REPUBLIC OF TURKEY
ISTANBUL GELISIM UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

Department of Electrical and Electronics Engineering

SPO_2 AND TEMPERATURE MEASUREMENT DEVICE BASED ON ATMEGA328P MICROCONTROLLER CHIP WITH MOBILE CONNECTION FOR REAL-TIME MONITORING

Master Thesis

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Supervisor
Asst. Prof. Dr. Mehlika KARAMANLIOĞLU

Istanbul – 2023

THESIS INTRODUCTION FORM

Name and Surname	**:**	Mohammed JANANEE
Language of the Thesis	**:**	English
Name of the Thesis	**:**	SpO_2 and Temperature Detection Device Based on ATmega328p Microcontroller Chip with Wi-Fi Connection for Real-Time Remote Monitoring
Institute	**:**	Istanbul Gelisim University Institute of Graduate Studies
Department	**:**	Electrical and Electronics Engineering
Thesis Type	**:**	Master
Date of the Thesis	**:**	02.06.2023
Page Number	**:**	84
Thesis Supervisors	**:**	Asst. Prof. Dr. Mehlika KARAMANLIOĞLU
Index Terms	**:**	MAX30100, MLX90614, ATmega328p microcontroller, SpO_2, oxygen saturation, Temperature measurement.

Turkish Abstract **:**

Hastaların kanındaki oksijen doygunluğunu (SpO_2) ve vücut ısısını sürekli olarak izlemek ve hastaları anında uyarmak için tanısal, invazif olmayan bir cihaz tasarlanmıştır. Bu sistemin, COVID-19 gibi enfeksiyonların tanısında ve ayrıca iyileşmiş COVID-19 hastalarında görülen kan pıhtısı oluşumu gibi rahatsızlıkların SpO_2 ölçümleri ile teşhisi için kullanılması amaçlanmaktadır. Hastalar, bu bakım noktası (POC) test sistemi tarafından ateş yükselmesi veya düşük SpO_2 durumunda bilgilendirilmektedir. Bu nedenle COVID-19 tanısı virüsü yaymadan çok daha hızlı yapılabilmekte ve ayrıca kan pıhtılaşmasına bağlı ölümlerin önüne geçilebilmektedir. İnvazif olmayan tıbbi sensörler ile mikrodenetleyici tabanlı bir elektronik

SpO_2 devre tasarlanmış ve uygulanmıştır. Kullanılan mikrodenetleyici ATmega328 tek çipli 8 bit işlemci çekirdeğidir. Devrede kullanılan nabız oksimetresi kandaki doymuş oksijen seviyesini tespit etme ve aynı zamanda kalp atış hızı ölçme yeteneğine sahip MAX30100 sensörüne dayanmaktadır. Cihazda ayrıca kızılötesi temassız sıcaklık sensörü MLX90614 de kullanılmıştır. Veriler sensörler tarafından toplanıp ve daha sonra ATmega328 mikrodenetleyici tarafından işlenirken, doğrudan elektronik devreye bağlı bir dijital LCD ekran veya bir akıllı telefon kullanılarak görüntüntülenebilmektedir. Mobil cihaza erişim, bir HC-05 Bluetooth modülü kullanılarak sağlanmıştır. Bu tasarım tıbbi ölçümlerde kullanılan güvenilir cihazlarla da karşılaştırılmış ve SpO_2 ve vücut sıcaklığının gerçek zamanlı olarak izlendiği gösterilmiştir.

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DECLARATION

I hereby declare that in the preparation of this thesis, scientific ethical rules have been followed, the works of other persons have been referenced in accordance with the scientific norms if used, there is no falsification in the used data, any part of the thesis has not been submitted to this university or any other university as another thesis.

Mohammed JANANEE

/ / 2023

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THE DIRECTORATE OF GRADUATE EDUCATION INSTITUTE

The thesis study of Mohammed Ghanim JANANEE titled as SpO2 and Temperature Measurement Device Based on ATmega328p Microcontroller Chip with Mobile Connection for Real-Time Monitoring has been accepted as MASTER THESIS in the department of Electrical and Electronics Engineering by out jury.

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APPROVAL

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Director of the Institute

SUMMARY

This thesis presents the development of a SpO_2, blood oxygen saturation, and temperature measurement device utilizing the MAX30100 and MLX90614 sensors equipped with an ATmega328p microcontroller and HC-05 Bluetooth module. The device aims to provide accurate and convenient health data monitoring while enabling real-time, online data transmission for remote monitoring.

MAX30100 sensor is utilized for SpO_2 measurement, employing photoplethysmography (PPG) to detect changes in blood volume through light emission and detection. MLX90614 sensor is employed for non-contact temperature measurement providing precise and reliable readings without any physical contact. The ATmega328p microcontroller chip acts as the central processing unit, responsible for data acquisition, processing and communication between the components of the device. HC-05 Bluetooth module enables wireless communication by connecting to the mobile device. By the use of this module, the collected measurements can be sent and saved to any Bluetooth compatible platform in real-time.

This thesis encompasses the integration of hardware components and firmware development to ensure accurate measurements and to minimize errors. The device's firmware is programmed to establish communication between the sensors, microcontroller chip, and HC-05 module. Additionally, appropriate data visualization techniques and user-friendly interfaces are implemented to enhance usability and interpretation of the transmitted measurements.

This SpO_2 and temperature measuring device with Bluetooth communication offers an innovative solution for real-time online health monitoring. It provides an efficient means of continuously monitoring vital signs while enabling remote monitoring and data transmission. The device's capabilities hold a significant potential in telemedicine and home healthcare. This device also has a potential for an earlier diagnosis of some health issues and therefore, facilitates an early healthcare delivery.

Key Words: MAX30100, MLX90614, ATmega328p microcontroller, SpO_2, Oxygen saturation, Temperature measurement

ÖZET

Bu tez çalışması, MAX30100 ve MLX90614 sensörlerini kullanan, ATmega328p mikrodenetleyici ve HC-05 Bluetooth modülü ile donatılmış bir SpO_2 (kan oksijen doygunluğu) ve sıcaklık ölçme cihazının geliştirilmesini sunmaktadır. Cihaz, gerçek zamanlı, çevrimiçi veri iletimini mümkün kılarken, sağlık verilerinin doğru ve uygun şekilde uzaktan izlenmesini amaçlamaktadır.

MAX30100 sensörü, ışık emisyonu ve ışık algılama yoluyla kan hacmindeki değişiklikleri saptamak için fotopletismografi (PPG) kullanan SpO_2 ölçümü için kullanılmaktadır. MLX90614 sensörü, temassız sıcaklık ölçümü için kullanılmaktadır ve fiziksel temas olmadan hassas ve güvenilir ölçümleri sağlamaktadır. ATmega328p mikrodenetleyicisi; veri toplama, işleme ve cihazın bileşenleri arasındaki iletişimden sorumlu olan merkezi işlem birimi görevi görmektedir. HC-05 Bluetooth modülü, mobil cihaza bağlanarak, kablosuz iletişimi sağlamaktadır. Bu modül sayesinde, toplanan ölçümler gerçek zamanlı olarak herhangi bir Bluetooth uyumlu platforma gönderilebilir ve kaydedilebilir.

Bu tez, doğru ölçümler sağlamak ve hataları en aza indirmek için donanım bileşenlerinin entegrasyonunu ve ürün yazılımı geliştirmeyi kapsamaktadır. Cihazın sabit yazılımı, sensörler, mikrodenetleyici çipi ve HC-05 modülü arasında iletişim kuracak şekilde programlanmıştır. Ek olarak, iletilen ölçümlerin kullanılabilirliğini ve yorumlanmasını geliştirmek için uygun veri görselleştirme teknikleri ve kullanımı kolay arayüzler uygulanmıştır.

Bu geliştirilen Bluetooth iletişimine sahip SpO_2 ve sıcaklık ölçme cihazı, gerçek zamanlı çevrimiçi sağlık izleme için yenilikçi bir çözüm sunmaktadır. Uzaktan izleme ve veri iletimini mümkün kıldığı için hayati belirtilerin sürekli olarak takip edilmesi için uygun olmaktadır. Cihazın kapasitesinin teletıpta ve evde sağlık hizmetlerinde önemli bir potansiyeli bulunmaktadır. Bu cihaz aynı zamanda bazı sağlık sorunlarını daha erken teşhis etme potansiyeline sahiptir ve bu nedenle erken sağlık hizmeti sunumunu kolaylaştırmaktadır.

Anahtar kelimeler: MAX30100, MLX90614, ATmega328p mikrodenetleyici, SpO_2, Oksijen doygunluğu, Sıcaklık ölçümü

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RESULTS AND DISCUSSION

ABBREVIATIONS

802.11	: IEEE Wireless Lan Standard
ADC	: Analog-to-Digital Converter
API	: Application Programming Interface
API	: Application Programming Interface
ATmega328p	: ATmega328p Microcontroller Chip
AVR	: Alf and Vegard's RISC Processor
BSS	: Base Station System
DCS	: Digital Cellular System
GPRS	: General Packet Radio Services
GSM	: Global System for Mobile Communication
HC-05	: Bluetooth Module
I2C	: Inter-Integrated Circuit
IDE	: Integrated Development Environment
IoT	: Internet of Things
IR	: Infra-Red
LED	: Light-Emitting Diode
MAX30100	: Max30100 Blood Oxygen Saturation Sensor
MCU	: Microcontroller Unit
MLX90614	: MLX90614 Temperature Sensor
NSS	: Network Switching System
OSS	: Operation And Support System
POC	: Point of Care
PPG	: Photoplethysmography
RISC	: Reduced Instruction Set Computer
SCL	: Serial Clock Line
SDA	: Serial Data
SpO_2	: Blood Oxygen Saturation
STM	: Serial Terminal Monitor
UART	: Universal Asynchronous Receiver-Transmitter
Wi-Fi	: Wireless Fidelity

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PREFACE

I would like to express my thanks and gratitud to my supervisor **Asst. Prof. Dr. Mehlika KARAMANLIOĞLU** for all her help and guidence throughout the preparation and writing of the thesis.

I would like to thank my loving **wife HANAN MUTTER NASIR** for all the support she has offered me during the period of my study.

INTRODUCTION

Continuous monitoring of vital signals such as body temperature, heart beat rate and blood oxygen saturation (SpO_2) for an early diagnosis of a disease is very important. Especially with the COVID-19 pandemic, the need for SpO_2 level detection is critical. SpO2 stands for peripheral capillary oxygen saturation. More specifically, it is the percentage of oxygenated hemoglobin (hemoglobin containing oxygen) compared to the total amount of hemoglobin in the blood (oxygenated and non-oxygenated hemoglobin) (Vasan et al., 2013). Normal SpO_2 values vary between 95 and 100%. During the pandemic, most patients had to visit medical facilities which caused hospitals to be overwhelmed due to the massive number of cases which lead to even more people getting infected. Therefore, there is a need for a simple wearable, low-cost device that can be used at home as a point-of-care (POC) testing system which can transfer data wirelessly to a monitoring device. The proposed device is also implemented with an alarm system to promptly alert the potential patient in case of a temperature raise or an SpO_2 drop. This system is not only for active patients but also for recovering COVID-19 patients. It has been found that some recovering COVID-19 patients can also suffer from long term effects in which the patient develops blood clots due to the side effects of the virus (Willyard, 2022). Blood clots are possible to be detected preliminarily by SpO_2 measurements as well. In this study, we aim to develop a device for SpO_2 and temperature measurements and the data is aimed to be displayed on an LCD screen and also on a smartphone using the Bluetooth HC-05 Module.

CHAPTER ONE

PURPOSE OF THE THESIS

1.1. Aims and Objectives

This study aims to design a diagnostic, non-invasive system to continuously monitor the blood oxygen saturation (SpO_2) and temperature of the patients when such vital signals are important for diagnosis such as in COVID-19 cases to promptly alert the patients through a smartphone device. Therefore, it is aimed to preliminarily diagnose COVID-19 via continuous vital signal monitoring and to diagnose blood clots in long COVID-19 sufferers at an early stage.

This design aims to simplify the process of collecting and storing information with fast access at a low cost that is accessible to all patients without the need to visit medical facilities. SpO_2 stands for peripheral capillary oxygen saturation, it's a measure of how much hemoglobin is currently bound to oxygen compared to how much hemoglobin remains unbound (Sari et al., 2021). In order to continuously monitor SpO_2 along with heart rate, MAX30100 sensor will be used. As for the temperature measurement, MLX90614, a non-contact IR temperature sensor will be utilized and this information will be monitored at a real time via a smartphone. The device will be connected to the smartphone by Bluetooth HC-05 Module. A non-invasive sensor called a pulse oximeter is used to determine the amount of oxygen present in the blood. It has the ability to quickly detect even minor changes in oxygen levels, which indicate how effectively the blood is transporting oxygen throughout the body, especially to the areas farthest from the heart. The sensor combined with the processing power of the ATmega328p will provide medical professionals the necessary data to keep track of the well-being of individuals with conditions that influence the oxygen level in their blood, particularly when the patients are not in a medical facility.

The proposed design utilizes a Bluetooth HC-05 Module as a means of connection to the monitoring device, acting as a hub for the date to be viewed. The HC-05 Module follows the IEEE 802.15.1 standardized protocol and will function as a means to access the sensors readings and transmit them to be monitored. Because of the COVID-19 outbreak, it is essential to continuously measure oxygen levels in the body as well as temperature which will also be measured by the proposed device.

This system is also aimed to be used in recovering COVID-19 patients as it has been found that especially elderly patients would suffer from blood clots after recovering from the virus (Willyard, 2022). The proposed small, wearable, low-cost device, which is easily accessible to all, can be utilized by medical professionals in various settings, such as emergency rooms or hospitals, as an alternative to larger and more costly equipment. It can also be used by certain doctors, such as pulmonologists, in their clinics. Patients can even use one at home making it a point of care (POC) device. The concept of point-of-care testing (POC), also referred to as bedside or near-patient testing, involves conducting medical examinations close to the location where the patient is being cared for. The current diagnostic laboratory system is slow to adapt and when thoroughly evaluated, it reveals the need for a more patient-centric system (Karami, 2014). Testing in this method allows for immediate access to test results, enabling quick diagnosis. POC testing systems are user-friendly, making it easy to operate and to diagnose quickly in remote locations where a clinical laboratory setup and expertise is not available (Khurshid, 2018) Also, POC systems coupled with biotelemetry, i.e., remote monitoring and measurement of human functions, would be ideal to be used by patients in quarantine with the aid of Bluetooth connections.

1.2. Importance of The Thesis

In this study, a diagnostic system will be designed to monitor vital body parameters such as SpO_2 levels and temperature to promptly notify the patient in case of an adverse situation. Keeping track of the patient's body temperature and oxygen saturation is crucial as it can aid in early detection of COVID-19 symptoms. This system will make the diagnosis faster, especially for people in high-risk groups. This system will provide a fast and accurate reading of temperature and SpO_2 levels which will be sent directly to a monitoring device. This device can be utilized by not only individuals who have been diagnosed with COVID-19, but also by people who have respiratory or cardiovascular conditions, young infants, and those who have contracted certain infections. And while some recovering COVID-19 patient may suffer from blood clots as a long-term side-effect (Willyard, 2022), the measuring of SpO_2 levels would preliminarily diagnose the presence of blood clots.

Oxygen saturation measurement is a test that measures the amount of oxygen in a person's blood. Specifically, it measures the amount of hemoglobin, a protein in the red blood cells, that is carrying oxygen. Hemoglobin is responsible for transporting oxygen from the lungs to the body's tissues and organs. Oxygen saturation is typically measured as a percentage, with normal levels being between 97% and 100%. Low oxygen saturation levels, below 90%, can be a sign of a serious medical condition and may require immediate attention. Oxygen saturation can be measured non-invasively using a pulse oximeter, which is a small device that attaches to a finger or earlobe, it can also be measured invasively by an arterial blood gas test (Sari et al., 2021).

SpO_2 levels may decrease due to exercising and may get as low as 88% for the first few minutes but will gradually build up once again as the body adapts to the situation so not all cases of decreasing SpO_2 levels may be critical and need immediate attention. Therefore, the person may have a low SpO_2 from a burst of activity or may have a serious case of COVID-19. With this device, in case the oxygen level gets below a certain value an alarm sound will be triggered alerting the patient to take action to prevent the levels from further declining. There are pulse oximeters to measure SpO_2 in the market but with no built-in alarm system nor with the ability to store the measurements or transfer the data to another location. Our design will continuously monitor and store not only SpO_2 but also temperature measurements with an alarm system.

In other studies, the ATmega328p chip wasn't used (Siddiq & Sulistiyowati, 2021) and in this study, the ATmega328p chip will be used to keep the device at a minimum cost. Also, in most of the pulse oximeters in the market and other studies, the data collected wasn't stored but viewed temporarily and discarded immediately making the ability to follow changes in oxygen levels unavailable (Giavarina et al., 2010). However, in our study, data collection and storage are essential.

In our study, we will measure SpO_2 with temperature which is more essential for COVID-19 cases and the device will have the ability to store the sensors' readings on the phone to see previous readings of the sensors and display them over a specific time frame.

1.3. Statement of Thesis

The goal of this project is to design and implement a wearable device for continuous monitoring of SpO_2 and temperature levels using an ATmega328p microcontroller chip and sensors. The device will be equipped with Bluetooth connection allowing for real-time and remote monitoring and alerting in case of abnormal readings. The device will be user-friendly and portable, making it suitable for use in various settings, such as in hospitals, home healthcare and fitness centers. The device will be tested in a controlled environment. The collected data will be analyzed to assess the performance of the device. The results of this project will contribute to the development of reliable and cost-effective monitoring solutions for healthcare and wellness applications.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL BACKGROUND

2.1 Introduction

Health monitoring systems have come a long way in recent years with a wide range of devices and technologies now available for tracking various vital signs and medical conditions. Some of the most popular health monitoring systems include wearable devices such as smartwatches, fitness trackers, and activity monitors, which can track things like heart rate, steps taken, and sleep patterns. There are also more specialized devices for monitoring specific conditions such as pulse oximeters for measuring blood oxygen levels, glucometers for monitoring blood sugar levels, and spirometers for measuring lung function.

In addition to these devices, there are also a number of mobile applications and software platforms that can be used to track and analyze health data as well as connect patients with healthcare providers remotely. These systems can be used to track symptoms, manage medications and even schedule virtual consultations with doctors.

Another area of health monitoring that is gaining popularity is remote monitoring of patients with chronic conditions such as diabetes and heart failures. These systems use sensors and other devices to collect data on the patient's condition, which can then be transmitted wirelessly using Wi-Fi or Bluetooth to healthcare providers for analysis and follow-up.

Overall, the current state of the art in health monitoring systems is characterized by a high degree of flexibility with a wide range of devices and technologies that can be tailored to the needs of individual patients. With advances in technology and data analytics, we can expect this field to continue to evolve and improve in the coming years.

Daily monitoring of some biological parameters like SpO_2 and temperature will ensure early diagnosis of some diseases. However, visiting a hospital every day to check vital body parameters is not easy and due to the lack of resources at many medical facilities, especially at simple ones, the need for information and communication technology (ICT) has been recognized by physicians and administrators (Jin et al., 2015).

Apart from this, the number of patients that require continuous monitoring is increasing the hospitalization and patient care fees which are ranging from 1.5 to 5 billion dollars annually already in the USA which is also expected to increase later on (Willyard, 2022). Therefore, in an effort to reduce care costs, the introduction of point-of-care (POC) testing systems with real-time, accurate, and rapid outputs and with high selectivity and sensitivity are introduced. POC technology refers to medical equipment used to perform testing outside of a laboratory setting, close to the patient, such as at the patient's bedside in the physician's office or at the patient's home (Karami et al., 2014). It has the ability to detect the presence or absence of diseases in body fluids.

Different prototypes of POC testing systems have been developed, which give immediate information on the patient's health status, either to the patient or to a healthcare provider's accessible medical database(Vasan et al., 2013). These systems are becoming more appealing and they help reduce the burden on the medical staff and reduce waiting duration and consultation times (Willyard, 2022).

In our study, we will be focusing on the continuous detection of blood oxygen saturation (SpO_2) levels, heart rate as well as temperature in the human body. The normal level of oxygen in the blood is usually 95% or higher; the range of body temperature of a healthy person should be between 36.4o to 37.2^{o}C; and the resting heart pulse rate is generally 72 beats per minute (bpm) (Jin et al., 2015). All this information can be transferred to the monitoring devices wirelessly using ZigBee, Bluetooth, or GSM (A. Abdullah et al., 2015) or transited to a web server which provides storage and data viewing at any time by the use of Wi-Fi technology since it transmits the patient’s data from a remote location to the cloud-based servers in real-time. Transferring information remotely using communication technology is known as biotelemetry (Gholamhosseini & Baig, 2013).

A study was carried out in mobile and health to detect silent Hypoxia using Pulse Oximetry (Teo, 2020). With remote monitoring, the medical staff can recognize changes in the parameters of patients without frequently visiting them and consequently take immediate action to prevent possible aggravations (Kanade et al., 2021). Remote monitoring allows for the early detection of changes in a patient's health condition which can help prevent serious complications and improve outcomes (Fanucci et al., 2013).

Sensors and wireless communication make it possible to monitor vital signs remotely and non-invasively (Tran et al., 2014). Non-invasive refers to a method of examination or treatment that does not involve implantation, operation or any insertion of instruments into the body.

Non-invasive procedures are generally considered to be less risky and more comfortable for patients than invasive procedures, as they do not involve the same level of risk or recovery time. Examples of non-invasive procedures include diagnostic imaging tests such as CT scans and MRI, as well as certain types of monitoring, such as pulse oximetry or electrocardiography (ECG). A proposed system can adjust to the patient based on their data and medical history. Specifically, this information is used to create an accurate reference model that is tailored to the patient's health condition. This system can be applied to different individuals and detect various vital signs, such as SpO_2 and temperature, by switching to sensors that are capable of measuring oxygen.

2.2 Components of the Proposed Biotelemetry Systems

Within the scope of this project, a diagnostic system will be designed to continuously monitor vital signals such as SpO_2 levels, pulse rate, and temperature to promptly notify the patient in case of an adverse situation. Therefore, the diagnosis will be faster, especially for people in high-risk groups.

Oxygen (O_2) is the most important element for vitality. Checking an individual's health status can be carried out by measuring and tracking the level of oxygen in their blood, which is a crucial indicator of their overall health. The oxygen saturation level in an individual's blood gives important insights into the functioning of both their cardiovascular and respiratory systems (Elagha et al., 2019).

Biomedical sensors were first invented in 1950 by L.L Clark. In general, biomedical sensors are used to detect, collect and forward the data to the microcontroller where the actual data processing will occur. Biomedical sensors are generally cost-effective and accessible diagnostic solutions and they are used in settings where conventional and sophisticated laboratory equipment are not present and hard to access in some rural locations. Biosensors are a class of biomedical sensors that contain a biological sensing element such as an enzyme and a transducer (Elprocus, 2020).

A pulse oximeter sensor is an optical sensor used in the design of the circuit to detect the oxygen saturation levels in the blood. It’s a non-invasive wearable device to measure blood oxygen saturation along with pulse rate (Niswar et al., 2019).

MAX30100 is the module used that integrates pulse oximetry and pulse sensors. The module is designed with two light-emitting diodes, a sensor optimized for capturing light and has an advanced technology to reduce noise in the received signal, allowing to accurately measure blood oxygen levels and heart rate (Melexis, 2019). The fundamental idea behind pulse oximetry is the variation in the absorption of photons passing through a blood sample at different wavelengths. It relies on the distinct light absorption properties of Hb for red light (660 nm wavelength) and HbO2 infrared light (940 nm wavelength) (Elagha et al., 2019).

In a study, a photoplethysmography, PPG, a non-invasive device used to measure changes in blood volume in the microvascular beds of the skin was developed by using MAX30100 sensor, NodeMCU microcontroller (Morad, 2015). An Android-based mobile application was used to create a telemedicine system for measuring heart rate and oxygen saturation (Morad, 2015). Another study built a system based on the Arduino microcontroller and MAX30100 sensor in an effort to create telemedicine solutions to be used by COVID-19 patients and the prototype delivered the data through Bluetooth to be shown in the Android application using the Sugeno fuzzy method for classification (Megantoro, 2020). In another study, the aim was to assess the reliability of the heart rate and SpO_2 data collected by a Samsung Galaxy smartphone's built-in sensor and light source; and to compare the data with measurements from vital signs monitor (VSM) and arterial blood gas (ABG) equipment (Tayfur & Afacan, 2019). Utilizing smartphone-based pulse oximetry could significantly improve the early diagnosis of silent hypoxia, lack of sufficient oxygen reaching the body's tissues, and consequently, the ability to spot the development of COVID-19 pneumonia (Teo, 2020).

MLX90614 is an infra thermometer non-contact temperature measurement sensor which has been calibrated by the factory with Digital Outputs PWM and SMB (System Management Buses) and has a wide range of applications (Melexis, 2019).

Research using an Arduino Pro Mini and MLX90614 sensor to monitor body temperature produced an output that showed the actual body temperature on an LED screen (Melexis, 2019).

Another study employed the MLX90614 to create an Android-based continuous temperature measuring device and the results were accurate to within 0.3 and 0.6 degrees centigrade (Sudianto et al., 2020). In one publication, a non-contact infrared thermometer for the non-contact liquid security identification system was developed using the MLX90614 sensor and the STM32F107 microprocessor where the primary function was temperature measurement of liquids in the safety inspection at the subway, airport and railway (Jin et al., 2015). A method of assessing the temperature during the machining process of aluminum alloy on a CNC milling machine using the MLX90614 infrared thermometer sensor controlled by an Arduino board was presented in a paper where the measured results were compared with those from an infrared fusion Fluke Ti400 device (Sudianto et al., 2020). Results from the measurements using both devices revealed comparable levels of precision with a variance of only about ± 2^0 C (Sudianto et al., 2020). An infrared thermometer measures the temperature of an object by detecting the infrared radiation it emits and uses that information to calculate the temperature (Saeed & Khalaf, 2019).

In this study, the design of the circuit, the ATmega328P was used. The ATmega328P is an 8-bit microcontroller that uses a Reduced Instruction Set Computer (RISC) architecture and consumes low power; and it is based on the AVR technology architecture with the ability to execute powerful instructions in a single clock cycle (Atmel, 2016). In a study, the ATmega328P was used with an airflow thermal sensor for respiration rate measurement and pulse oximetry for heart rate and blood oxygen saturation measurement to monitor the vital signals of patients (Niswar et al., 2019). In a different study, PIC18F4520 was used as a microcontroller which has a built-in 13-channel 10-bit ADC converter (Elagha et al., 2019).

Numerous medical applications of Arduino have been developed, including systems for monitoring body temperature and heart rate as well as treatments for diabetes, heart disease, and measuring body temperature. The ATmega328p is used as the base to create many different electronic devices which are used in the medical field (Widadi et al., 2020).

In a study, ATmega328P microprocessor was used with a Bluetooth module, an analog signal conditioner, and an X-ray detector circuit to display and control the test results on mobile devices (Widadi et al., 2020). The ATmega328p was also used in a study as the primary controller of the system, transferring the humidity data through a GSM/GPRS module to a server's database (Mirayanti et al., 2018).

Arduino was used in a study where it gave researchers the ability to apply their understanding of microcontrollers to a variety of IoT-based sensors because of its high-speed digital signal processing capabilities and minimal cable wiring for communication (Sudianto et al., 2020). However, in our study, we used the ATmega328p microcontroller chip insisted of the entire Arduino board thus reducing the size, power consumption, and cost of the device dramatically.

In our thesis, the device will connect to the mobile device and will have the ability to transfer its data by the use of the HC-05 Bluetooth module. The authors of another study discussed the implementation of a lightweight messaging protocol, known as Message Queuing Telemetry Transport (MQTT), on a development board that uses ESP8266 Wi-Fi and they connected sensors and actuators to the ESP8266 and set up an MQTT broker, which is based on Mosquitto, for remote monitoring and control (Kodali & Soratkal, 2017).

One publication (Parane et al., 2014) described a Cloud-based Intelligent Healthcare Monitoring System (CIHMS), which connected the measuring gadget to the internet and offered the patient medical feedback and help via the cloud (Škraba et al., 2017). A study detailed the creation of a prototype that allows for the monitoring of heart rate and the time between each beat, the prototype was constructed using NodeMcu ESP8266 hardware modules, a library for WebSocket communication, node-js, and JavaScript programming languages (Guney et al., 2022).

In a study, a configurable monitoring system based on the ATmega328p microcontroller was discussed as a replacement for the previously employed namely level stick sensor in the beverage industry (Hidayat et al., 2019). In another study, the authors aimed to create a system that seamlessly switches between solar and wind energy sources, using a website and an ESP8266 Wi-Fi module where the module receives the data wirelessly and controls the energy sources accordingly (Srivastava et al., 2018).

The aim of another project was to create a wireless heart rate monitor using Bluetooth Low Energy (BLE) technology and the photoplethysmography principle was applied by using the MAX30100 as the heart rate sensor (Onubeze, 2016).

In another study, Node MCU ESP8266, DS18B20 sensor and MAX30100 sensor are components of a monitoring system designed where Wi-Fi was utilized for communication during information exchange (Hikmah et al., 2022). The data about body temperature and oxygen saturation was viewed using applications created with MIT App Inventor (Hikmah et al., 2022)

2.3 Overview of Current State-of-the-Art Health Monitoring Systems

Health monitoring systems are tools or technologies that monitor and measure vital signs, such as heart rate, blood pressure and activity levels. These systems are intended to provide up-to-date or near real-time data on the user's health status, as well as to alert the user or healthcare professionals in case of any abnormal readings. Health monitoring systems are used in various settings, such as at hospitals, home healthcare, and fitness centers, and are targeted towards different populations, such as adults, children and athletes.

There are a variety of health monitoring systems available on the market, ranging from simple devices that measure a single vital sign to more complex systems that measure multiple vital signs. These systems can be classified based on different parameters. One of the main trends in health monitoring systems is the increasing use of artificial intelligence (AI) and machine learning (ML) algorithms to process and interpret the collected data. These algorithms can be used to identify patterns and trends in vital signs, as well as to provide insights and alerts based on the data. For example, AI and ML algorithms can be used to predict the risk of a heart attack or to detect early signs of disease. There are also a number of challenges that need to be addressed in the development and implementation of health monitoring systems. One of the main challenges is the accuracy and reliability of the sensors and algorithms used to measure and interpret vital signs.

Inaccurate or unreliable data can lead to false positives or false negatives, which can have serious consequences, particularly in the case of emergency alerting. Another challenge is the security and privacy of the collected data, as sensitive personal health information is at risk of being accessed or misused by unauthorized parties. Finally, there is the issue of user acceptance and adherence, as health monitoring systems may require a high level of engagement and compliance from the user.

2.3.1 Wearable health monitoring systems

Another main trend in healthcare systems is the increasing integration of health monitoring systems with wearable technology (Dias & Cunha, 2018). Wearable health monitoring sensors and systems have become increasingly popular in recent years.

These devices are designed to be worn on the body and can measure a wide range of vital signs, including heart rate, blood oxygen levels, body temperature and activity levels. They are typically small and lightweight, making them easy to wear throughout the day. Some common types of wearable health monitoring systems include fitness trackers, smartwatches and activity monitors. These devices can be used to track personal health data, such as steps taken and calories burned and can also be used to monitor specific medical conditions, such as sleep apnea or heart arrhythmias. Wearable health monitoring sensors and systems can be connected to smartphones, tablets, or personal computers, allowing users to easily track their health data and share it with healthcare providers. This technology has the potential to revolutionize the way we monitor our health and manage chronic conditions.

Wearable devices, such as smartwatches, fitness trackers, and smart clothing, are becoming more popular for health monitoring due to their convenience, portability and user-friendliness. Wearable devices are equipped with sensors that measure various vital signals and transmit the data to a central server or a healthcare professional using wireless communication technologies such as Bluetooth and Wi-Fi (Zhou, 2020).

These systems are designed to be lightweight, portable, and convenient, making them suitable for use in various places like hospitals, home settings and fitness centers.

One of the main advantages of wearable health monitoring systems is their ability to provide real-time data on the user's health status. This can be particularly useful for individuals with chronic conditions, who may require frequent monitoring to manage their condition effectively. Wearable systems can also be used to alert the user or healthcare professionals for any abnormal readings allowing for timely intervention.

There are a variety of wearable health monitoring systems available on the market, ranging from simple devices that measure a single vital sign to more complex systems that measure multiple vital signs(Ring et al., 2010).

In general, health monitoring systems can be classified based on the type of vital signs they measure, the technology they use and the target population they are designed for. Wearable health monitoring systems can be classified based on the type of vital signs they measure, such as cardiovascular, respiratory, or neurological. Cardiovascular monitoring systems are designed to measure vital signs related to the heart, such as heart rate, blood pressure and blood oxygen saturation (SpO_2). Respiratory monitoring systems are designed to measure vital signs related to the respiratory system, such as breathing rate and volume. Neurological monitoring systems are designed to measure vital signs related to the nervous system, such as brain activity and sleep patterns.

In conclusion, health monitoring systems are a rapidly evolving field with a wide range of technologies and applications. Wearable devices and AI/ML algorithms are among the main trends in the current state of the art, while accuracy, reliability, security, and user acceptance remain key challenges. Further research and development are needed to address these challenges and to enhance the capability and usability of health monitoring systems with more diverse electronic devices and microcontrollers which can also be implemented in wearable technologies (Sugathan et al., 2013).

2.4. Blood Oxygen Saturation Definitions and Measurements

Blood oxygen saturation, also known as oxygen saturation or SpO_2 is a measure of the amount of oxygen being carried by the red blood cells in the body. Hemoglobin (Hb) is a protein found in red blood cells that binds with oxygen and carries it throughout the body and Oxyhemoglobin (HbO_2) is the form of hemoglobin that has bound with oxygen.

HbO_2 is the form that is responsible for carrying oxygen to the body's tissues (Strogonovs, 2017). Deoxyhemoglobin (Hb) is the form of hemoglobin that has not bound with oxygen. Pulse oximeters use two different wavelengths of light to measure oxygen saturation in the blood. The first wavelength is typically red light (R) with a wavelength of 660 nanometers (nm). The second wavelength is typically infrared light

(IR) with a wavelength of 940 nm (Rahman et al., 2021). These wavelengths are chosen because they correspond to the peak absorption spectra of oxygenated hemoglobin (HbO_2) and deoxygenated hemoglobin (Hb), respectively (Hafen et al., 2021). HbO_2 absorbs IR and when the photodiode generates light at these two wavelengths the oximeter determines the red-light to IR ratio (R/IR).

Blood oxygen saturation is typically expressed as a percentage, with normal levels ranging from 95% to 100%.

Low blood oxygen saturation, also known as hypoxemia, can be a sign of a serious health condition, such as respiratory or cardiovascular disease, and can lead to serious complications if left untreated.

There are several methods for measuring blood oxygen saturation, including pulse oximetry, arterial blood gas analysis, and near-infrared spectroscopy. Pulse oximetry is the most commonly used method, and involves the use of a device called a pulse oximeter, which is typically worn on the finger or earlobe. The pulse oximeter uses light-emitting diodes (LEDs) and photodetectors to measure the amount of light absorbed by the blood, which is then used to calculate oxygen saturation. Pulse oximetry is non-invasive, easy to use, and relatively inexpensive, making it a popular choice for continuous monitoring of oxygen saturation.

During a pulse oximetry reading, a small clamp-like device is placed on a finger, earlobe, or toe (Maxim-Integrated, 2014). Small beams of light pass through the finger measuring the amount of oxygen in the blood. It carries this out by measuring changes in light absorption of oxygenated or deoxygenated blood. The device has two LEDs, one emitting red light and another emitting infrared light. For pulse rate, only infrared light is needed. Both red light and infrared light are used to measure oxygen levels in the blood. When the heart pumps blood, there is an increase in oxygenated blood as a result of more amount of blood.

As the heart relaxes, the volume of oxygenated blood also decreases. By knowing the time between the increase and decrease of oxygenated blood, the pulse rate is determined.

It turns out, oxygenated blood absorbs more infrared light and emits more red light while deoxygenated blood absorbs red light and emits more infrared light. This is the main working principle of the MAX30100. A device based on MAX30100 reads the absorption levels for both light sources and stores them in a buffer that can be read via an I2C communication protocol, transferring the measured data to the ATmega328p (Bakhri et al., 2020).

2.5. Temperature Definitions and Measurements

Temperature is a physical parameter to show the heat or coldness of an object or substance. It is typically measured in degrees Celsius (°C) or Fahrenheit (°F). Normal body temperature is typically considered to be around 37°C (98.6°F) although there can be some variation depending on factors such as age, sex, and activity level.

An abnormal body temperature, either too high (fever) or too low (hypothermia), can be a sign of a serious health condition and can lead to complications if it is left untreated (Ilsley et al., 1983).

There are several methods for measuring body temperature, including oral, rectal, axillary, and temporal artery measurements. Oral temperature measurement involves placing a thermometer under the tongue or in the mouth. Rectal temperature measurement involves placing a thermometer in the rectum. Axillary temperature measurement involves placing a thermometer in the armpit. Temporal artery temperature measurement involves using a special thermometer to measure the temperature of the artery in the forehead. Each of these methods has its advantages and disadvantages, and the choice of method may depend on factors such as the age of the patient, the severity of the condition, and the availability of equipment (Ring et al., 2010). Temperature can be measured by several instruments. Conventionally, a glass thermometer containing mercury or alcohol can be used but more accurate ones are electronic and infrared thermometers.

Electronic thermometers and infrared thermometers are examples of temperature measurement devices that are commonly used in various applications including industrial, medical and scientific settings. An electronic thermometer typically uses a thermistor, which is a type of resistor that changes its resistance in response to changes in temperature.

The thermistor is connected to an electronic circuit that measures the resistance and converts it into a temperature reading. Thermocouples can also be used. Electronic thermometers can be used to measure a wide range of temperatures from very low temperatures to very high temperatures. They are also highly accurate and precise, making them suitable for use in laboratories and other applications where precise temperature measurements are needed. Infrared thermometers, on the other hand, use infrared radiation to measure the temperature of an object. Infrared thermometers work by measuring the amount of infrared energy emitted by an object and converting it into a temperature reading. They can be used to measure the temperature of an object without actually coming into contact with it, making them suitable for use in applications where it is not possible or desirable to make contact with the object being measured. For example, temperature measurements of patients with infectious diseases such as COVID-19 are more suitable with IR thermometers for hygiene. Infrared thermometers are commonly used in industrial settings to measure the temperature of machinery and other equipment, as well as in medical settings to measure body temperature. In a study, a measurement device was created using the MLX90614 sensor and a microphone to monitor an infant's breathing and remotely monitored the vital signals using field programmable gate array (FPGA) technology (Tran et al., 2014).

Both types of thermometers have their advantages and disadvantages. Electronic thermometers are considered more precise and accurate, but infrared thermometers are more convenient as they don't require contact with the object being measured and they are also useful for measuring the temperature of moving objects (Grodzinsky & Sund-Levander, 2013).

In conclusion, blood oxygen saturation and temperature are important vital signs that can provide valuable information on the health status of an individual. Blood oxygen saturation can be measured using various methods, including pulse oximetry, arterial blood gas analysis, and near-infrared spectroscopy. Temperature can be measured using various methods, including oral, rectal, axillary, and temporal artery measurements. It is important to accurately and reliably measure these vital signs in order to identify and manage any health conditions that may arise. Further research is needed to improve the accuracy, reliability, and convenience of these measurement methods.

2.6. Point of Care (POC) Testing, Biotelemetry & Remote Health Monitoring systems

Point of care (POC) testing (near patient, bedside) refers to the use of diagnostic tests that can be performed at or near the site of patient care instead of conventional and sophisticated laboratory settings. POC tests are typically portable, easy to use and they provide rapid results, making them suitable for use in various places such as hospitals, clinics and home healthcare. POC tests are used to diagnose a wide range of conditions such as infectious diseases, cardiovascular diseases and diabetes.

Biotelemetry refers to the measurement and remote transmission of biological data from an individual using electronic devices. These devices can include sensors that measure a variety of physiological parameters such as heart rate, blood pressure, and body temperature (Sonal & Kadav, 2020). The data is typically transmitted wirelessly to a remote location where it can be analyzed and used to monitor the individual's health. Biotelemetry is commonly used in research, sports medicine, and clinical settings (Das & Yoo, 2015).

On the other hand, remote health monitoring (RHM) is a broader term that encompasses the use of technology to monitor and manage a patient's health remotely. It includes the use of biotelemetry but also encompasses use of other technologies such as telemedicine and remote patient monitoring. It allows for the collection of data from patients in their homes or other non-clinical settings, which is analyzed and used to provide feedback to the patient, clinician or other healthcare providers. This can help to improve the quality of care, reduce costs and increase patient satisfaction (Faiz et al.,2023).

In summary, biotelemetry and remote health monitoring are related but distinct concepts, Biotelemetry is a subset of Remote Health monitoring that specifically deals with the measurement and remote transmission of biological data. While remote health monitoring is more comprehensive and encompasses other aspects of healthcare such as telemedicine and remote patient monitoring (Kanade et al., 2021).

There are several advantages of POC testing, biotelemetry- remote health monitoring systems. These technologies can provide rapid and convenient access to diagnostic and monitoring services, particularly in underserved or remote areas.

They can also reduce the need for hospitalization and other costly interventions and also can improve patient outcomes and satisfaction. However, several challenges need to be addressed, including the accuracy and reliability of the tests and sensors, the security and privacy of the collected data, and user acceptance and adherence to these technologies.

In conclusion, POC testing, biotelemetry, and remote health monitoring systems are promising technologies that can provide rapid and convenient access to diagnostic and monitoring services and improve patient outcomes. However, several challenges need to be addressed. Further research and development are needed to address these challenges and to enhance the capabilities and usability of these systems.

2.7. Communication Methods

Wireless communication methods are essential for the transmission of data from health monitoring devices to a central server or a healthcare professional. There is a wide range of wireless communication technologies available, each with its characteristics and capabilities.

One of the most widely used wireless communication technologies in health monitoring is Bluetooth. Bluetooth is a technology that enables devices to connect and exchange data wirelessly through radio waves over a short range and it is commonly used in health monitoring devices, such as wearable fitness trackers and smartwatches, as it is low power, easy to use and relatively inexpensive. Bluetooth can support a range of data rates and can be used for both data and voice transmission.

Another wireless communication technology used in health monitoring is Wi-Fi. Wi-Fi is a technology that enables wireless communication between devices over a distance utilizing radio frequency signals. It allows devices such as computers, smartphones and tablets to connect to a network and access the internet without the need for physical cables. It is commonly used in health monitoring devices, such as home health monitors and telemedicine platforms as it can support high data rates and it provides internet connection.

Wi-Fi can operate in both the 2.4 GHz and 5 GHz frequency bands and can support a range of protocols, including IEEE 802.11a/b/g/n/ac (Ostrowski et al., 2015).

The third wireless communication technology used in health monitoring is cellular, which is a technology that uses a network of small transceiver cells to communicate with mobile devices such as smartphones and tablets. Each cell is a geographic area that is serviced by a base station, which is a wireless transceiver that communicates with the mobile devices within its coverage area (Saravanan et al., 2022). Cellular networks are divided into two main types: 2G (second generation), which uses analog and digital signals, and 3G (third generation) and 4G (fourth generation) which use digital signals, and offer faster data transfer rates, and more advanced features such as video and high-definition voice calls (Soni & Year, 2007).

5G (fifth generation) is the latest cellular technology, which offers even faster data transfer rates and lower latency, making it suitable for applications such as self-driving cars and remote surgery and in health monitoring devices, such as mobile health apps and remote patient monitoring devices. It can operate in a range of frequency bands, depending on the region and the provider and can support a range of protocols, including GSM, CDMA, and LTE.

Cellular and Wi-Fi are both wireless technologies that allow devices to communicate with each other. The main difference between them is the way they transmit data and the distance over which they can communicate (Mozaffariahrar et al., 2022). There are several advantages to using wireless communication methods in health monitoring. Wireless communication methods are convenient, as they do not require the use of cables or other physical connections. They are also flexible, as they can be used to transmit data over a wide range of distances and in a variety of environments. Wireless communication methods are also relatively low-cost, as they do not require the installation of expensive infrastructure.

One of the main challenges is the security and privacy of the transmitted data, as wireless communication methods are vulnerable to interference and hacking. Another challenge is the reliability and coverage of the wireless signal, as the quality of the signal may vary depending on the location and the presence of obstacles. Finally, there is the issue of power consumption as wireless communication methods can drain the battery of the devices (Ghamari et al., 2015).

Additionally, Bluetooth is also a means of communication. It is used in different fields to transfer multiple types of data between devices. A voice-controlled car was discussed in this study with the main remote control type being Bluetooth (Saran et al., 2021). Another study discussed the use of the HC-05 Bluetooth module used in devices for medical purposes in medicine (Kaur et al., 2023).

In conclusion, wireless communication methods are essential for the transmission of data from health monitoring devices to a central server or healthcare professional. There is a wide range of wireless communication technologies available, each with its characteristics and capabilities.

However, there are also several challenges that need to be addressed to ensure the security, reliability and efficiency of these technologies. Therefore, further research and developments are needed to address these challenges and enhance the capabilities and usability of wireless communication methods in health monitoring (Milenković et al., 2006).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Materials

In the design of the device, we took several commercial, business and engineering factors into account. Moreover, while putting the system into practice cost, ease of use, simplicity, efficiency and environmental friendliness were considered. Based on these factors, a microcontroller coupled with two main sensors and a means to transfer the data were implemented into a device. One of the main objectives was to keep the device small and with low power consumption. ATmeag328p was used as the microcontroller in this study. Even though, it is available in a predesigned single chipboard called Arduino UNO as seen in Figure 1, we opted to use only the microcontroller itself. One can initiate a motor, activate an LED, post online or receive inputs such as light detected by a sensor with the use of this microcontroller.

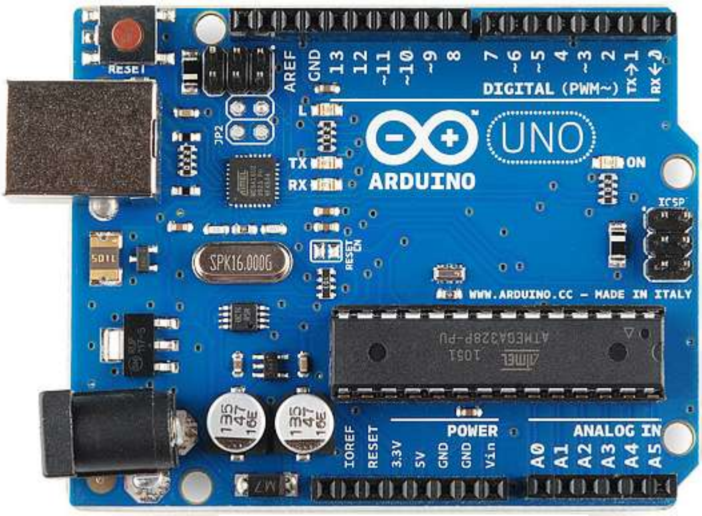


Figure 1. Arduino UNO

To provide a set of instructions to the microcontroller on the Arduino board, the Arduino Software IDE (Integrated Development Environment) running on a computer is used. The IDE is used to write and upload computer code to the board. Arduino senses the environment by receiving inputs from many sensors and affects its surroundings by processing, controlling and transmitting the information. With multiple input/output pins and a variety of ways to power, the extra functionality wasn't required, therefore we only used the microcontroller chip which reduced the size of the device and also reduced the power required for the device to function effectively. Figure 2 shows the basic components of our device with each sensor.

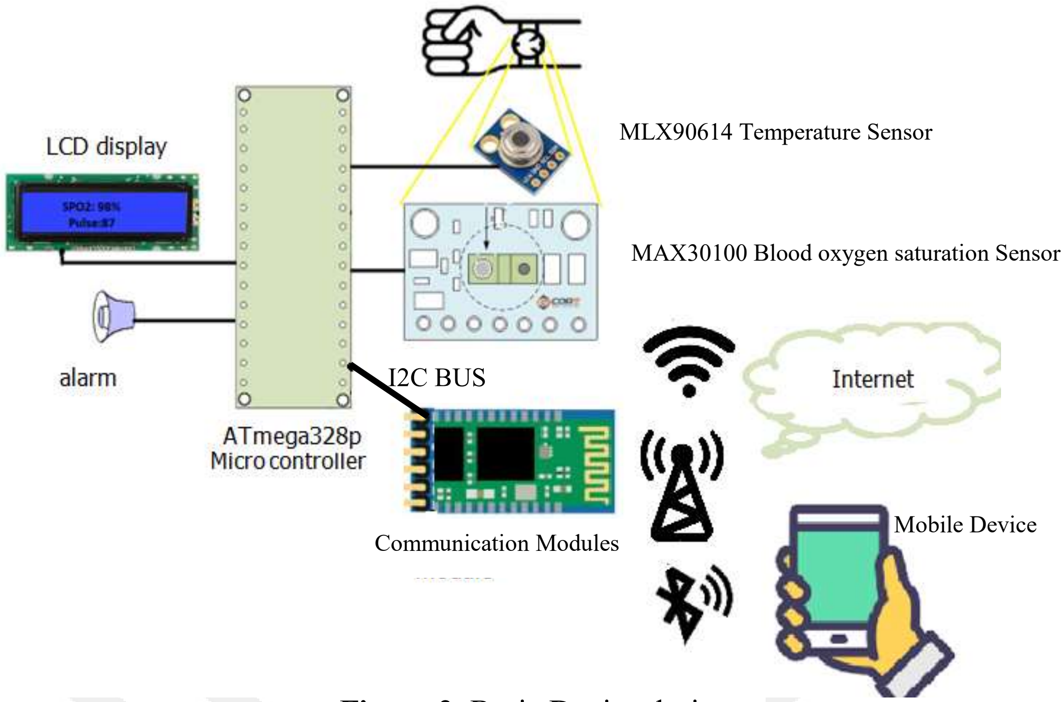


Figure 2. Basic Device design

3.1.1. ATmega328P Microcontroller

The ATmega328P by Atmel is an 8-bit microcontroller with low-power CMOS and is based on the RISC (Reduced Instruction Set Computer) architecture. It has the ability to execute powerful instructions in a single clock cycle, providing throughputs close to 1 MIPS per MHz, allowing the system designer to optimize the device for either power consumption or processing speed (Atmel, 2016). The Atmel AVR core is equipped with a rich instruction set and 32 general-purpose working registers, which are directly connected to the Arithmetic Logic Unit (ALU) (Šipoš & Šimoňák, 2020). This enables two independent registers to be accessed in a single instruction executed in one clock cycle, which makes the architecture highly code efficient and achieves throughputs up to ten times faster than traditional CISC microcontrollers.

The ATmega328P microcontroller boasts a range of features, including 32 Kbytes of In-System Programmable Flash with Read-While-Write capabilities, 1 Kbytes EEPROM, 2 Kbytes SRAM, 23 general-purpose I/O lines, a Real Time Counter (RTC), three flexible Timer/Counter pairs with compare modes and PWM, 1 serial programmable USARTs, 1 byte-oriented 2-wire Serial Interface (I2C), a 6-channel 10-bit ADC (8 channels in TQFP and QFN/MLF packages), a programmable Watchdog Timer with an internal 8MHz Oscillator, an SPI serial port and six software selectable power-saving modes (Atmel, 2016) shown in Table 1.

In addition, the ATmega328P offers several power-saving modes to optimize power consumption. The Idle mode stops the CPU, SRAM, Timer/Counters, SPI port, and interrupt system while allowing other functions to continue functioning. The Power-Down mode saves the register contents but freezes the oscillator, disabling all other chip functions until the next interrupt or hardware reset. The Power-Save mode keeps the asynchronous timer running, allowing the user to maintain a timer base while the rest of the device is in sleep mode.

In order to reduce the potential for switching noise during ADC conversions, the ADC Noise Reduction mode is utilized, which halts the CPU and all I/O modules with the exception of the asynchronous timer and ADC. During Standby mode, the crystal/resonator oscillator remains active while the other components of the device are put to sleep. This configuration allows for rapid start-up while maintaining low power consumption. In Extended Standby mode, both the main oscillator and the asynchronous timer remain operational.

We used a DIP (dual in-line package) chip shown in Figure 3 as it was easy to mount or remove in case replacement was required. Also, minimal wiring was needed to connect to other components and it costs less than the SMD chip.

Table 1. ATmega328p Configuration Summary

Features	ATmega328/P
Pin Count	28/32
Flash (Bytes)	32K
SRAM (Bytes)	2K
EEPROM (Bytes)	1K
General Purpose I/O Lines	23
SPI	2
TWI (I^2C)	1
USART	1
ADC	10-bit 15kSPS
ADC Channels	8
8-bit Timer/Counters	2
16-bit Timer/Counters	1

Considered to be one of the leading 8-bit architectures, the AVR architecture gives the ATmega328P microcontroller a relatively simple instruction set, with most instructions executing in a single clock cycle. Its 32 general-purpose registers can also be used for data manipulation and storage.

When the level of difficulty that is involved in executing instructions on a specific system is considered, the RISC architecture is typically viewed as advantageous since RISC computers typically feature simpler instructions (Atmel, 2016)

The microcontroller communicates with peripheral devices through ports, which act as gateways between the CPU core and other parts of the microcontroller, or between the CPU and devices outside of the chip, such as sensors or mechanical equipment like servo motors or relays (Shakarji & Golcuk, 2022).

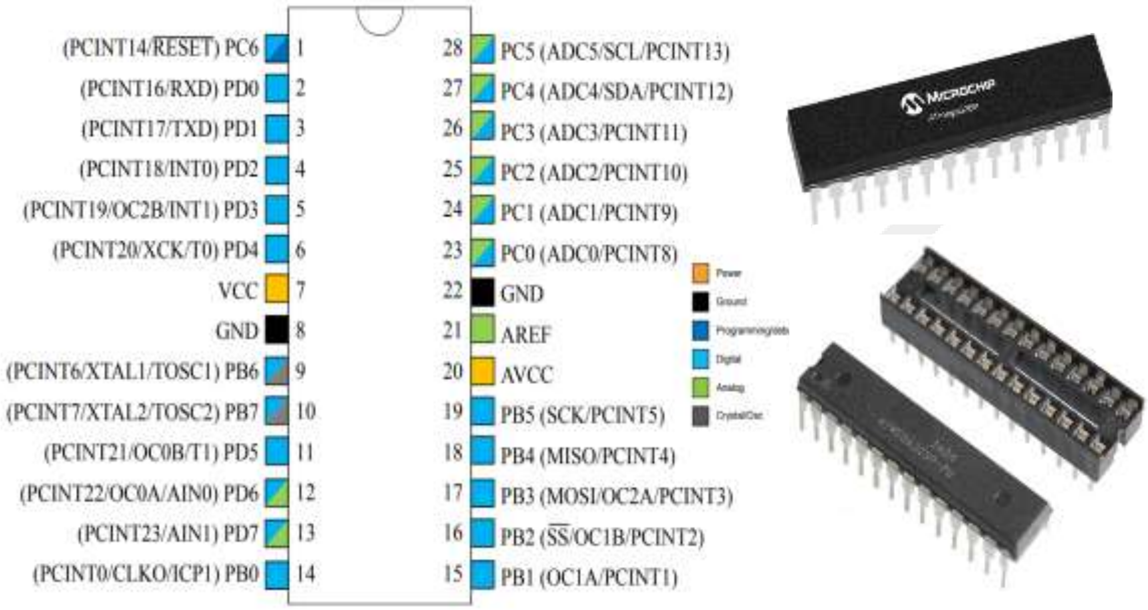


Figure 3. ATmega328p Microcontroller

The microcontroller offers three ports - B, C, and D - for digital input/output. Each of these ports is controlled by three registers, namely the DDR register, the PORT register and the PIN register.

The DDR register is responsible for determining the direction of the pin either input or output. The PORT register is used to set the pin to a high or low level, whereas the PIN register is used to read the state of input pins or toggle the value of a specific PORT bit by writing '1' to the corresponding bit of the PIN register.

To send data to a particular port, for instance, port B, one needs to write to the register PORTB, with each of its bits representing a corresponding pin of the port.

To read the current value, one can read the PINB register and evaluate the relevant bit. Figure 4 provides a block diagram of the ATmega328P, which offers a visual representation of the internal components of the microcontroller and how they are interconnected. Components are explained below:

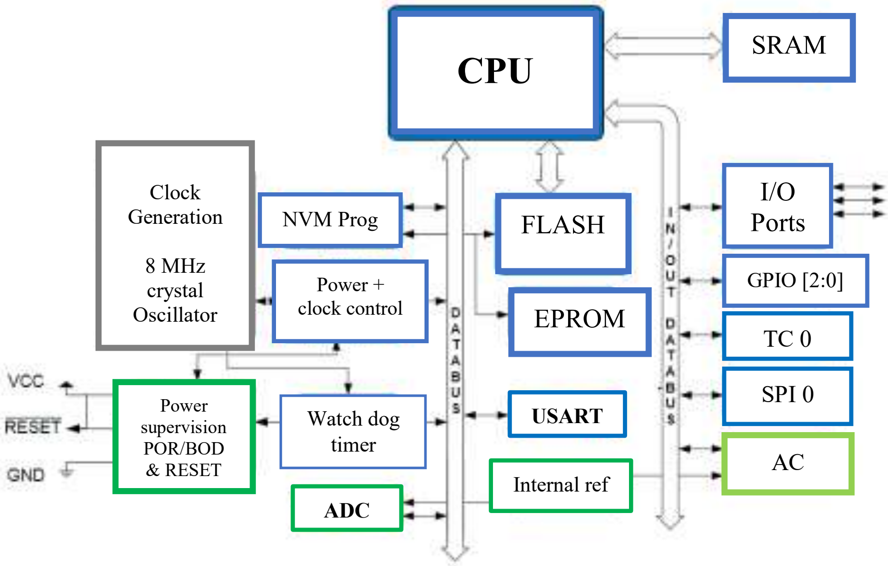


Figure 4. ATmega328p microcontroller ATmega328P Memory Bus block

1. CPU: This block is the central processing unit of the microcontroller. It executes instructions and controls the overall operation of the device. The ATmega328P has an 8-bit RISC CPU with a clock speed of up to 20MHz.
2. Flash Memory: This block stores the program code that is executed by the CPU. The ATmega328P has 32KB of flash memory.
3. SRAM: This block provides temporary storage for data that is being manipulated by the CPU. The ATmega328P has 2KB of SRAM.
4. EEPROM: This block provides non-volatile storage for data that needs to be retained even when the power is turned off. The ATmega328P has 1KB of EEPROM.
5. I/O Ports: These blocks provide the interface between the microcontroller and external devices. The ATmega328P has a total of 23 I/O pins, which can be used for a variety of functions, including digital input/output, analog input, and PWM output.
6. Timer/Counter Units: These blocks provide the ability to generate timing signals, count external events, and perform other timing-related functions.
7. Analog-to-Digital Converter (ADC): This block converts analog signals from external sensors and devices into digital values that can be processed by the CPU.
8. Serial Interfaces: These blocks provide the ability to communicate with external devices using serial protocols such as UART, SPI, and I2C.
9. Watchdog Timer: This block provides a mechanism for detecting and recovering from system faults or failures.

3.1.2 SIM800L Mobile GSM/GPRS Communication Module

The SIM800L Mobile GSM Module is a small, adaptable communication module that gives electronic devices GSM/GPRS capability developed by SIMCOM Technologies. It is made to allow wireless connection via the Global System for Mobile Communications (GSM) network (Saravanan et al., 2022), making it appropriate for uses including data transfer, messaging and remote monitoring. The SIM800L module shown in Figure 5 works on frequencies GSM850MHz, EGSM900MHz, DCS1800MHz. The module allows GPRS data transfer, enabling data communication and internet connection. To enable dependable wireless connection, the module also includes an RF (Radio Frequency) transceiver, a power amplifier and a low-noise amplifier. It has serial UART (Universal Asynchronous Receiver-Transmitter) communication capabilities, making it simple to connect to microcontrollers and other devices. It also offers digital I/O pins for managing sensors or external components(Components101, 2021). This module establishes a connection between the microcontroller and the mobile network so that it can send and receive text messages (SMS), make and receive phone calls and access the internet through GPRS, TCP, or IP.(SIMCOM, 2013).

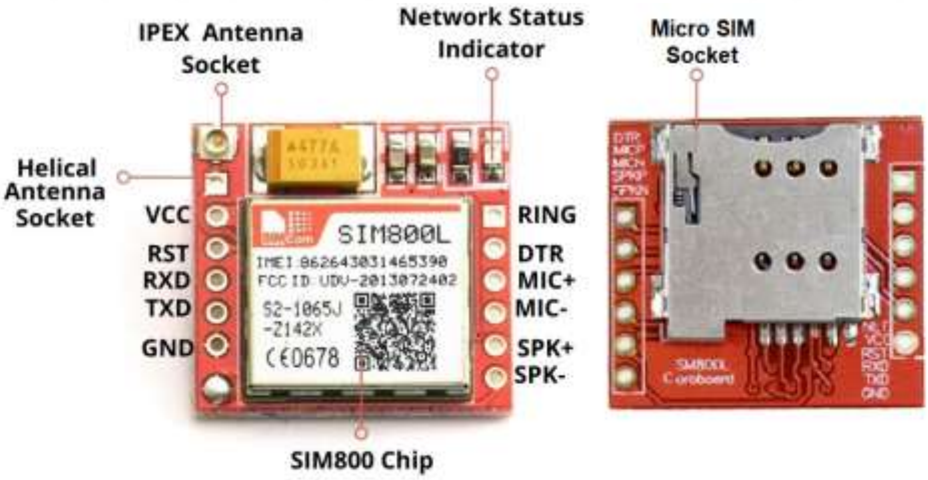


Figure 5. SIM800L Mobile GSM/GPRS

The module would operate with any 2G or 3G Micro SIM card well, but was also tested with a 4G sim and it functioned properly. The operating voltage range of the module is 3.4 V to 4.4 V. The power consumption of the chip in GSM850 mode is 2 W; and 1 W for DSC1800

The chip features 88 pins of LGA packaging providing one full modem serial, audio channel consisting of speaker and receiver output and two microphone inputs, FM and PWM support and one USB interface (pins 59,19) for debugging and software download and 5*5*2 Keypad support. Pin diagram is shown in Figure 6.

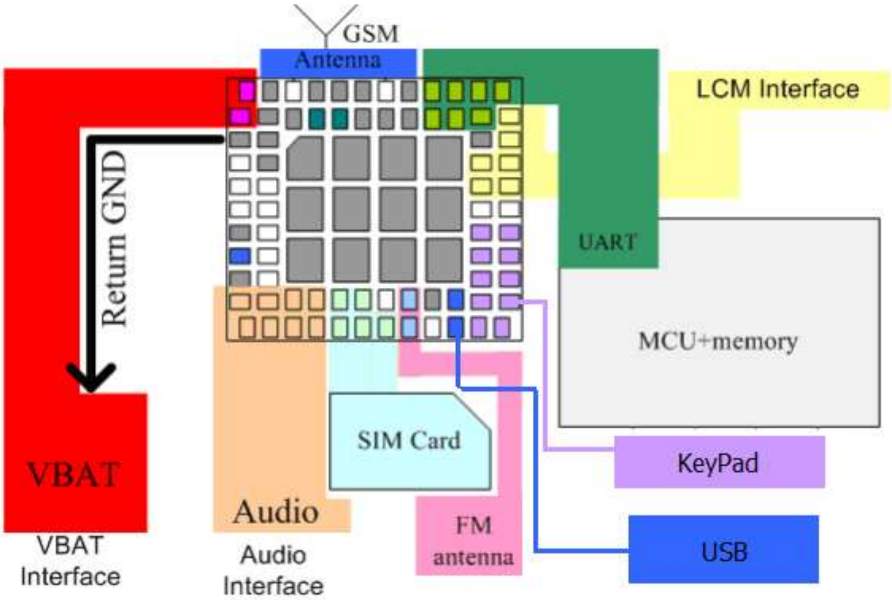


Figure 6. SIM800L chip pins

3.1.3 ESP8266 Wireless chip Module

ESP8266 is an independent system on a chip that includes a TCP/IP protocol stack, Wi-Fi direct peer-to-peer (P2P), and access point (AP) mode (Espressif-Systems, 2022). The pin distribution and dimensions of the ESP8266 model is shown in Figure 7.

The module's general-purpose input/output (GPIO) pins enable integration with sensors and other application-specific hardware. It is a compact Tensilica L106 encapsulation module with an ultra-low power 32-bit 80 MHz Xtensa Tensilica processor, 32 KB instruction RAM, 80 KB user-data RAM, 4 MB flash ROM, RF frontend on-board antenna for IEEE 802.11 b/g/n Wi-Fi, GPIO, I2C, ADC, and UART (Ai-Thinker, 2015). The ESP8266 can run both the TCP/IP stack and application codes in itself without using an external host microcontroller.

The ESP8266 is capable of full and independent Wi-Fi networking and can operate either as a standalone application or as a slave to a host MCU (Multipoint Control Unit) with a frequency range of 2400 to 2483.5 MHz (Yoppy et al., 2019)

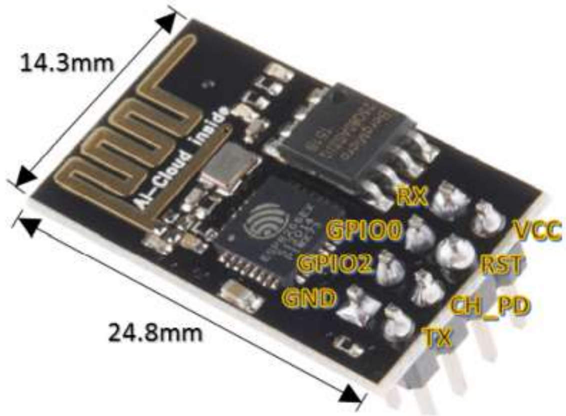


Figure 7. ESP8266 pins' distribution and dimensions

The ESP8266 is interfaced with ATmega328p via its TX and RX pins as it is directly connected to the digital TX and RX, pin 15 and 16 of the ATmega328p, respectively. It is given access to the internet by providing the SSID and password of the local network enabling it to start transmitting the data (Rosli et al., 2018). A 3.3 V and up to 250 mA power supply are needed for the ESP8266 series of devices (Rosli et al., 2018).

3.1.4 Bluetooth HC-05 Module

A straightforward Bluetooth SPP (Serial Port Protocol) module, the HC-05 Bluetooth Module is made for setting up transparent wireless serial connections. Bluetooth version 2.0 + EDR (Enhanced Data Rate) standard serves as the foundation for the HC-05 module. As indicated by the "HC" in HC-05, which stands for "Host Controller," this device is primarily made to be used as a slave that interfaces with a host such as a microcontroller or computer via a UART interface. It can be set up as a master or slave device It communicates using serial transmission, which interacts with a PC, smartphone or any Bluetooth enabled device simple.

The HC-05 Bluetooth module shown in Figure 8 offers master and slave mode switching; therefore, it can be used for either data reception or data transmission (Iteadstudio, 2010).

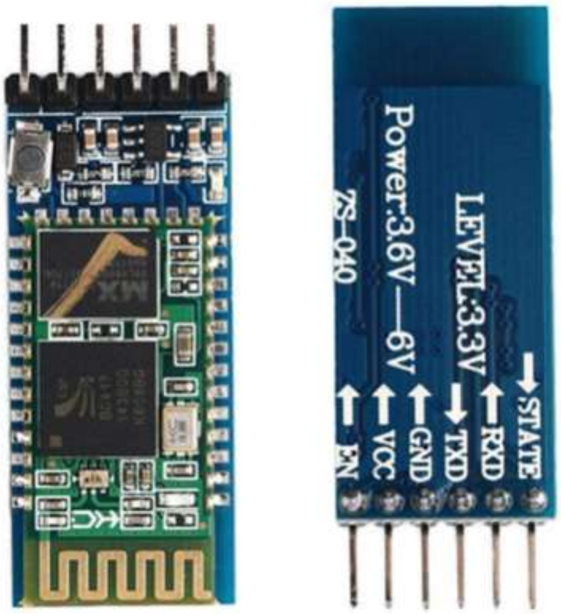


Figure 8. HC-05 Bluetooth Module

The serial port Bluetooth module is fully qualified Bluetooth V2.0+EDR (Enhanced Data Rate) 3Mbps Modulation with complete 2.4GHz radio transceiver and baseband. It uses CSR Bluecore 04-External single-chip Bluetooth system with CMOS technology and with AFH (Adaptive Frequency Hopping Feature). It has a footprint as small as 12.7mm x 27mm (itead.studio, 2010).

The red LED on the HC-05 shows the connection state, whether Bluetooth is active or not. This red LED continually and irregularly blinks before being connected to the HC-05 module. It blinks for two seconds when it is in Bluetooth range of any other devices. Transmitting speeds up to 1Mbps ranging to 10 meters. Vcc for the module is 3.3 V, but an input voltage of 5V is also acceptable since the module contains a built-in 5 to 3.3 V regulator, and has a minimal power operation of 1.8V (itead.studio, 2010).

There is no need to change the transmit level of the HC-05 Bluetooth module because it has a 3.3V level for both Tx and Rx; and the microcontroller can detect that level. An onboard antenna transmits at up to +4 dBm RF transmit power, and a pairing current in the range of 30 ～ 40 mA (Cho et al., 2008). The pin diagram of the HC-05 chip is shown in Figure 9.

Although the chip has 34 connection pins, when the chip is connected to the breakout board, the connections are reduced to only 5 pins (En, Vcc, GND, Tx, Rx, and STATE). The HC-05 module receives commands and data through the UART interface and communicates with the host device accordingly. It does not have native support for the I2C protocol.

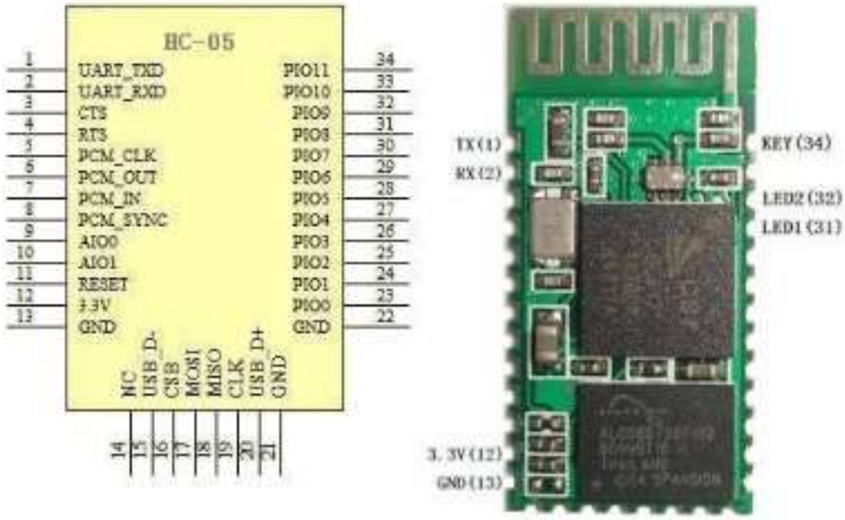
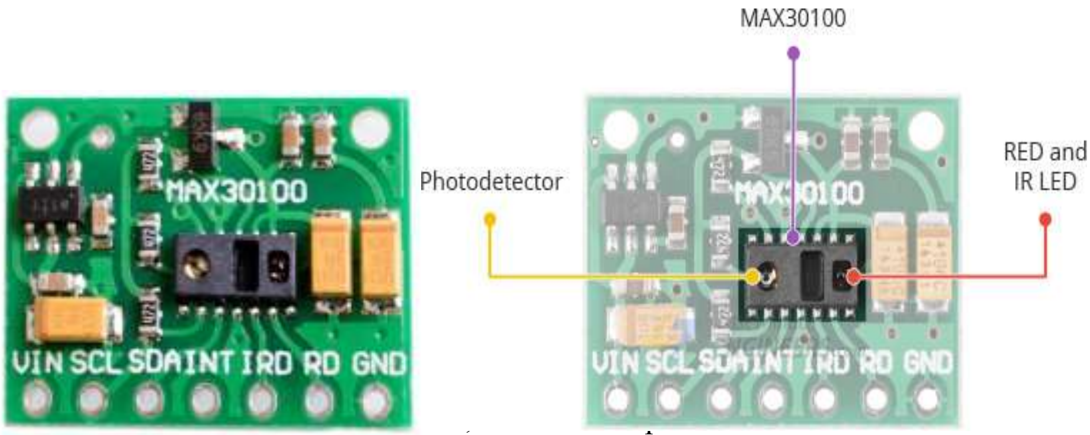


Figure 9. HC-05 BT chip and pinout

'Data Mode' and 'Command Mode' are the two modes of operation for the module. In Command Mode, AT Commands are used to interact with the Bluetooth module and it configures the module's numerous settings and parameters. This includes modifying the Baud Rate, the module name or the firmware details. It can also be used to designate HC-05 as a master or slave as well. The baud rate in command mode is 38400bps. As for Data Mode, the baud rate is 9600bps and is used to communicate with other Bluetooth devices (Iteadstudio, 2010).

3.1.5. MAX30100 Oxygen Sensor

The MAX30100 is an integrated pulse oximetry and heart rate monitor sensor solution, shown Figure 10. This sensor consists of two LEDs emitting light: red light (650 nm) and Infrared (950 nm). It contains a photodetector, optimized optics and low-noise analog signal processing to detect pulse oximetry and heart-rate signals. The MAX30100 operates from 1.8V to 5 V power supply and can be powered down through software with negligible standby current.



the microcontroller, whi

Figure 10. MAX30100 sensor

The sensor is positioned on anywhere where the skin is thin enough for both light frequencies to easily pass through such as the finger, earlobe, or wrist. A photodiode is used to measure the absorption after both of them have been shone through the skin.

Table 2. MAX30100 pins

VIN	Modules' power source
SCL	Serial Clock line
SDA	Serial Data line
INT	Active-Low Interrupt
IR-DRV	IR LED Cathode and LED Driver Connection Point
R-DRV	Red LED Cathode and LED Driver Connection Point
GND	Analog Ground

As previously explained in Chapter 2, the ratio between the absorbed red light and IR led will vary depending on how much oxygen is in the blood (Strogonovs, 2017). Therefore, it is feasible to determine how much oxygen is in the body.

According to the following equation, oxygen saturation is calculated as the ratio of HbO_2 to the sum of Hb and HbO_2 accessible in the arteries:

$$SpO_2 = [HbO_2] / [HbO_2 + Hb]$$

HbO_2 = Oxyhemoglobin (Hemoglobin containing oxygen)

Hb = Deoxyhemoglobin (Hemoglobin that doesn't contain oxygen)

The block diagram and placement sensor module are shown in Figure 11.

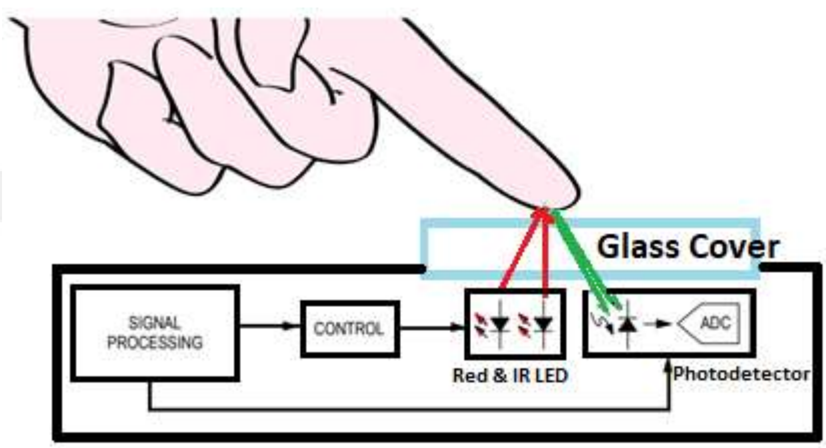


Figure 11. Block diagram and IC placement

A somewhat steady DC signal is produced when light intensity is reduced by venous blood flow. While a relatively unstable signal—an AC signal—is produced when light intensity is reduced by arterial blood flow. Infrared light absorption over red light indicates high oxygen saturation, and vice versa (Bakhri et al., 2020). Red light absorption over infrared light indicates low oxygen saturation. The MAX30100 sensor's circuit diagram is shown in Figure 12.

For the measurements, the MAX30100 sensor is positioned on the body. The skin receives light from both LEDs, some of which is absorbed and part of which is reflected. The photodiode on IC MAX30100 reflects light, which results in a voltage on the photodiode, which is then sent along to an integrated signal conditioner and ATmega328p receives a signal from the MAX30100 sensor module using the I2C communication protocol (Bakhri et al., 2020).

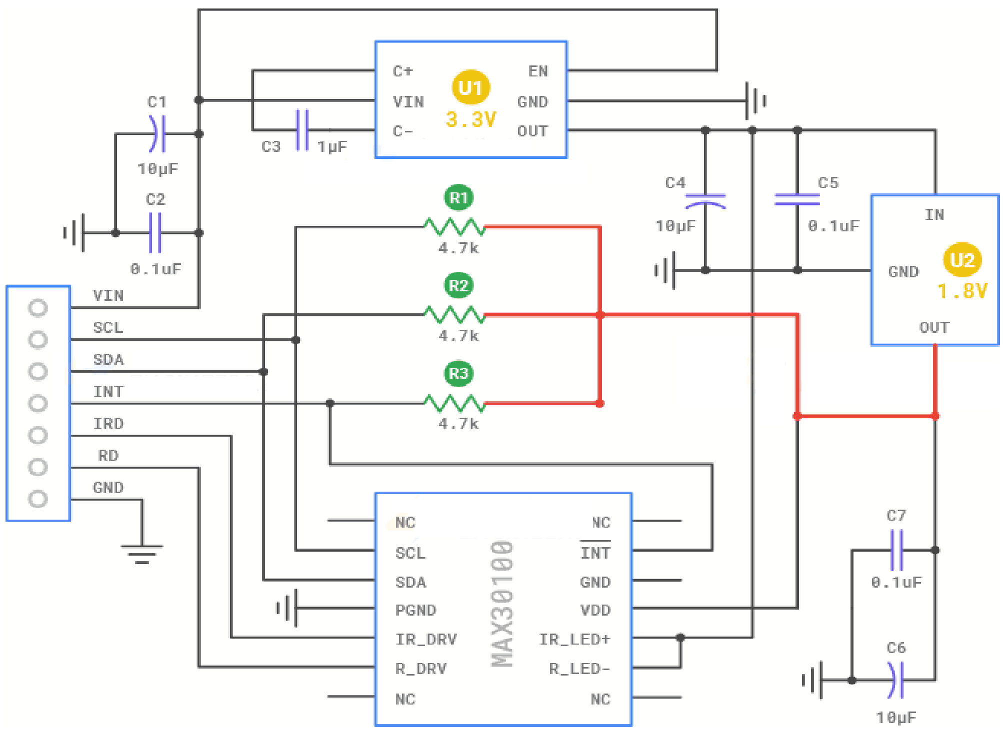


Figure 12. Circuit diagram of the MAX30100 sensor

3.1.6. MLX90614 Temperature Sensor

In this study, MLX90614 sensor is used as an infrared thermometer for non-contact measurements. High thermometer precision and resolution are enabled with a low noise amplifier, a 17-bit ADC and a powerful DSP unit. The thermometer has factory-installed calibration using the SMB (System Management Bus) output and digital PWM. A 10-bit PWM is often set up to continuously transmit temperatures measured between -20 and 120 °C with an output precision of ±0.14 °C (Dionisi, 2016).

The MLX90614 sensor shown in Figure 13, is specially designed to detect the temperature by absorbing infrared radiation and automatically calibrating the infrared radiation energy into a temperature scale for non-contact temperature measurements (Jin et al., 2015). The packing sensor is a TO-39 variant with an IR-sensitive thermopile detector chip and ASIC signal conditioning, which consists of a low noise amplifier, 17-bit ADC, and a potent DSP unit, allowing for the thermometer's great accuracy and resolution (Z. Abdullah et al., 2022). The MLX90614 sensor is built on the Gy-906 Breakout Board which has a voltage regulator and a pull-up resistor, shown in Figure 14.

The output pins of the Gy-906 Breakout Board are Vin, GND, SCL, and SDA. This board contains a 17-bit ADC, which translates to digital data output in the range of 17 bits.

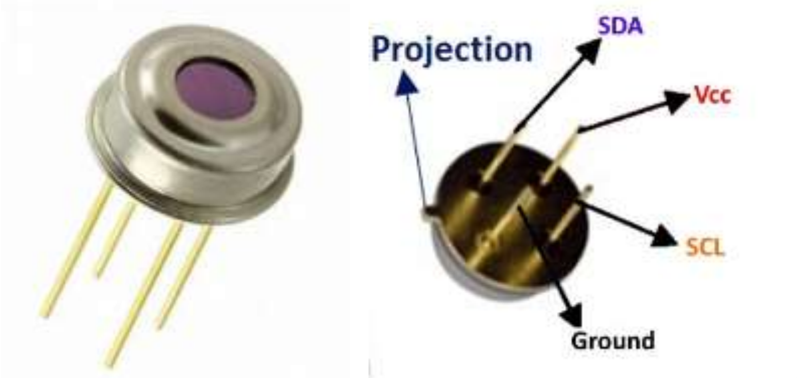


Figure 13. MLX 90614 Temperature sensor

A built-in optical filter on the MLX90614 reduces the impact of visible and near-infrared light on readings. Additionally, it offers protection from sunshine and ambient light. The module has a 662 K 3.3 V precision voltage regulator as well as a voltage level translator, allowing it to work with either a 3.3 V or 5 V power source. The MLX90614 uses less than 2 mA while conducting measurements, and has the capability to carry out two temperature measurements; an object temperature and an ambient temperature (Jin et al., 2015). The ambient temperature measures the temperature surrounding the sensor, whereas the object temperature measures the non-contact temperature of the object. With its cone-shaped field of view that is 90° wide, the MLX90614 has a 2 cm increase in sensing surface area for every 1 cm, shown in Figure 15 (Melexis, 2019).

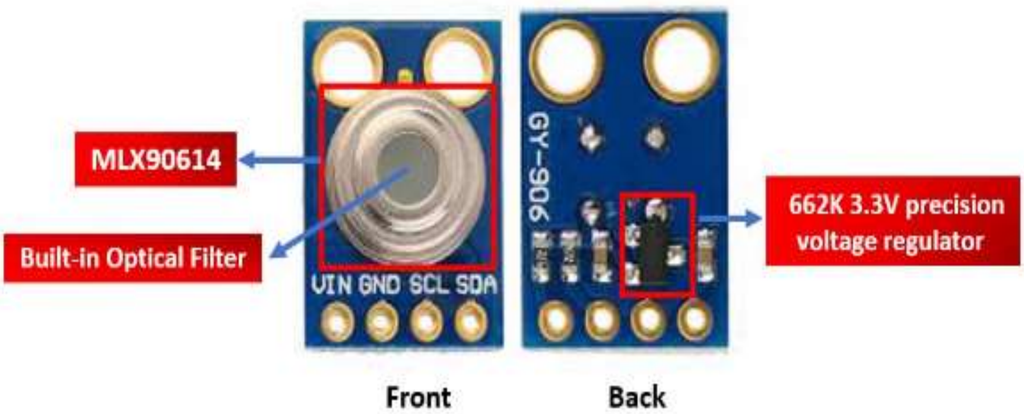


Figure 14. MLX90614 module on Gy-906

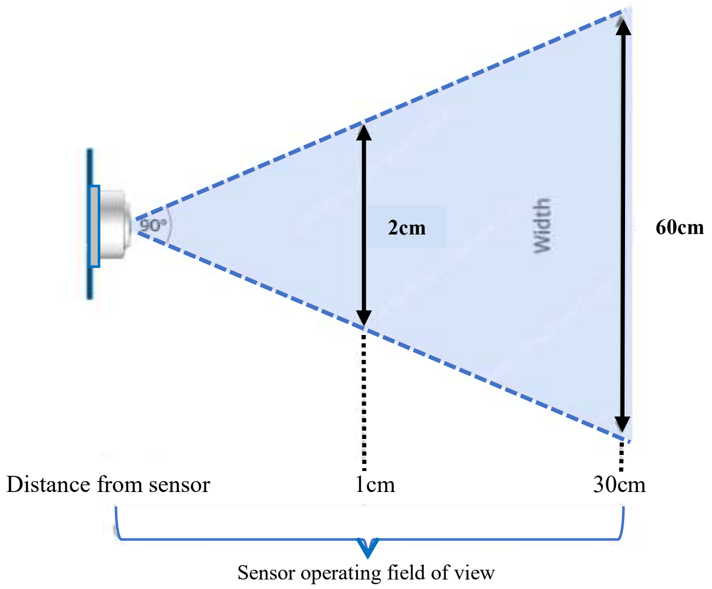


Figure 15. Field-of-view of the MLX90614

The MLX90614 is an example of an infrared thermometer that makes use of the Stefan-Boltzmann rule, which states that the radiant emittance of an ideal black-body cavity at a given temperature under thermal equilibrium conditions is proportional to the fourth power of its absolute temperature. It is based on that everything above absolute zero (0°K or -273°C), including people, emits light in the infrared band that is directly proportionate to its temperature. Figure 16 shows the block diagram of the MLX90614, where the IR radiation emitted by an object or human is first focused by a converging (convex) lens onto a specialized infrared detector known as a thermopile (Siddiq & Sulistiyowati, 2021).

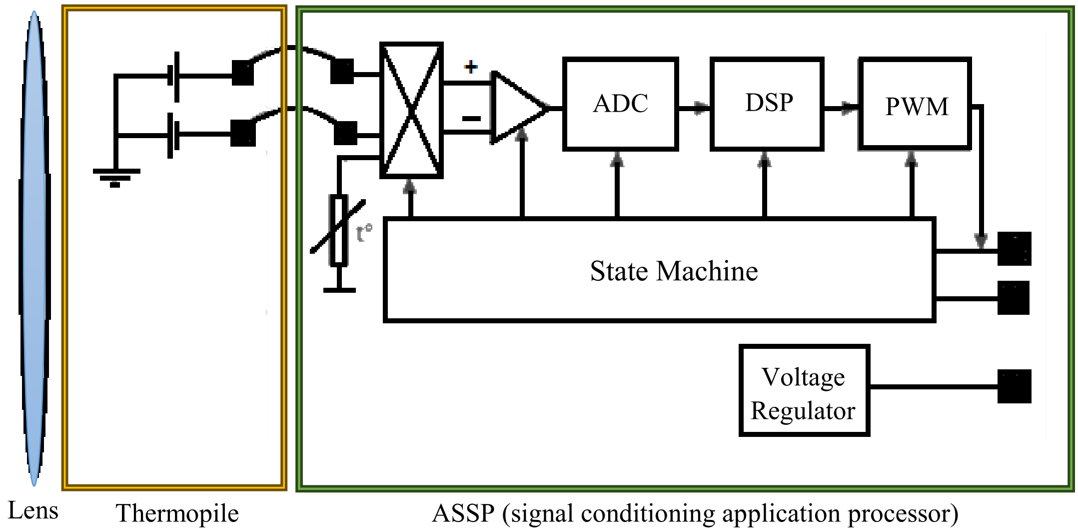


Figure 16. Internal block diagram of the MLX90614

Internally, the MLX90614 is a pair of two devices: an infrared thermopile detector and an ASSP (Signal-Conditioning Application Processor). The amount of infrared radiation radiated by objects in the thermopile's field of vision (FOV) is detected, and a signal is produced that is proportional to that amount. The ASSP's 17-bit ADC detects the voltage generated by the thermopile and processes it before sending it to the microcontroller.

3.1.5. Parallel LCD Display

A small lightweight low power consumption LCD with blue backlight is shown in Figure 18. Parallel LCD is used to monitor the output of the sensors when there is no internet connection as it can easily be connected to and disconnected from the device at any time. Removing the display from the device will reduce the weight and power consumption prolonging the battery life. This LCD 16×2 line Parallel LCD Display shown in Figure 17 with blue backlight is very easy to interface with any controller board or used with the microcontrollers directly. With an operating voltage of 3 V to 5 V, it connects to the device using an I2C interface (Handson Technology, 2020). It has the ability to show up to 189 different characters due to its (CG-RAM) generator memory and because of the (DD-RAM) data memory there is no need to resend the same data as it is stored in the memory register (Morad, 2015).

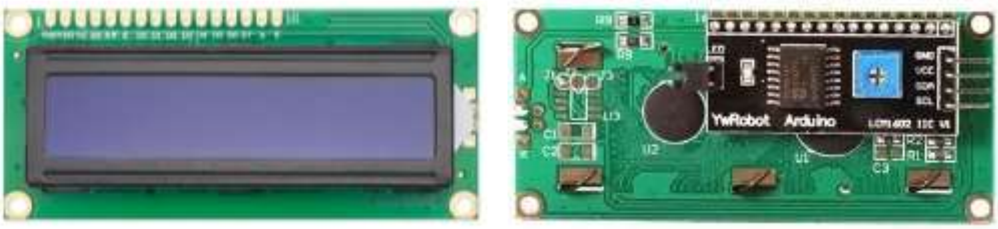


Figure 17. 16*2 LCD display with I2C

3.1.6. I2C Communication Bus and Protocol

The I2C (synchronous serial communication protocol) or Inter-Integrated Circuit shown in Figure 18, is used to transmit data over a short distance between microcontrollers, sensors and other devices. A serial clock line (SCL) and a serial data line (SDA) make up the two-wire interface.

The SCL line is the clock signal which synchronizes the data transfer between the devices on the I2C bus and it's generated by the master device, while the SDA line carries the data between the devices.

Many devices can be linked to a single I2C bus since each one of the connected devices is given a different address so the master can choose with which devices will communicate. Figure 19 shows I2C Bus which will be the main way for data transmission between the different components of the device. The I2C protocol permits the use of slave and master devices on the same bus (Handson Technology, 2020).

Figure 18. I2C interface

While the slave device complies with the master's requirements, the master device starts the data transfer and creates the clock signal for synchronous communication.

A slave device can be read from or written to by the master using particular commands and addressing patterns.

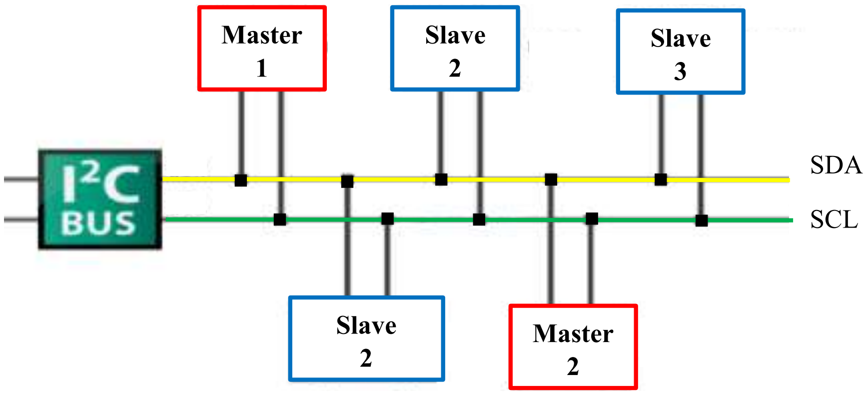


Figure 19. I2C Bus

Therefore, the first 8 bits sequence that represents the address of the slave to which the data is being transferred appears following the occurrence of a particular start condition.

3.2. Methods

3.2.1. Device Connections

This study is based on developing a system with ATMega328p, a heart rate sensor, and a temperature sensor coupled with a wireless communication device and an LCD. Software was developed to monitor changes in heart rate and body temperature with these instruments, resulting in a generic operating system. The developed system is also open to upcoming updates and enhancements.

The aim of the system was that the sensors can collect data that can be sent wirelessly and viewed online or a visual representation of the measurements is shown on an LCD screen.

When designing the device three main factors were considered; size, weight, and cost. Most of this was achieved by using the ATmega328p microcontroller chip as it's the main component of the Arduino Uno board, and it's possible to use the ATmega microcontroller itself without the rest of the Arduino board. The ATmega328 used had the bootloader preinstalled.

By connecting a 16MHz oscillator crystal, a 10Kohm resistor, and two 22pf capacitors, the microcontroller chip can operate independently from the rest of the board, Figure 20 shows the pin functions for the ATmega chip.

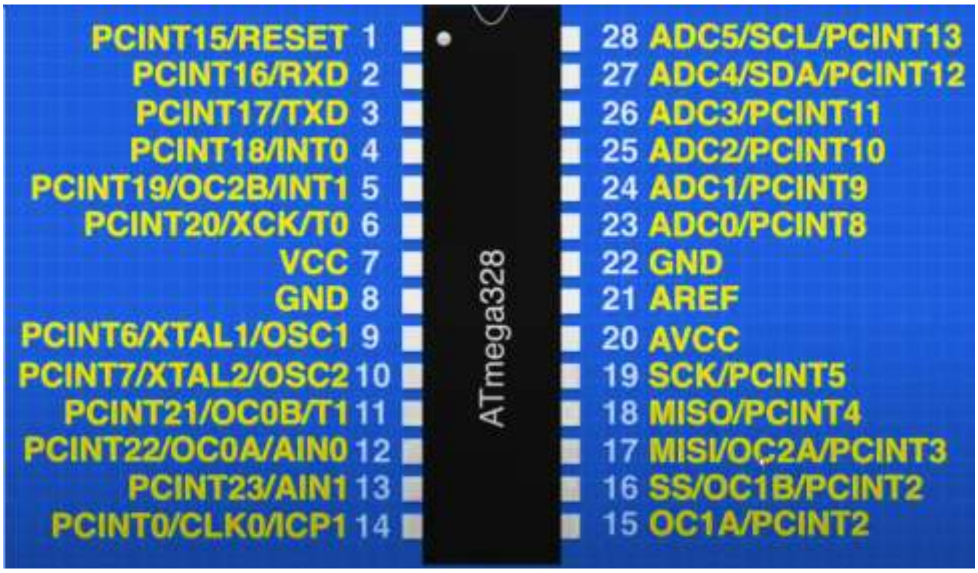


Figure 20. ATmega 328p pin functions

When compared to the ATmega microcontroller, Arduino UNO board is much bigger and has an extra number of pins that are not needed. Thus, only using the ATmega328p in this study reduced the size, weight and cost of the device dramatically.

Figure 21. ATmega 328p pins in relation to Arduino

Figure 21 shows what each pin represents when comparing the ATmeage328p to the whole Arduino UNO. In our case, we only needed to use eight pins (1, 7, 8, 9, 10, 20, 21, 22) of the ATmeage328p to get it function as it does on the Arduino board. Connecting pins 7, 20, and 21 of the ATmega to a 3V power supply; and connecting pins 8 and 22 to the ground; and adding a 10K resistor between pin 1 and 3V power source kept it at a high logic state to prevent the ATmega from resetting.

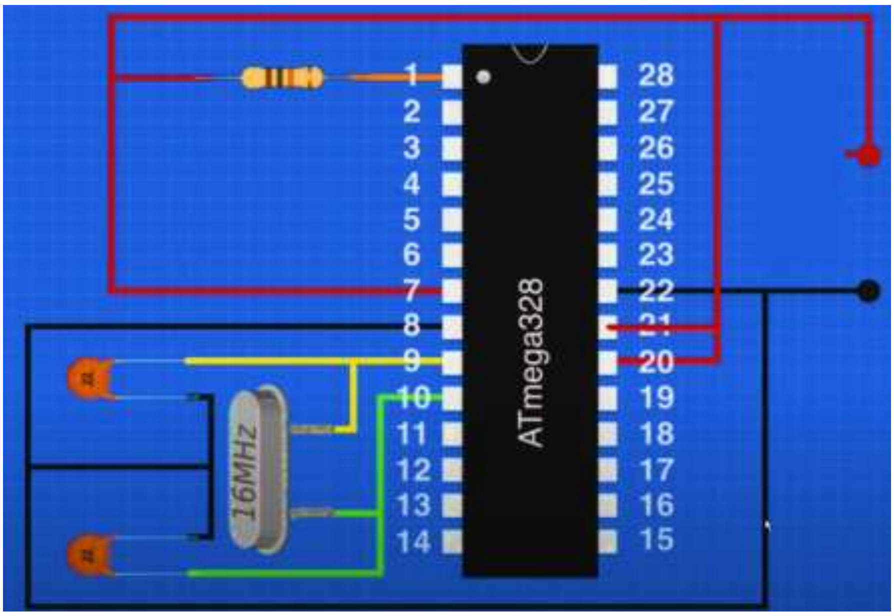


Figure 22. ATmega 328p wire diagram

The crystal is connected to pin 9 and 10. Crystals are not sensitive to polarity so they can be in any polarity. One side of each of the 22pf capacitors are connected to each lead of the crystal as the other side of the capacitors are connected to ground, as seen in Figure 22 & 23. After connecting the components needed for the ATmega to function; the two sensors, LCD, buzzer and Bluetooth module are all connected. Each of the sensors and LCD have four pins which are Vin, Ground, Serial Clock Line (SCL), and Serial Data Line (SDA).

When connecting to the ATmega, we connected the SCL to pin 28 and the SDA to pin 27. The sensors and display will draw power directly from the power source. Adding a buzzer and a LED to the circuit provided an alarm in case the SpO_2 levels were abnormal. The buzzer is connected to pin 19 with the led in series. The LCD can also be detached from the device to reduce size and weight and it can depend on the buzzer alarm for indication of critical issues. The buzzer and the LED are connected together in serial, the +ve pin of the buzzer was connected to pin 19 with the -ve connected to the led. Both the buzzer and led will activate indicating a critical case for the patient.

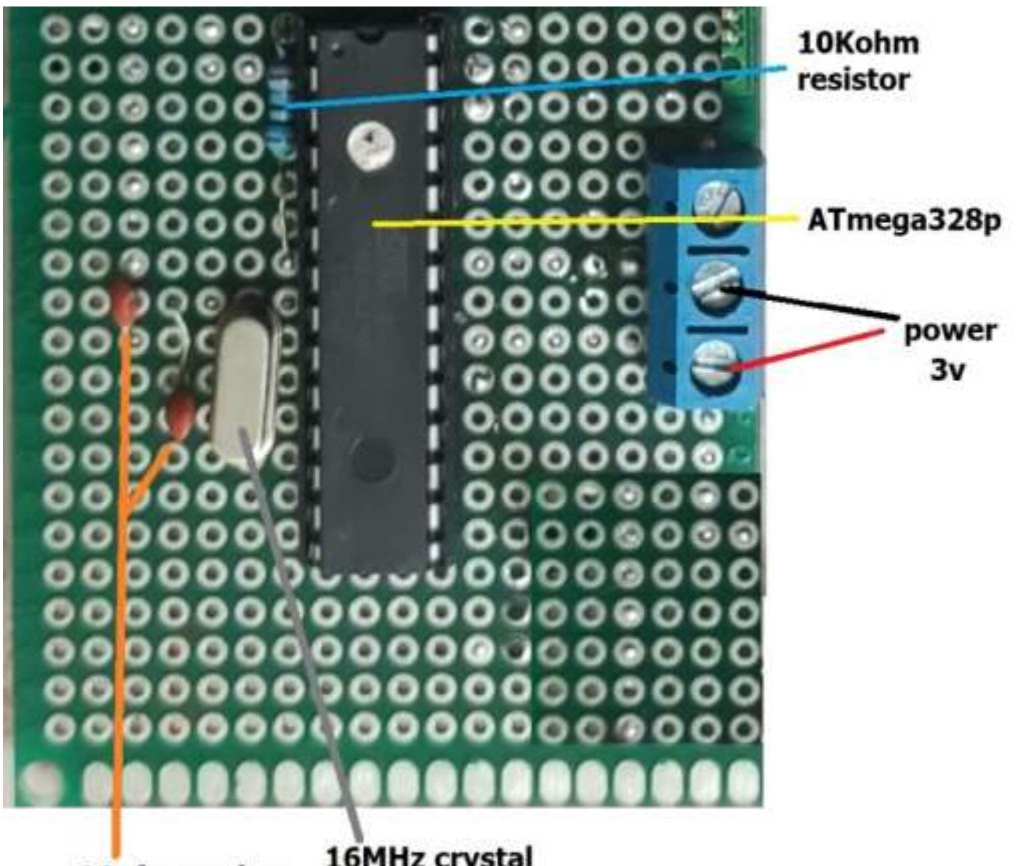


Figure 23. Actual designed ATmega 328p with peripherals

One issue with the MAX30100 is its three pull-up resistors (R1, R2, R3) shown in the circuit diagram of Figure 12. MAX30100 has two voltage regulators which give a constant output of 3.3 V, where the input voltage can be anything from 1.8 to 5.5 V. The three pull-up resistors also shown in Figure 24, are connected in parallel with the second voltage regulator providing them with 1.8 V to make them pull up. In order to make the sensor operate correctly we cut the line between the resistors and the 1.8 V of the second regulator; and connected the resistors directly to the 3.3 V output of the first voltage regulator, as shown in Figure 25.

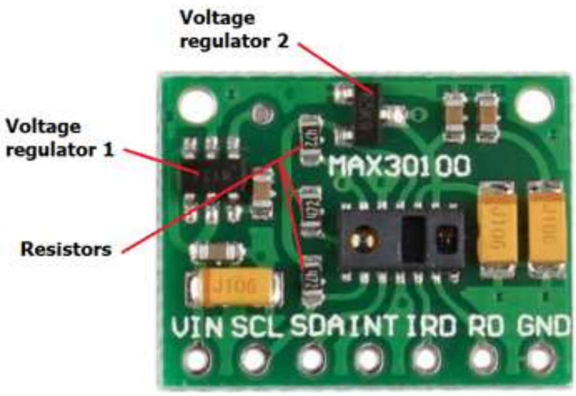


Figure 24. MAX30100 voltage regulators and resistors

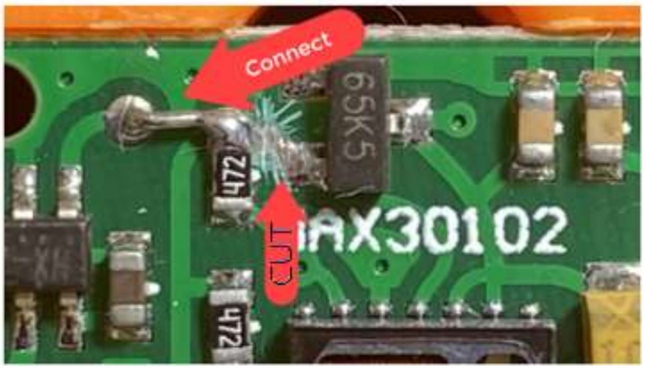


Figure 25. MAX30100 Design Fix

When sending the data to a remote device, the HC-05 Bluetooth Module was mainly used by interfacing it with the microcontroller via two digital pins, pins 4 and 5. The TX was connected to pin 4 and Rx was connected to pin 5. We were able to view the sensor readings on the serial terminal monitor application via Bluetooth. And was powered by directly connecting it to the battery.

By using the final design shown in Figure 26 and 27, we were able to measure the SpO_2, heart rate and body temperature of the patient with the data displayed on the LCD. If the SpO_2 measurements were below 85% the alarm would go off and with the LED flashing to indicate an urgent situation that needs attention.

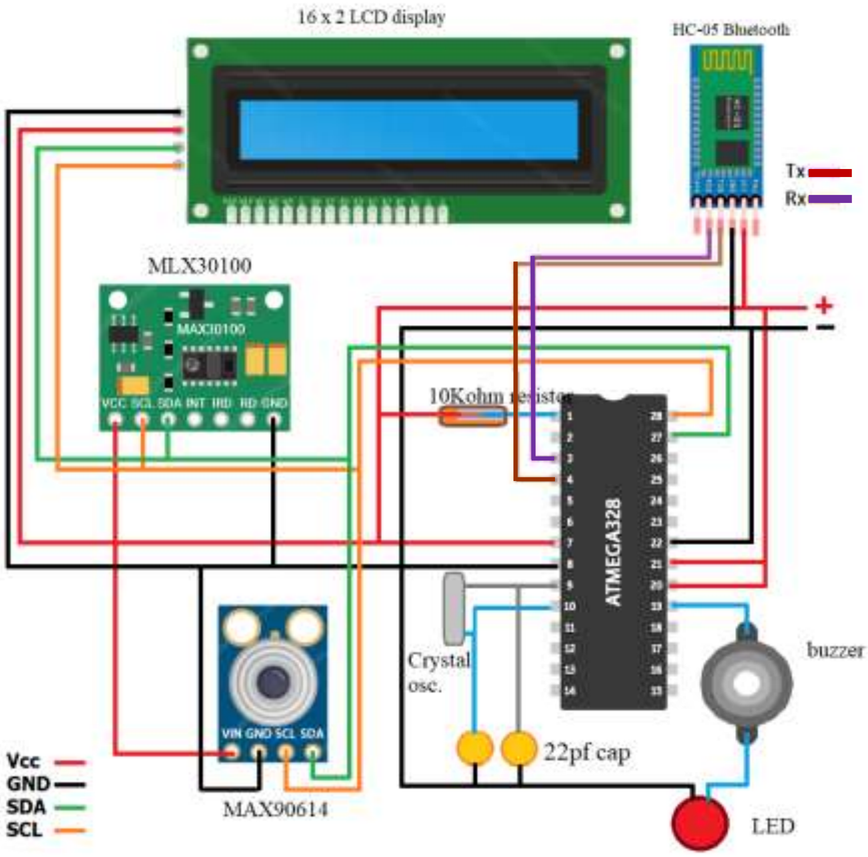


Figure 26. Circuit diagram of the device

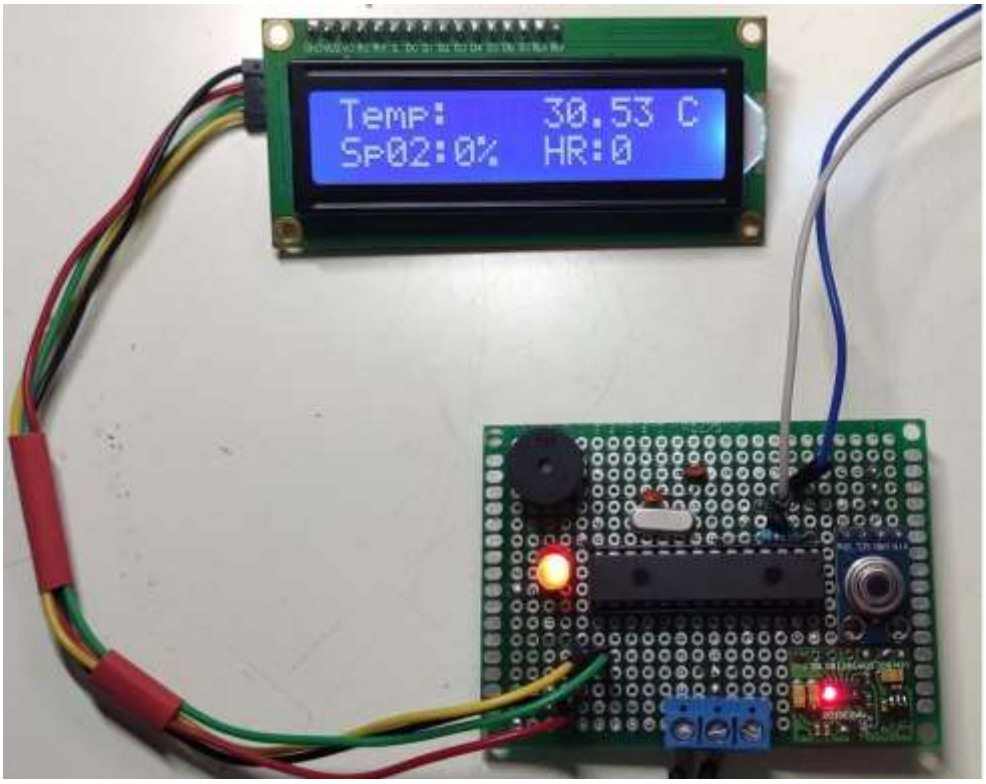


Figure 27. Realized device

3.2.2. Communication Methods

Three main communication methods were tested during the period of this study: Mobile GSM (Global System for Mobile Communications) using the SIM800L, Wi-Fi using the ESP8266 and Bluetooth using HC-05. Each of the three modules have Tx and Rx connections and each were connected to Pin 4 for Tx and pin 5 for Rx of the ATmega328p separately. 802.11ah is the standard used for GSM operating in sub-gigahertz unlicensed bands having a bandwidth of 1, 2, 3, 4, 8, and 16 MHz depending on the region. The SIM800L GSM module connects to the base station system (BSS) of the mobile network using GSM900 connection by sending a registration request to the network to acquire authentication and authorization and it establishes a communication link with the network by synchronizing with the network's frequency and time enabling it to make calls and send data. For Wi-Fi, ESP8266 was used and it connects to the network using the 802.11g/b 2.4GHz broken up into 14 channels (1-14), each 20 MHz wide ranging from 2412 to 2484 Hz spaced at 5 MHz from each other. After providing the SSID and password of the Wi-Fi access point, the ESP8266 would connect and start to send the data. The data output while using both the GSM and Wi-Fi modules was sent to a web server (thingspeak.com) to be viewed. The HC-05 also uses the 2.4 GHz frequency for communication but there is no need for an extra connection point like GSM or Wi-Fi as it establishes a direct connection with the phone using a serial terminal monitoring application installed on the phone. It also makes the connection more reliable and data transmission faster. Bluetooth connection is simple to use and broadly supported across a range of hardware and operating systems. It offers a robust and dependable connection while consuming less power also enables data transfer and audio streaming at the same time. Additionally, Bluetooth devices can create ad-hoc networks that let them talk to one another and exchange data.

3.2.3. Power Source

The main power source used was a 2500 mA h 3.7 V Flat Lithium Rechargeable Battery which was enough for the microcontroller, both the sensors, and the Bluetooth module as they can operate at voltages ranging 3-5 V but the 3.7 wasn’t enough for the LCD which required a 5 V power source. Therefore, we had to use a Mini DC-DC Boost Converter with an input voltage ranging from 0.9 to 5 V at an input of 5V.

The power for the LCD was taken directly from a boost-up converter as we converted the voltage input of the battery from 3.7 V to 5 V using the Robodo SUB05V0600 DC-DC step-up booster module with a maximum current of 600 mA. As it's a charging chip, it will heat up; therefore, by keeping it within its temperature range of -40 to +85, it will operate optimally with a conversion efficiency as high as 96%. After we removed the USB A port, it became even smaller in size as shown in Figure 28. It is made to function as a transportable power supply for USB devices, including smartphones, tablets and other portable gadgets.

For charging the battery the TP4065 charging board was implemented as shown Figure 29. It's a linear charger for lithium-ion and LIPO batteries. This module has the ability to recharge single-cell batteries.

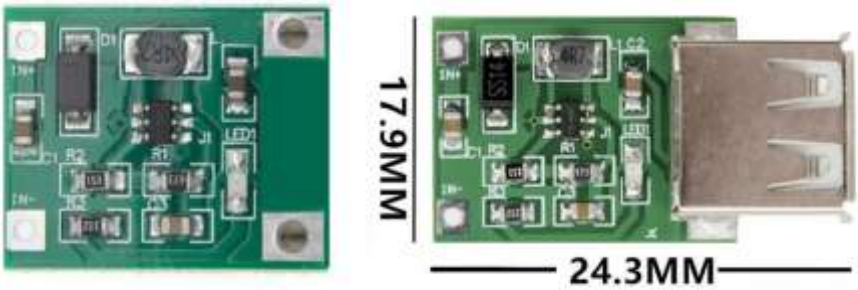


Figure 28. DC-DC step-up booster module

The TP4065 charging board is ideally suited for charging 18650 cells but can also charge Flat Lithium 3.7 V batteries due to its capacity to supply 4.2V. Any input voltage ranging from 4 V to 8 V and 1A supply, such as a USB source, wall adapter, etc., can power the charger, with the ability to protect the battery from over and under-charging.

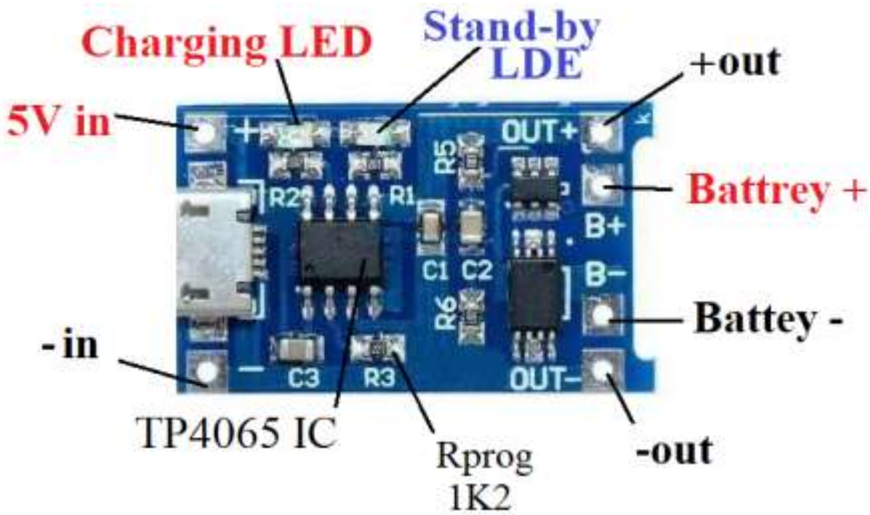


Figure 29. TP4065 charging board

The charging board has two status LEDs indicating charging and Stand-by, and a programmable charge current of up to 1 A. Automatic recharge is available that keeps batteries optimally charged when connected to a charger because of its Constant Current / Constant Voltage charging method which provides a 2.9 V trickle charge threshold, it has an onboard programming resistor (R3 or Rprog) which is set to 1.2 Kohm which provides 1A programming charge rate.

This combination of battery, boost converter, and charging board was the main power source of the device as shown in Figure 30 and was able to keep the device operating for 10 hours.

Figure 30. TP4065, SUB05V0600 and Battery

3.2.4. Software and the Code

The code for the device was written using the Arduino Integrated Development Environment (IDE) software. The Arduino programming language itself is a simplified version of C++ and it is based on the wiring programming language. The Arduino IDE was a simple interface for writing, compiling and uploading our code to the microcontroller with minimal interactions.

Arduino IDE mainly has a screen for writing the sketch and has the compose and upload buttons alongside a connected device selector. We select the device we are uploading the sketch to and there is a bottom panel to view the output log screen and serial monitor.

The principal platform for viewing the data is the LCD connected to the device. However, Bluetooth module gives remote access to the sensors' data. The measurements were displayed on a smartphone using a serial Bluetooth terminal monitor (STM) application. After the application was installed and opened, we simply selected the HC-05 module and directly connected to the device. The SpO_2 and temperature measurements were displayed on the mobile phone simultaneously with the LCD display.

The STM application was created to make it easier for a Bluetooth-enabled device and another device to communicate via the serial communication protocol often ASCII-based over Bluetooth link, enabling a two-way communication link between a wired and wireless device. Some applications have the ability to adjust a number of variables, including baud rate, parity, stop bits and flow control; to correspond to the settings of the connected device.

The Arduino IDE screenshot shown in Figure 31. It includes libraries that simplify the process of programming the microcontroller which can be used to control various hardware components. It also provides a serial terminal program known as Serial Monitor and the commands used are AT commands. It's a tool for serial communication between a microcontroller or development board and a computer. It enables the user to communicate with the program or project in real-time by allowing text-based data to be transmitted and received. This data is also known as AT commands and are used to program different communication devices connected to the ATmega like Bluetooth or Wi-Fi modules. Serial monitor also works as a display to view the output of the devices in case there is no physical display or there is no need to view the data physically.

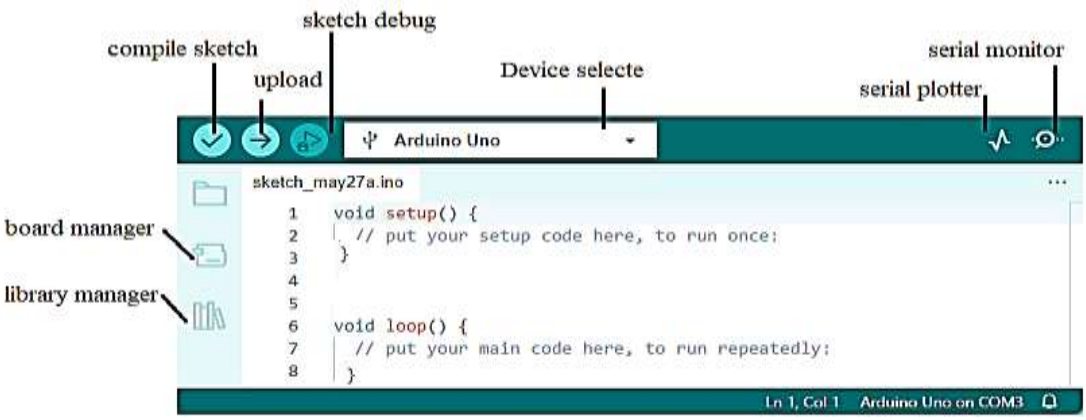


Figure 31. Arduino

When writing the sketch in the IDE for the device to function correctly and get the readings from the sensors and send the data to the internet, we first included the libraries necessary for each sensor along with the LCD and the Bluetooth module, then gave each of them a name to be used in the actual programming to simplify the process.

During the SETUP stage [void setup()], the LCD, sensors, and HC-05 are initiated. Proceeding that, the LOOP stage [void loop()] begins, in the is stage the Sensors start measuring the SpO_2, heart rate, and temperature. The [mlx.readObjectTempC()] command measures the temperature and the [pox.getHeartRate()] and [pox.get SpO2()] measure the heart rate and SpO_2 respectively. During this stage, the data is periodically sent from the sensors to a smartphone using the HC-05 module. The data is displayed on the LCD and at the same time sent to the remote monitoring device using the [bt_serial.print] command which sends the sensor readings via Bluetooth. With the ability to view the readings on the LCD using the (lcd.Pirnt()) string, the date will be in two locations at the same time.

This code is then compiled and uploaded to the device. Once the code is uploaded to the device, it runs continuously, performing the specified tasks as programmed. Figure 32 shows the final code used to program the ATmega328p controlling all the connected components and to view the measurements.

```
#include <LiquidCrystal_I2C.h>
#include <Wire.h>
#include <MAX30100_PulseOximeter.h>
#include <SoftwareSerial.h>
#include <Adafruit_MLX90614.h>
#define REPORTING_PERIOD_MS 1000
SoftwareSerial bt_serial(2, 3);
LiquidCrystal_I2C lcd(0x27, 16, 2);
PulseOximeter pox;
Adafruit_MLX90614 mlx;
uint32_t tsLastReport = 0;
int buzzer = 13;
void(* resetFunc) (void) = 0;
void setup()
{
  Wire.begin();
  bt_serial.begin(9600);
  lcd.init();
  lcd.backlight();
  lcd.clear();
  pox.begin();
  mlx.begin();
  pinMode(buzzer , OUTPUT);
}
void loop ()
{
  pox.update();
  if (millis() - tsLastReport > REPORTING_PERIOD_MS)
   {
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print(String("Temp:    "));lcd.print(mlx.readObjectTempC(),1);lcd.print(String(" C"));
    lcd.setCursor(0,1);
    lcd.print(String("Sp02:"));lcd.print(pox.getSpO2());lcd.print(String("%"));
    lcd.print(String("  HR:"));lcd.print(pox.getHeartRate(),0);
    bt_serial.print(String(" HR: ")+int(pox.getHeartRate())+String("   O2: ")+(pox.getSpO2()));
    bt_serial.print(String("   T: "));
    bt_serial.println(mlx.readObjectTempC(),1);
   if (pox.getSpO2() >= 30 && pox.getSpO2()<=85)
   {
    delay(100);
    digitalWrite(buzzer , HIGH);
    delay(7000);
    digitalWrite(buzzer , LOW);
    resetFunc();
    }
    tsLastReport = millis();
  }
}
```

Figure 32. Final Code.

3.2.5. Measurements

Measurements were taken from 17 male and female volunteers with different ages ranging from 16 to 73. The volunteers had different medical histories, some suffered from heart-related illnesses and some from lung and breathing disorders, and the others were healthy with no medical issue. ATmega measurements were compared with medical grade and generic devices for SpO_2, heart rate and temperature.

A commercial device, CMS50D+ Pulse Oximeter (China) and a medical-grade device, Wellue Viatom Handheld Pulse SpO_2 Pulse Oximeter (United States), were used for SpO_2 and heart rate measurements. Commercial and medical grade devices were placed to on the index finger of the volunteers and ATmega was worn on the wrist for SpO_2 measurements. A Braun ThermoScan-7 medical in-ear thermometer (Mexico) and the DT8826a a non-contact infrared thermal gun (China) was used to measure the temperature. In-ear thermometer was placed inside the ear canal. The temperature gun was pointed at the forehead and ATmega measured the temperature from the wrist.

RESULTS AND DISCUSSION

4.1 Sensor Results

In our study, an electronic medical device was developed for real-time remote monitoring of SpO_2 levels and body temperature. The device was based on the ATmega328p microcontroller with an attempt at remote monitoring using Bluetooth connection. The SpO_2 measurement was carried out using the MAX30100 sensor. The MLX90614 was used for temperature measurement and connection was obtained using the HC-05 communication module.

A group of 17 volunteers participated, including both males and females of all ages with different medical histories. It is possible to gain a deeper knowledge of the experiment's results and potential variances among various demographic groups by including a varied sample of volunteers. Any gender-specific differences or impacts can be seen by including both men and women. Additionally, considering the various ages of the volunteers offers insights into how aging may affect the outcomes. This strategy makes sure that the experiment's results are more generalizable and applicable to a larger population, improving the study's validity and reliability.

In this study, we present the experiments that we carried out to analyze the performance of the ATmega328p module with the MAX30100 and MLX90614 sensors and analyze the capability of this device to remotely monitor the measurements. The sensors were connected to the ATmega328p microcontroller using the I2C interface. The device made the measurements non-invasively from the wrist. In the design of MAX30100, the sensor's LED was factory configured to emit light at two different wavelengths. The signal obtained from the sensors were processed by the ATmega328p microcontroller using the built-in pulse oximetry and temperature algorithm to calculate the SpO_2 and body temperature values. The results obtained were compared with the ones measured using commercial devices which are shown in Figure 33 and also Figure 34.

4.1.1. SpO_2 Results

Blood oxygen saturation (%) results obtained by ATmega device with MAX30100 sensor, the medical-grade device and the generic device (Figure 33) are shown in Table 3 on which is obvious that SpO_2 results of the MAX30100 are very close to that of the medical device. The generic device also has close readings but has a bit more error compared to the medical device.

Table 3. reading of the different devices for each volunteer

Volunteer	SpO_2 % (ATmega)	SpO_2 % (Medical device)	SpO_2 % (Generic device)
1	99	99	92
2	82	81	80
3	99	98	100
4	88	86	80
5	93	92	90
6	94	94	90
7	80	80	84
8	99	97	95
9	79	80	87
10	85	87	90
11	90	90	91
12	94	94	88
13	95	96	94
14	99	97	94
15	100	99	98
16	81	83	90
17	96	95	89

The SpO_2 reading for Volunteer 1 had 7% lower measurements when using the (CMS50D+) generic device, noting that he is male at the age of 24 with no heart or lung related illnesses. After taking a closer look at where the device was positioned, he had an injury on the finger where the (CMS50D+) device was located which created scar tissue and thickened the skin and that might have given an abnormal reading. As for volunteer 4 generic device reading was also less than the reading of the medical device. The volunteer was a 72-year-old female, with thick wrinkled skin due to her age, we can even see that our devices reading was off by 2% when compared with the medical device. A reading of 80% can be considered critical in some cases which might require immediate medical attention but in fact the correct reading was 86% according to the medical grade device to which our device was closer.

Volunteer 9 was an asthma patient and the reading was taken after he suffered an episode. We can see the measurement of our device is much closer to the medical device's reading, therefore our device is much more accurate than the generic device.

Volunteers 16 and 17 had unusual generic device, CMS50D+, measurements as both of their readings differed from the medical device by more than 3 percent.

An error of 2% can be considered acceptable when working with non-medical grad devices, but percentages exceeding that is not acceptable.

Figure 33. SpO_2 measurement devices

In principle, transparent things can be measured from one or two sides. If measurement is from one side only as in MAX30100, a reflecting surface is needed and if measurement is from two sides as in CMS50D+, no reflection source is needed but there must not be any light blocking areas between the light emitter and light detector. When measuring the light emitted from the diode of the CMS50D+ and the MAX30100 under a spectrometer (Andreas, 2020), the diode of the generic device emitted red light at about 660 nm and infrared light at around 870 nm which should have been closer to the suggested 940 nm (Elagha et al., 2019) but can still be considered as reasonable.

The CMS50D+ used two analog switches and the Cyprus ARM-M0 which is considered a powerful MCU (Andreas, 2020). The switches were used at about 200Hz to switch the LEDs on and off and this can be seen by using an oscilloscope and a photodiode (Andreas, 2020).

The SpO_2 measurements slightly varied depending on various factors such as the quality of the sensor used, the presence of motion artifacts, skin pigmentation, and the presence of peripheral vasoconstriction.

In general, the measurements of pulse oximeters ranged from +/- 2% to +/- 3% compared to arterial blood gas measurements which is considered to be the most accurate SpO_2 measurement method (Ekkernkamp et al., 2015)

However, the accuracy can also depend on the specific device and its calibration. The accuracy of SpO_2 measurements also can be affected by certain medical conditions such as anemia, hypotension, or hypothermia, which can alter the oxygen-carrying capacity of the blood. In such cases, pulse oximeters may not provide accurate readings and arterial blood gas measurements may be necessary.

4.1.2. Heart Rate Results

Pulse readings (BPM) obtained by MAX30100 sensor with ATmega, medical device and generic device for each volunteer are shown in Table 4. While obtaining the readings for the heart rate we kept in mind that the results depend on various factors and may fluctuate almost immediately with the person's movement. Some of the factors that affected the accuracy of heart rate measurement include the type and quality of the sensors used, the location of the sensors on the body, the individual's physical characteristics, and the presence of any external factors that can affect the heart rate. For example, if the sensors are not properly positioned on the body or if there is movement during the measurement, it can lead to inaccurate readings.

The results of the MAX30100 can be considered normal for heart rate measurements and are similar to that of the medical device with some minor differences as in the readings for volunteers 6, 13, and 15 where the variability in heart rate during the same cycle can be attributed to several physiological and physical factors and this is also the case for the CMS50D+, the generic device.

Table 4. Reading of Heart rate using different devices

Volunteer	pulse (ATmega) BPM	pulse (medical grade) BPM	pulse (generic device) BPM
1	89	89	85
2	102	105	102
3	70	78	77
4	80	77	70
5	111	107	107
6	66	73	70
7	73	80	82
8	100	98	103
9	77	77	80
10	91	89	89
11	106	100	98
12	69	72	70
13	71	79	82
14	91	91	90
15	70	79	77
16	98	95	90
17	100	100	98

Additionally, if the individual has certain medical conditions or is on medication that affects the heart rate, it can also affect the accuracy of the measurement. Also, the accuracy of heart rate measurement can vary depending on the device being used, for example, some devices use photoplethysmography (PPG) sensors to measure heart rate, while others may use electrocardiography (ECG) sensors. PPG sensors work by measuring changes in blood volume in the capillaries, whereas ECG sensors measure electrical signals from the heart.

The accuracy of heart rate measurements decreased during high-intensity exercise or movement, as blood flow to the extremities may be reduced. It's important to note that no device, especially these non-invasive POC devices, can provide close to 99% accurate heart rate measurements all the time.

In general, the results obtained using the MAX30100 were found to be within an acceptable range when compared with those obtained using a medical grade as the difference between the MAX30100 and the medical grade device was less than about 3%. Therefore, our device can be considered within the standards and can be accurately used in any kind of environment. In conclusion, for SpO_2 measurements, in most cases our device had almost identical readings to the medical device and, therefore, can be considered accurate and reliable enough to be used in medical cases as a POC device but not in surgical operations since the accuracy is required in those cases.

4.1.3. Temperature Results

For temperature measurements in °C, our device, ATmega containing MLX90614 sensor was compared with a medical grade in-ear thermometer (Figure 34a) and a commercial non-contact thermometer (Figure 34b). Similar to MAX30100, the MLX90614 temperature sensor was also connected to the ATmega328p microcontroller using the I2C interface. The sensor was placed on the wrist alongside the SpO_2 sensor. After initialization, the sensor began measuring temperature values.

The sensor provided similar readings for both ambient and object temperature when compared to the thermal temperature gun, however we were primarily interested in the object temperature which was represented on the LCD.

During the COVID-19 outbreak, the most common safety measurement, aside from social distancing and mask-wearing, was temperature screening. Therefore, the use of a non-contact temperature gun was common since it prevents cross contamination (Venturelli et al., 2023). The majority of common non-contact infrared thermometers performed outside the accuracy range specified by the makers and the medical standard when tested for their capacity to detect temperature traceable to the International Temperature Scale of 1990 (ITS-90) (Aw J, 2020), Therefore, when compared to a medical in-ear thermometer Figure 41a leads to different and at first glance inaccurate results.

The readings of the in-ear are considered to be closer to the normal body temperature (37±0.5 degrees) because it measures the temperature inside the ear canal which is considered to be a contact method of measurement and it is closer to the internal organs of the body. The measurement of each device obtained from the volunteers is shown in Table 5.

a. in-ear thermometer

b. non-contact thermal gun

Figure 34. Different thermometer devices

Table 5. A temperature reading of the different devices for each volunteer

volunteer	°C (in-ear thermometer)	°C (ATmega)	°C (Temp Gun)
1	36.8	36.2	31.8
2	37.3	36.5	33
3	36.5	36	32.1
4	36.9	36.7	33.4
5	36.2	35.8	31.8
6	37	36.3	32.5
7	36.6	36.1	33.2
8	36.2	36	31.8
9	36.6	36.1	34.1
10	36.9	36.1	33.7
11	36.7	35.9	32.3
12	36.2	35.8	33.2
13	37	36.1	33.8
14	36.4	35.5	32.8
15	37	35.8	34
16	36.8	36.1	33.8
17	37	35.7	33

The results of the MLX90614 were lower than the in-ear thermometer less than 1 degree Celsius and when comparing to the temperature gun, it can be considered more accurate since its measurements are closer to the in-ear thermometer. Moreover, MLX90614 is positioned only a few millimeters away from the skin and therefore, it is not affected by surrounding objects' temperatures.

The temperature gun is usually pointed at a distance of about 30 cm to the forehead or wrist which is much more subjected to the elements of the environment like direct sun light or cold winds. Temperature gun had lower readings than the normal body temperatures. Therefore, in this case, MLX90614 provides a much more accurate reading than the temperature gun.

In conclusion, for all sensor measurements, ATmega328p worked flawlessly with no errors, at reasonably fast speeds. No issues occurred to that indicate that it couldn't handle all the peripheral devices connected to it.

Also, it had enough processing power to operate both of the sensors and to display the data on the LCD. Moreover, its small size and light weight was excellent for the ease of use. The buzzer alarm of the device was set off and the LED indicator turned on every time when the SpO_2 measurement was less than 85%. The results were displayed on an LCD for direct information viewing and sent to the remote monitoring device via the HC-05 Bluetooth.

Overall, the ATMega328p in combination with the MAX30100 and the MLX90614 had almost identical readings to the medical devices and can be considered accurate and reliable enough to be used as a POC testing device.

4.2. Communication and Remote Monitoring

Multiple ways of communication were taken into account. Using the SIM800L Mobile Communication Module, being a GSM/GPRS communication module, granted the device the access to the internet enabling the measured data to be sent to the web server. The GSM module was connected to the ATmega328p by the Tx and Rx pins. The Tx was connected to pin 4 and the Rx was connected to pin 5.

Using GPRS, a connection was established but when sending the sensor readings to the thingspeak web server (https://thingspeak.com/), we only received the temperatures' reading and the SpO_2 measurements were at zero which is the initial state of the sensor. This was mostly due to the delay periods accumulated in the code as there is a delay after each stage of SIM800L up to 13 seconds with an additional 5 sec for each (ShowSerialData()) command (Figure 35). This delay interfered with the MAX30100 measurement cycle as they are both working in the same timed loop as it measures every 500 msec.

Another option to transmit the data was to use the ESP8266. The implementation of Wi-Fi was carried out by using the ESP8266 Wi-Fi module which was used to send the data remotely to a web server and receive the measurements on a web browser. However, when uploading the data, we noticed that only the temperature via the MLX90614 sensor readings was being received and no other data was displayed on the website. Neither the oxygen saturation nor the heart rate was available. However, after further study, it was discovered that the ESP8266 does not have an I2C hardware module. Instead, it emulates I2C communication using the software.

```
gprsSerial.println("AT+CIPSEND");     //data begin send  to remote server
delay(4000);
ShowSerialData();

String str="GET https://api.thingspeak.com/update?api_key=013AOCHYYNU2LQ19&field1="
+ String(t) +"&field2="+String(h); Serial.println(str);

gprsSerial.println(str);     //begin send data to remote server

delay(4000);
ShowSerialData();

gprsSerial.println((char)26);     //sending
delay(5000);   //waiting for reply, important! the time is based on the condition of internet

gprsSerial.println();
ShowSerialData();

gprsSerial.println("AT+CIPSHUT");     //close the connection
delay(100);

ShowSerialData();
}
void ShowSerialData()
{
while(gprsSerial.available() !=0)
Serial.write(gprsSerial.read());
delay(5000); }
```

Figure 35. SIM800L code to send data to the server

Emulating I2C communication using the software can be challenging because it requires precise timing. As a result, the software implementation of I2C on the ESP8266 was not compatible with the MAX30100 module resulting in an unreliable communication.

When writing the sketch for the ESP Wi-Fi module to communicate with the web server, we noticed that the specific code for the ESP to transmit the measurements was also taking too long to execute like the SIM800L and it took up to 10 seconds to send the readings which delayed the MAX30100 reading process as the sampling rate of the MAX30100 is between 50 to 1Ksps (Maxim-Integrated, 2014). This delay reflected on the outcome causing the sensor not to send the data, meanwhile, the measurements were displayed on the LCD correctly with no issues.

The use of the HC-05 Bluetooth module was very convenient as it was low in cost and had very low power consumption. The results of pairing our device with a smartphone through the HC-05 Bluetooth module and displaying the measurements from the MAX30100 SpO_2 and MLX90614 temperature sensor on the phone's serial terminal monitor application were successful.

The phone's serial terminal app served as a practical interface for displaying the temperature and SpO_2 readings in real-time. The serial terminal app accurately displayed the measurements, with almost zero delay time making it simple and convenient to keep track of vital indicators. The application also has the ability to store the received measurements to be viewed at a later time or on different devices. The maximum transition for the device was about 10 meters as it’s the maximum transmit rage f the HC-05 Bluetooth module.

Figure 36 shows the application we used to monitor the sensor readings on the phone remotely in real time. The results were displayed every second showing the measurements for the SpO_2, temperature, and heart rate.

Table 6 shows a comparison between the communication methods used in this study to compare the transfer time, frequency and sensor data transition monitored in real time. When SIM800L and ESP8266 were used, the data was sent to thingspeak website, an online webserver used to monitor different data values (https://thingspeak.com/); and when the HC-05 was used, the data was transmitted to the mobile phone.

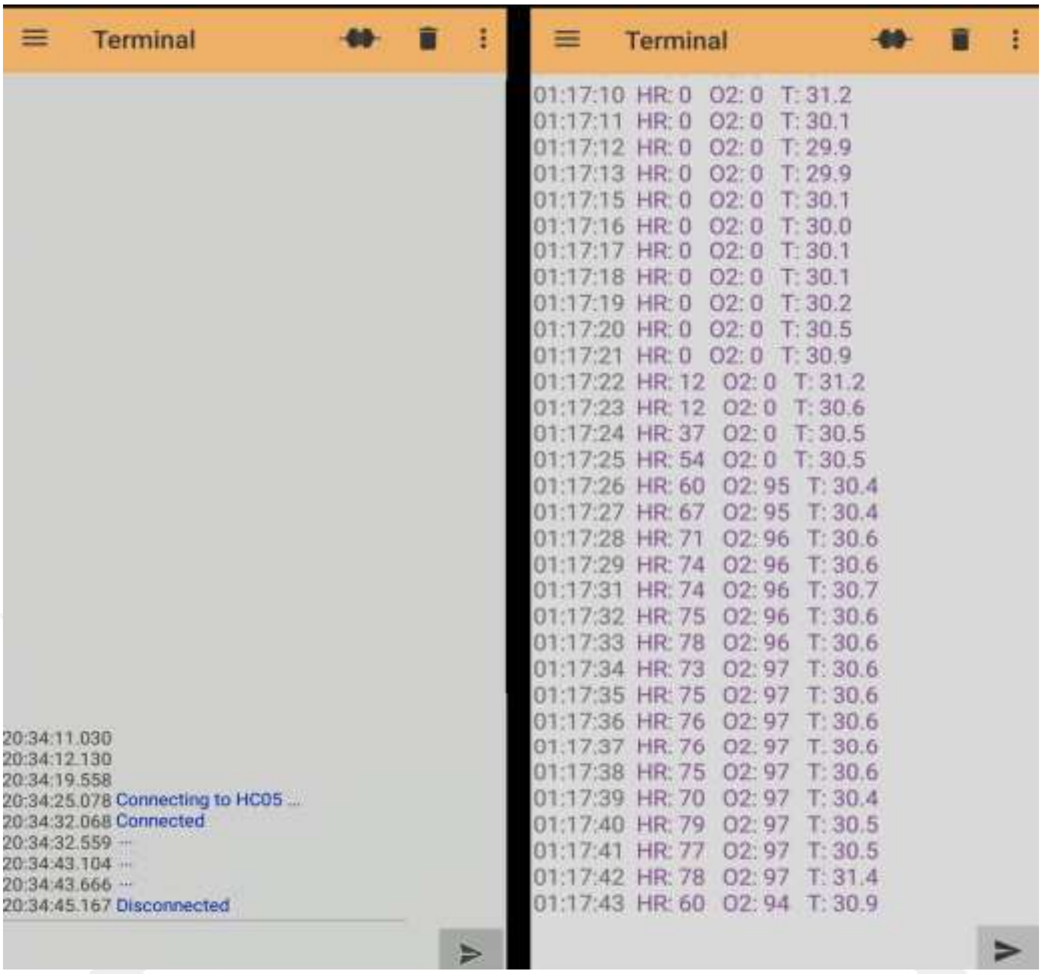


Figure 36. Serial monitor application

Table 6. Comparison of the communication methods

	SIM800L (Mobile communication)	HC-05 (Bluetooth)	ESP82266-01 (Wi-Fi connection)
MAX30100 reading	Not available	Available	Not available
MLX90614 reading	Available	Available	Available
Transfer time (For single reading)	20 sec.	< 1 sec.	20 sec.
Communication freq.	GSM 900 MHz	2.4GHz	802.11 b/g 2.4GHz

Overall, the results of the study indicate that the ATmega328p microcontroller can be used in combination with the MAX30100 and MLX90614 sensors to develop a reliable and accurate real-time monitoring device for SpO_2 and body temperature measurements using the HC-05 which transferred all the data with minimal delay and the best reliability. The device has the potential to be used in various healthcare applications and as a POCT device and can be further developed to incorporate additional sensors and features.

CONCLUSION AND RECOMMENDATIONS

In our study, we have successfully developed a SpO_2 and temperature measurement device using the ATmega328P microcontroller in conjunction with the MAX30100 and MLX90614 sensors. The primary objective was to create a reliable electronic device capable of accurately and continually measuring vital signs and transmitting the data to the mobile device for real-time and also remote monitoring with Bluetooth connection using the HC-05 module.

The ATmega328P microcontroller played a crucial role in our project, offering a low-power CMOS architecture and a rich instruction set. Its compatibility with various communication protocols facilitated the integration of the MAX30100 and MLX90614 sensors, enabling efficient control and data acquisition. The MAX30100 sensor showed highly reliable SpO_2 measurements when compared with the medical grade device. Also MLX90614 sensor had good performance in temperature measurement. SpO_2 and temperature measurements are still very important as the risk of COVID-19 is still looming over along with other infectious diseases.

During the evaluation of the device and the additional components connected to the device, it was concluded that the ESP8266 Wi-Fi module did not perform as expected since it was unable to transmit the MAX30100 readings to the internet. As for the Sim800L GPRS, it was not an ideal candidate, either, due to its additional cost and having the same issues as the ESP8266. The use of the HC-05 Bluetooth model was introduced in our project as it provided remote, real-time connection at a low cost with minimal power consumption making it a good candidate.

Through the integration of the components, we successfully developed a comprehensive, low-cost, small, portable SpO_2 and temperature measurement device used in POC. It also provided remote monitoring capabilities facilitating prompt interventions which is expected to enhance patient care.

Based on our findings, we present the following recommendations for future studies in this field:

1. Expand sensor capabilities: We recommend incorporating additional sensors to expand the device's functionality. For instance, integrating a blood pressure or ECG sensor monitor would provide a more comprehensive health monitoring solution.

2. Implement data encryption and security measures: Enhance the device's security by implementing data encryption and security protocols during data transmission. This ensures the confidentiality and integrity of sensitive patient information.

3. Use of the ESP32: Implement the ESP32 in the device as it can operate as the microcontroller and grant Wi-Fi access at the same time without the need for additional devices. Moreover, Wi-Fi would send data much further than Bluetooth allowing remote monitoring to be more efficient.

4. Using an organic light-emitting diodes (OLED) display: Changing the LED for an OLED will reduce the size and weight of the device even more and will consume less power than the LED.

By considering the recommendations and conducting further research and validation, this technology holds a great potential to revolutionize healthcare monitoring, enhance patient outcomes and contribute to the advancement of telemedicine and remote healthcare practices.

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