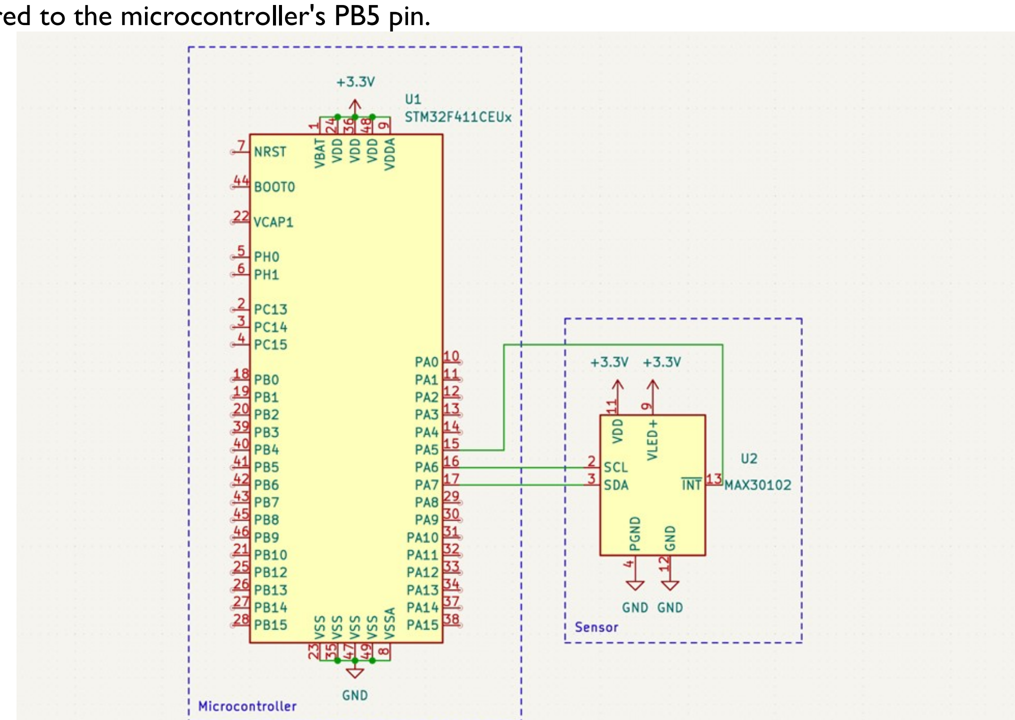

Fig.3.0 Circuitry connection of the Health monitoring device

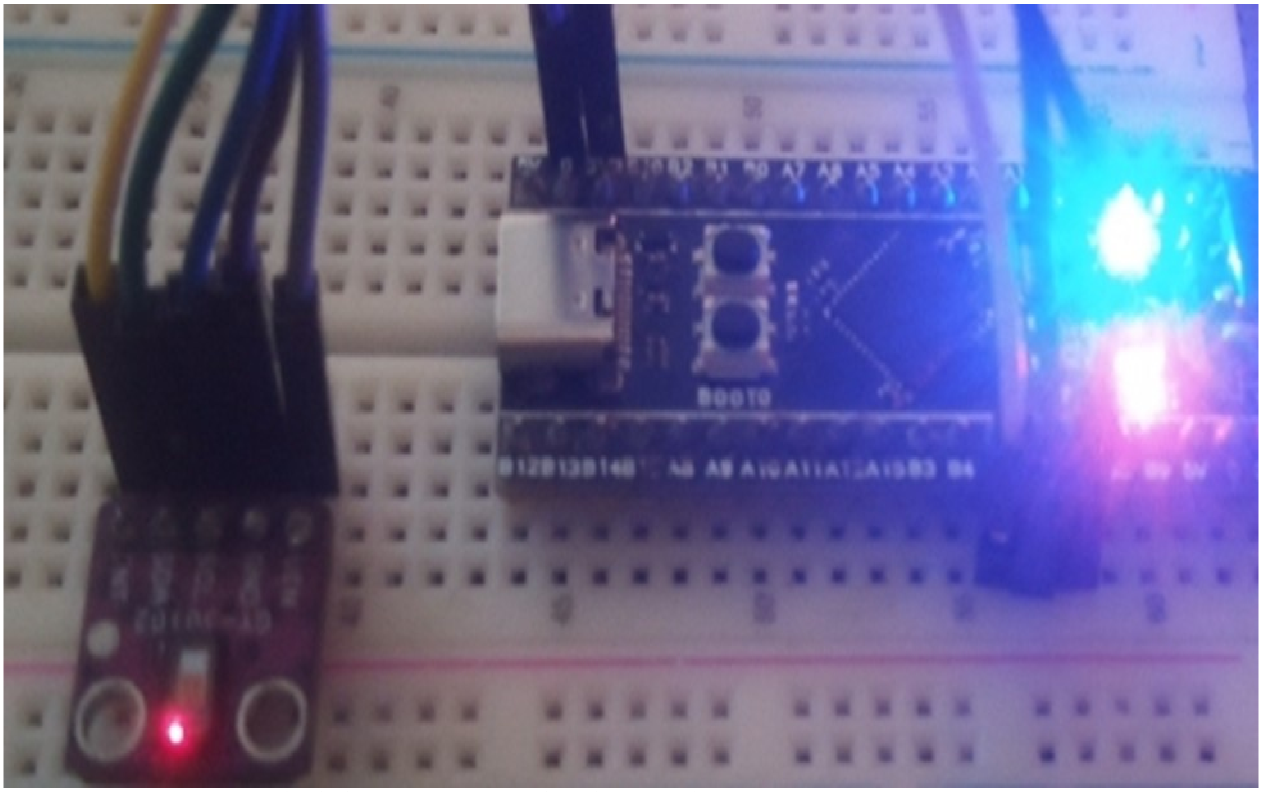

Fig.3.0b Health Monitoring device components setup

2.4 IDE description

The STM32CubeIDE was used as the integrated development environment (IDE) for the microcontroller in this study. Figure 4.0 shows how simple cross-platform development with the STM32CubeIDE can be. You can configure peripherals, generate code, compile code, and debug STM32 microcontrollers and microprocessors with the help of the STM32CubeIDE. Developed on top of the Eclipse®/CDTTM framework, it makes use of the GCC toolchain and GDB for programming and debugging, respectively.

Simplifying the process of setting up and creating code for STM32s, the STM32CubeIDE incorporates all the features of the STM32CubeMX. The user can choose between a blank STM32 microcontroller, a microprocessor, a preconfigured microcontroller, and a microprocessor when deciding between a board and an example. As soon as the project is created, the initialization code can be generated. The user can rewrite the initialization code at any time during development without impacting the user code when initializing or setting up peripherals or middleware.

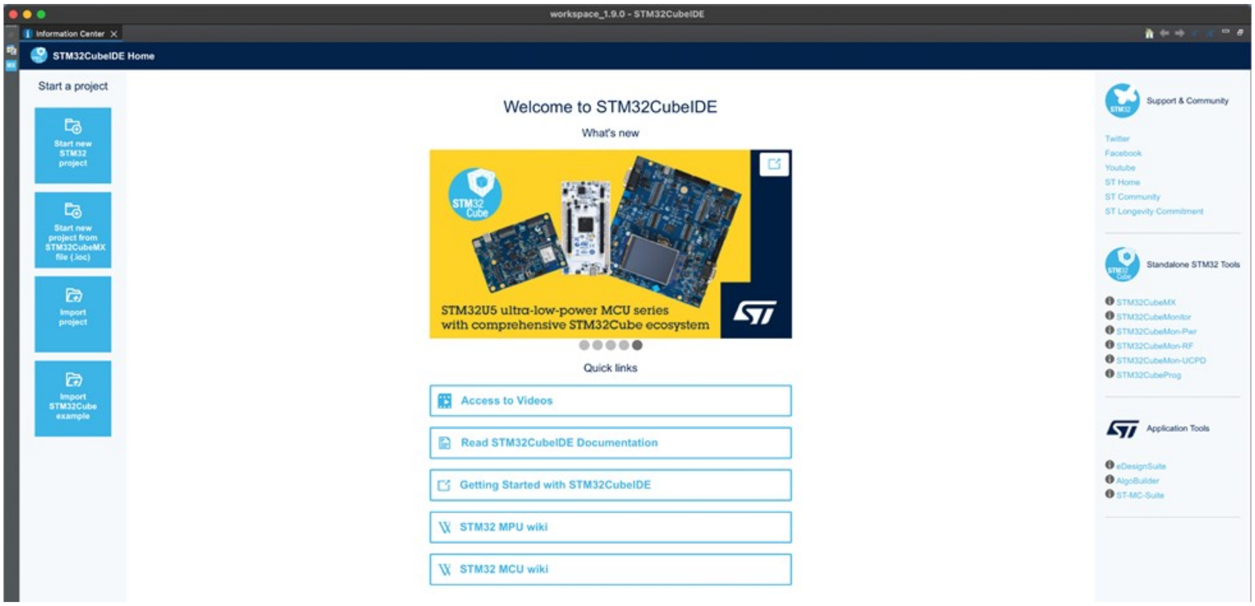

Fig.4.0 STM32CubeIDE for programming the microcontroller

3. METHODOLOGY

Figure 5.0 depicts the architecture and design of a remote health monitoring device based on the STM32 microcontroller for patients with cardiovascular disease. The study's research design goal is to develop a remote wearable health monitoring device that can monitor the patient's SpO2 and heart rate signals using the Internet of Things (IoT).

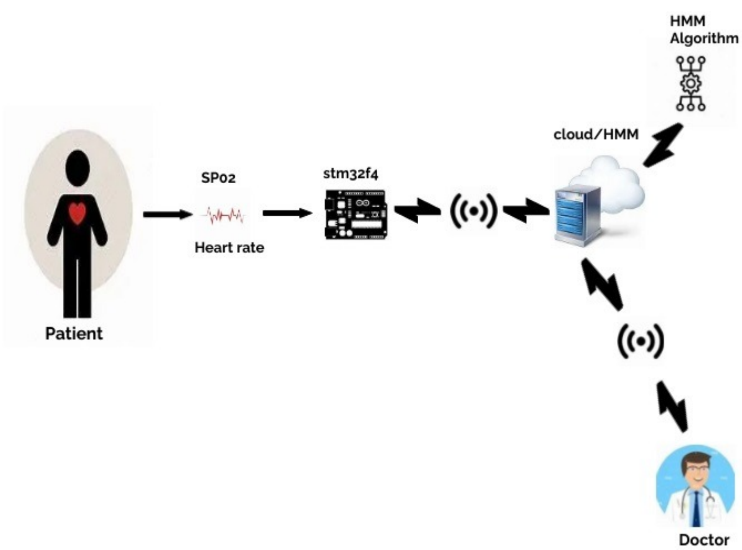

Figure 5.0 IoT Remote Health monitoring system model using STM32 Microcontrollers

The device's data is sent to the cloud, where the doctor can access it from a remote server. In the cloud, a machine learning model can be used to process and learn from stored data. This model can detect and predict heart diseases when the device is attached to the patient's body and vitals are taken.

(i) Algorithm

The algorithm for the MAX30102 sensor used in this research work was provided by Maxim Integrated. The algorithm calls for the photodiode and LEDs to be adjacent to one another (in other words, they are reflective). The algorithm determines SPO2 and heart rate by monitoring the peaks of the PPG cycle and the corresponding AC/DC of red and infrared signals. Due to register overflows, the SPO2 formula was unable to achieve accuracy when the algorithm was designed for Arm M0 and M3 processors.

(ii) Heart rate

Taking a four-point moving average of an IR signal after removing the DC component yields its pulse rate. In order to achieve this, first a difference is performed on the signal in order to smooth it out, then a 2-point moving average is calculated, and finally the hammer window formula is applied. Turning the waveform upside down and using a peak detector to look for dips in the signal is a common technique. The heart rate can be computed after the threshold has been established. The output value will be the valid heart rate if the result was valid, otherwise it will be -999.

(iii) SPO2

After accessing the AC and DC components of the IR and red PPG buffers, the heart rate is computed. After acquiring these data, it is necessary to calculate the minimum of these values near their respective IR signal valleys. A check is performed to determine if the received signal is out of range. If the SPO2 value is outside of the acceptable range, the result will be -999. If not, the calculation will continue as usual.

Based on the obtained signal, a four-point moving average is computed. For the calibration ratio, the AC and DC components of the IR and red signals are calculated using a grid of specific valley locations within the IR signal. The DC and AC maximums of the raw IR and red signals are calculated between two valley locations. The obtained value is then evaluated to determine whether it is valid. SPO2 computes the ratio between the IR and red signals' AC and DC components. Therefore, it is necessary to subtract the linear DC components from the resulting signal. After validating the result, a value of 999 is displayed if it is valid, and a value of -999 is displayed if it is invalid.

3. SOFTWARE DESIGN OF HEALTH MONITORING DEVICE

The STM32Cube software ecosystem includes the STM32CubeIDE, a cross-platform development environment shown in fig.6.0c. It is possible to configure peripherals, generate code, compile code, and debug programmes written for STM32 microcontrollers and microprocessors with the help of STM32CubeIDE, an advanced C/C++ development platform. The GCC toolchain, the GDB debugger, and the Eclipse®/CDTTM framework are the foundation upon which it stands. As a result, hundreds of previously developed plugins can now be integrated into the Eclipse® IDE. Fig.6.0a shows how the device configuration tool in STM32CubeIDE can be used to graphically set up the target device.

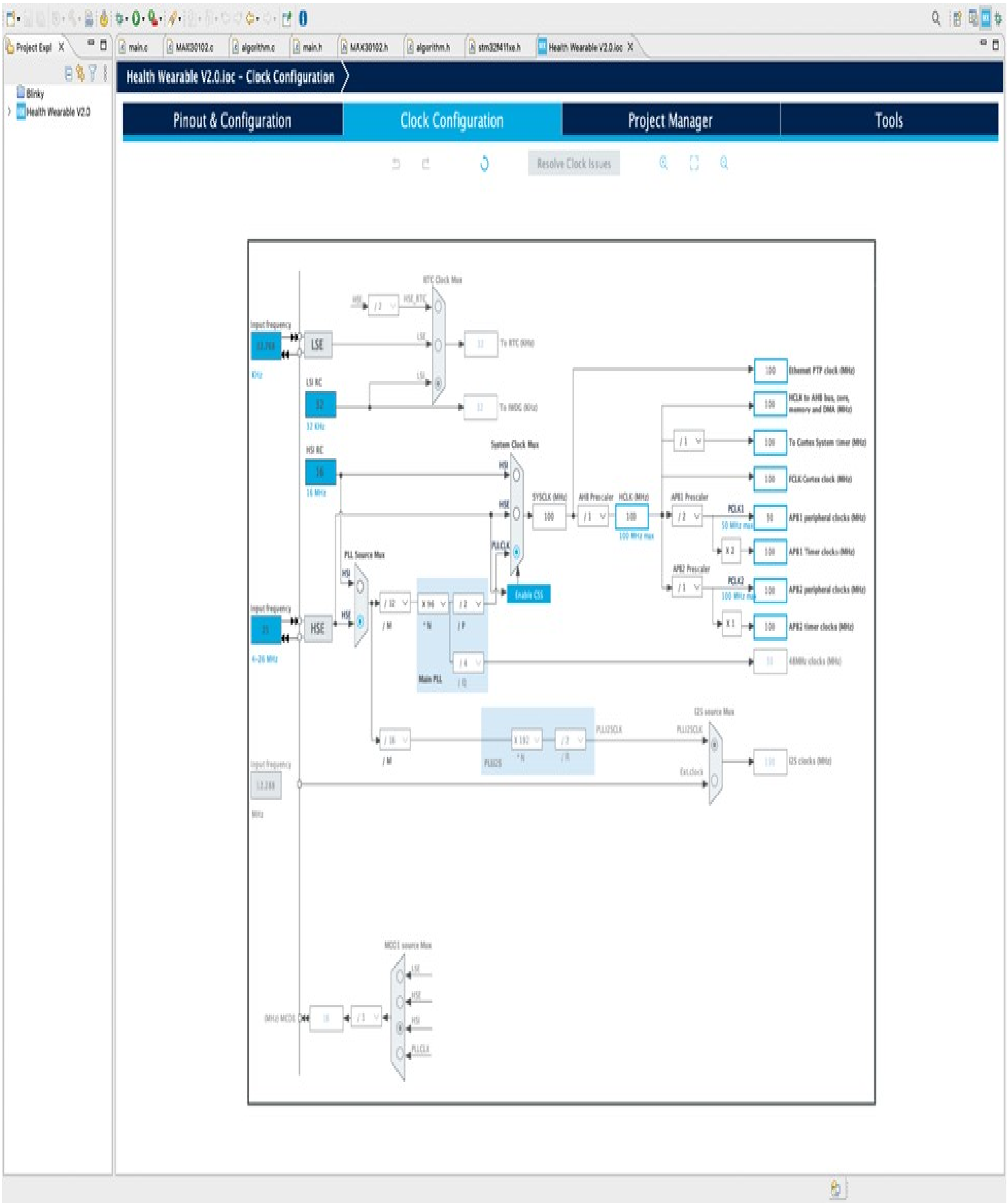

Figure 6.0a STM32 device configuration tool

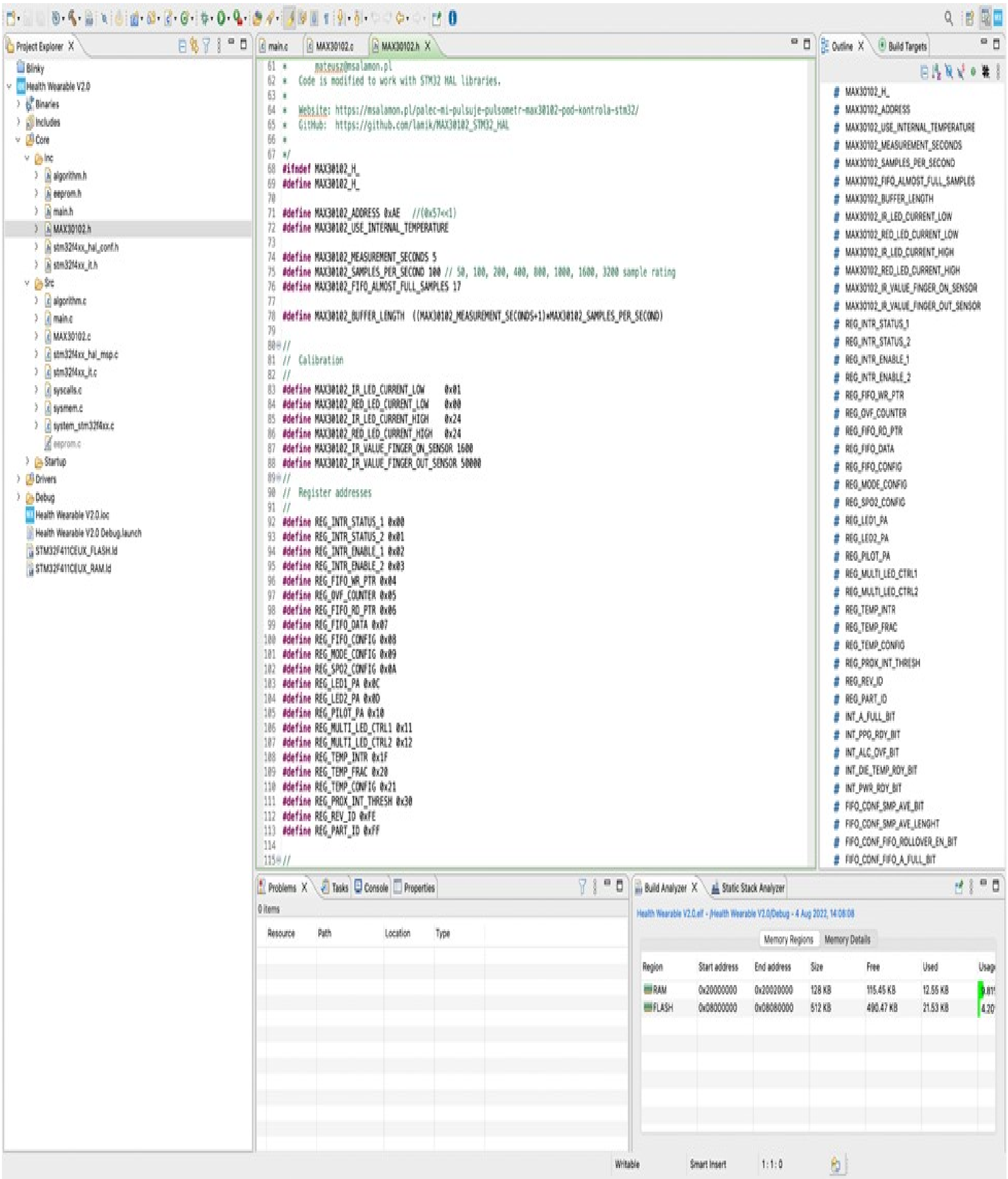

Figure 6.0c STM32CubeIDE code editor

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4. RESULTS AND DISCUSSIONS

After completing the device, it was tested on two users in order to perfect and observe the precise setting where the sample rate can be adjusted in the final code. Until the desired outcome was achieved, the following steps were taken. In the first instance (figure 7.0a), when 100 samples were taken at 5 seconds and compared to other readings, the heart rate data obtained appeared to be relatively stable. Few SP02 data points have been collected due to the low sampling rate.

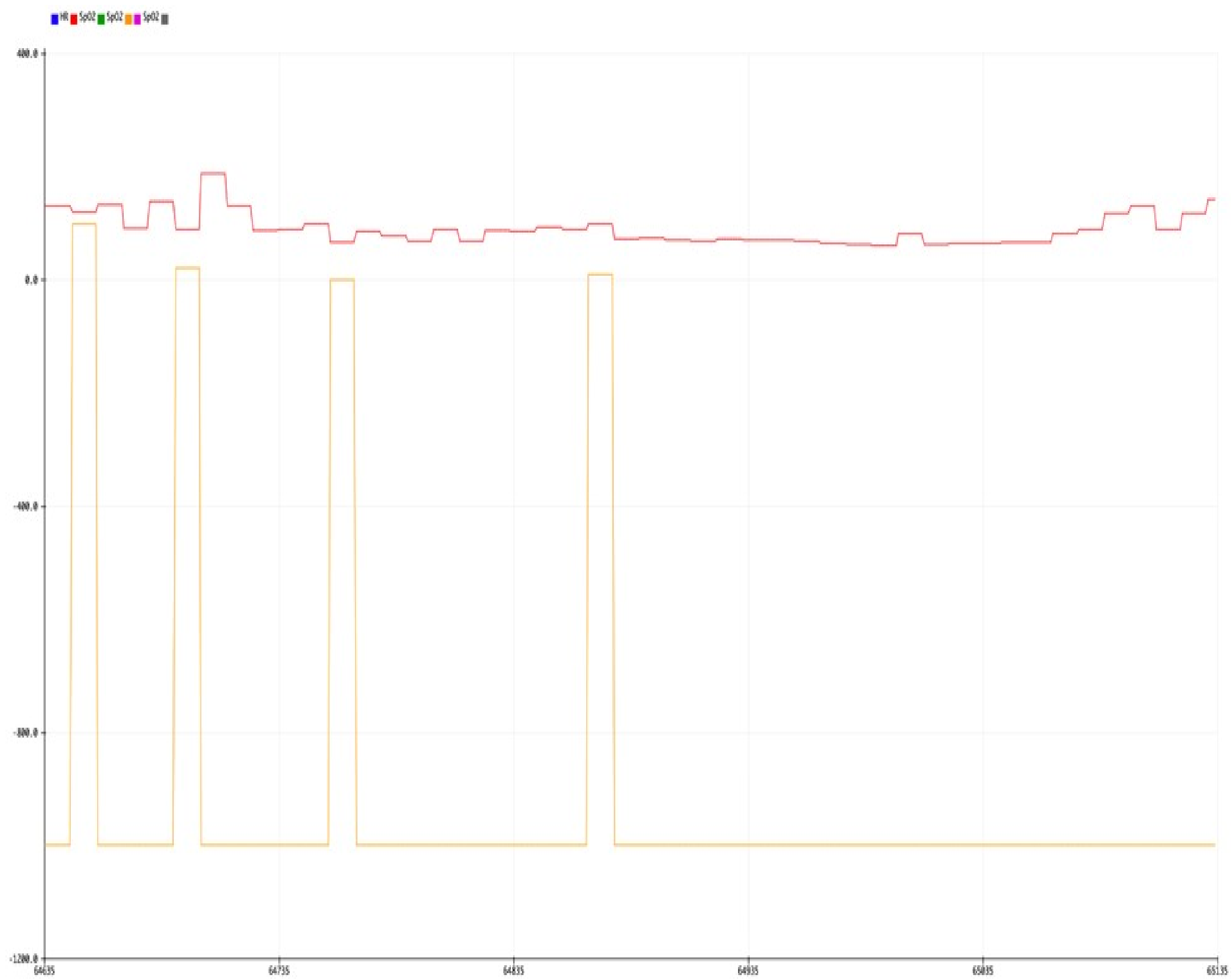

Figure 7.0a Graphical output for 100 sample rate for 5s

In the second instance (Figure 7.0b), when 100 samples were taken over the course of 4 seconds, it was clear that the heart rate data was less stable than in the first instance. Less SP02 data is collected because the sampling rate is lowered.

Figure 7.0b Graphical output for 100 sample rate for 4s

In (figure 7.0c), Comparing the results of a sample period of 3 seconds at the same sample rate of 100 versus a longer duration of 5 seconds, we find that the The heart rate data is not as steady as it was in the first reading. This is due to shorter-than-average sample times. There is not a lot of SP02 data stored because of the low sample rate.

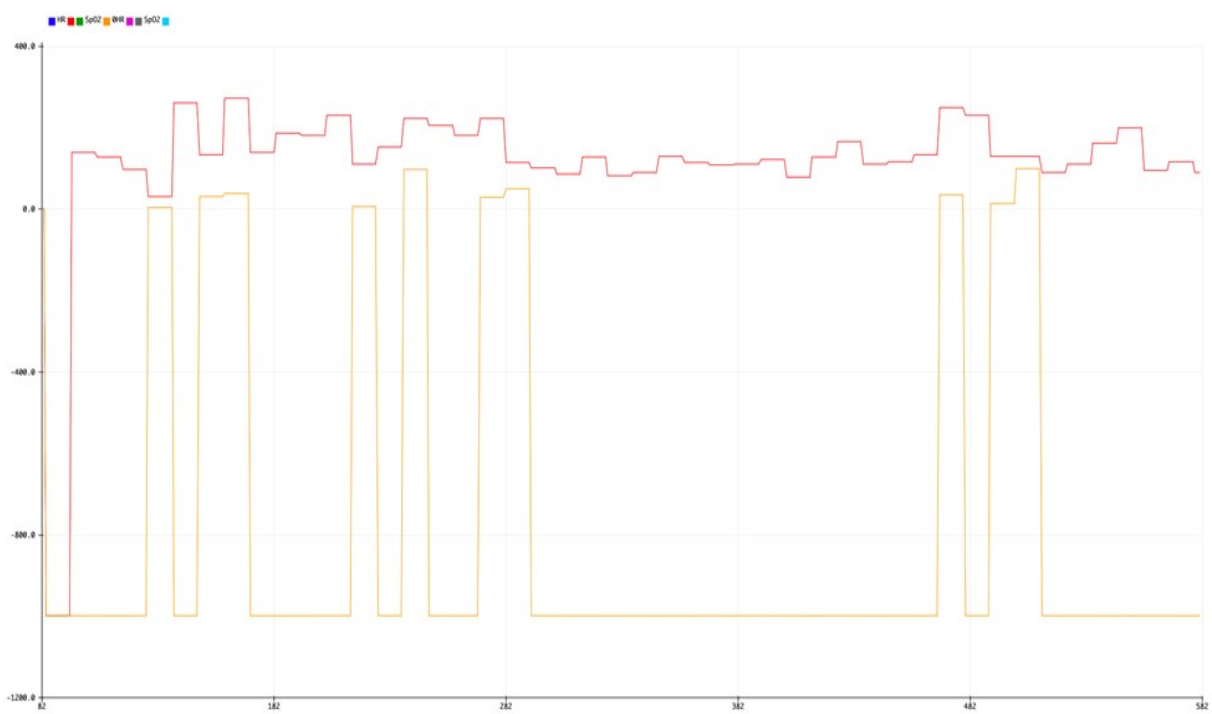

Figure 7.0c Graphical output for 100 sample rate for 3s

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The sampling rate was increased by a factor of two while the sample interval remained unchanged at 3 seconds (Figure 7.0d). Due to a decrease in sample time, the heart rate data is less stable than it was in the previous reading. A greater quantity of SP02 data is now accessible than ever before due to a faster sampling rate.

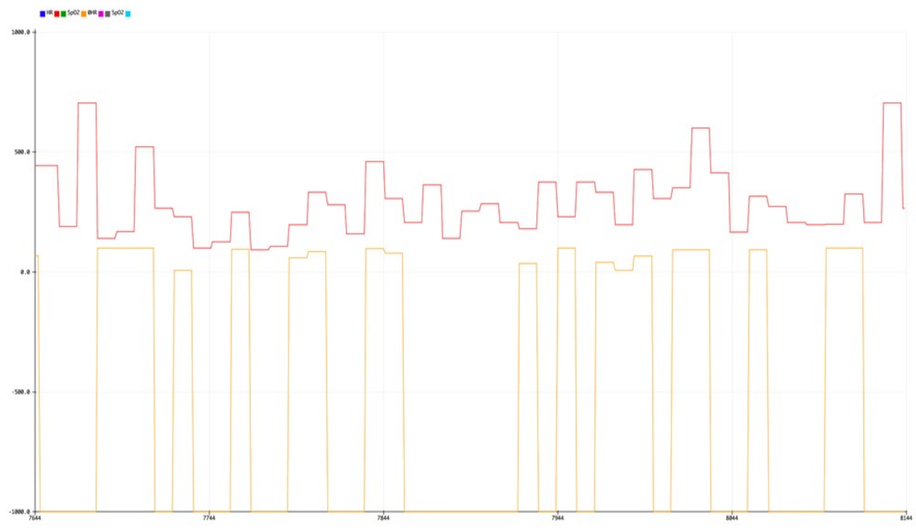

Figure 7.0d Graphical output for 200 sample rate for 3s

Observation:
Due to the increase in sample time, heart rate data is less stable when the sample rate is set to 200 and the time is increased to 4 seconds (Figure 7.0e). Increasing the sample rate captures additional SP02 data.

Figure 7.0e Graphical output for 200 sample rate for 4s

In this instance, doubling the sample rate and decreasing the sample time from 4 seconds to 3 seconds (Figure 7.0f) results in a decrease in sample time and an increase in sample rate, which renders the heart rate data less stable than the previous reading. As the sample rate has increased, more SP02 data has been collected.

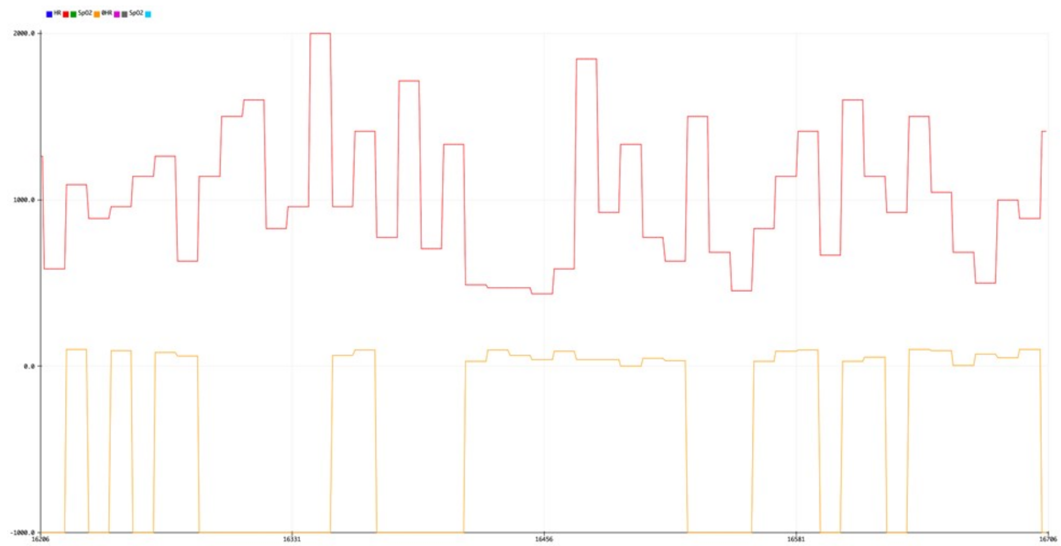

Figure 7.0f Graphical output for 400 sample rate for 3s

Keeping the sample rate at 400 and increasing the time to 4 seconds in figure 7.0g renders the heart rate data extremely unreliable when compared to previous readings. When both the sample time and sample rate are increased, more SP02 data are collected.

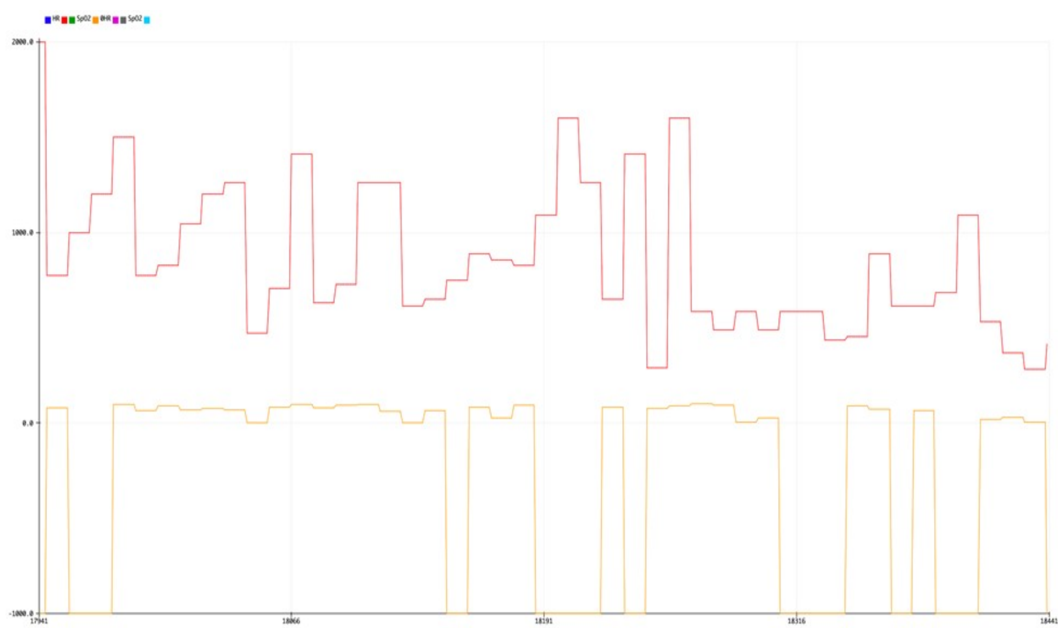

Figure 7.0g Graphical output for 400 sample rate for 4s

In the final instance, keeping the sample rate at 400 and increasing the time to 5 seconds (Figure 7.0h), it is evident that the heart rate data is highly stable in comparison to earlier readings, with the highest data peak resulting from an increase in sample rate and time. Increases in sample time and rate make it possible to collect more SP02 data.

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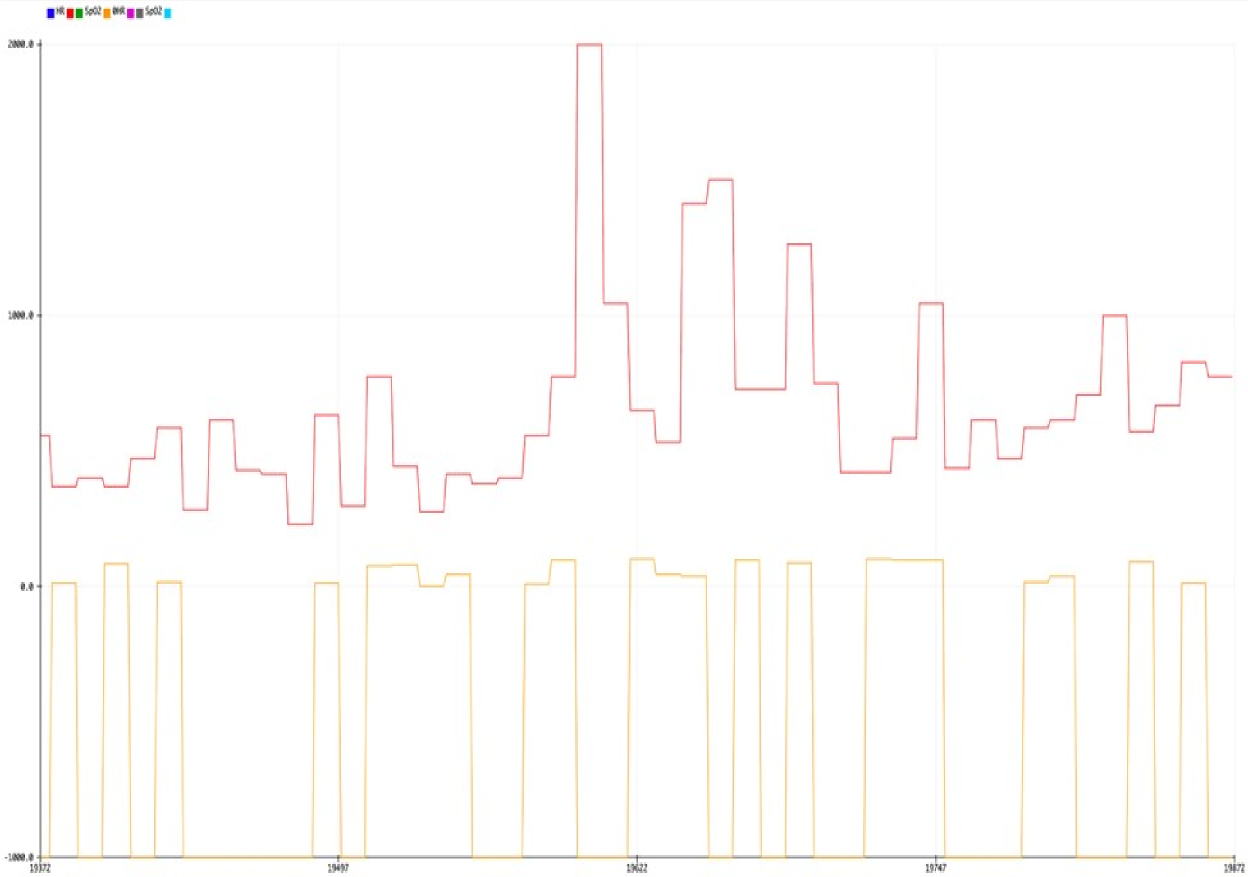

Figure 7.0h Graphical output for 400 sample rate for 5s

5. CONCLUSION AND RECOMMENDATIONS

To bridge the gap between patients and healthcare facilities, remote health monitoring devices using the STM32 microcontroller and Max30102 were designed and developed. The recent exodus of medical professionals from Nigeria has exacerbated the manpower shortage in the health sector. The developed device has enabled efficient remote management of patients with cardiovascular disease. This system will alleviate the hospital's facility- and personnel-related strain. Because each patient can stay in their own location and the doctor can manage them remotely, the cost of healthcare will be reduced. At the specified intensity, where the sample rate was 400 and the time was 3 seconds, the developed device provided accurate output. This makes the developed device more precise when measuring a patient's vital signs.

Other microcontrollers can be used with the same sensor for future research, and their performance can be compared to determine which will be more accurate during real-time monitoring and uploading of vital data.

Based on the findings of this study, the following recommendations are made:

(iii) The use of other microcontrollers to obtain vital data and compare the two to determine which has a better performance.

(iv) Include additional sensors for vital signs collection such as body temperature, blood pressure, and ECG.

(v) Take vital data from the device and compare it to the commercially available device dataset.

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