SOCIAL DISTANCING AND VITAL MONITORING MASK (SDVM MASK)

By

AYAH KAMAL	**1707922**
BAYAN ALMUZAINI	**1606159**
ALIA ALTAROUTI	**1708655**
ROAA ALHARBI	**1420348**

Project Customer

CITIZENS OF COVID-19 AFFECTED COUNTRIES

Project Advisor

DR. CHADIA ZAYANE

SDP Committee Coordinator

DR. THANGAM PALANISWAMY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
FACULTY OF ENGINEERING
KING ABDULAZIZ UNIVERSITY
JEDDAH – SAUDI ARABIA

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ROAA ALHARBI 1420348

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Approved by

Supervisor (NAME: Dr. Thangam Palaniswamy) …………………..

Examiner (NAME: Dr. Fatima Abdelhedi) …………………..

ALSU (NAME: Ms. Elaine Jalal) …………………..

SDP (NAME: DR. Chadia Zayanne) …………………..

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING
FACULTY OF ENGINEERING
KING ABDULAZIZ UNIVERSITY
JEDDAH – SAUDI ARABIA

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بسم الله الرحمن الرحيم
والصلاة والسلام على خير الورى عدَّ الحصى والرمل والثرى
وعلى آله وأصحابه ومن تبع هداهم واهتدى
نحمد الله العلي القدير الذي قدَّرنا على إنهاء هذا المشروع في الوقت المحدد

ABSTRACT

Social Distancing and Vital Monitoring (SDVM) Mask

One of the most prominent terms of 2020 is COVID-19, which is the virus that has caused one of the greatest pandemics in recent years. The virus is characterized by how fast it spreads, and although it causes mild flu-like symptoms, there have been cases where the symptoms progressed to a deadly stage. Currently, there is no market-ready vaccination for the virus. So, countries have opted for preventative measures such as social distancing, wearing masks, washing hands, etc. These preventative measures have become habitual day-to-day rituals that must be abided to decrease the virus's spread. However, there have been difficulties containing the virus in overcrowded situations where social distancing is hard to follow. There have also been multiple instances where patients have shown delayed symptoms and unknowingly spread the virus to those nearby. These difficulties indicate that there should be a smarter method of implementing proper preventive measures where individuals can feel confident in going out to perform their everyday routines in the current pandemic situation. Therefore, the proposed solution is a mask that can help the user maintain social distancing and monitor their vital signs to be aware of their health status. The baseline design of the proposed solution consists of a mask with detachable and adjustable straps. The mask consists of sensors that detect the distancing of people around the user and the user's temperature and oxygen saturation levels. It is also connected to a mobile application, where all the alerts and information from the mask are displayed. The application helps the user track their vital signs and receive alerts in case of any abnormalities. In addition, it alerts the user when social distancing is not being respected. The mask's main features are that it is lightweight so that it is comfortably worn, and it is easily cleaned for reusability.

Index Terms *— Social Distancing, Vital Signs Monitoring, Smart Mask, COVID-19, Distance Detection, Mobile Application, Preventative Measures.*

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“In the Name of Allah, the Most Beneficent, the Most Merciful. All the praises and thanks be to Allah, the Lord of ‘Alamin (mankind, jinns, and all that exists)”

Our gratitude begins first foremost to Allah, who blessed us with sound health, abilities, and gives us the courage to perform and complete our work in a successful manner. With His guidance and protection, the project was seen through to the end and complete satisfaction was reached in the work done.

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CHAPTER – 1 INTRODUCTION

1.1 ABOUT THE PROJECT

The Social Distancing and Vital Monitoring Mask (SDVM Mask) is a smart face mask with special features designed to help the user better keep track of their health by monitoring their vital signs in real-time and maintain proper social distancing in situations that require people to keep a distance from one to another. The proposed design promotes preventative measures in dealing with airborne infectious diseases and is an especially essential tool during the current COVID-19 pandemic or for workers in the health sector that deal with patients who would be vulnerable to infectious airborne diseases. To make it more user friendly, the mask is connected to a mobile phone application where the users can view their health status readings and receive notifications in case of problems in any of the readings.

1.2 BACKGROUND

Every part of a human's life relies on having good health. Health is essential as it affects different aspects of our lives; according to the World Health Organization (WHO), "Better health is central to human happiness and well-being. It also makes an important contribution to economic progress, as healthy populations live longer, are more productive, and save more." [1] Human health could be affected from time to time by diseases and infections, which are only instigated to spread faster in overcrowded places. The diseases are usually caused by external organisms that intersect a human's natural barriers and invade his/her health. [2]

COVID-19 is one of the greatest pandemics the world has faced in recent years. The disease is a new form of coronavirus that originated in the city of Wuhan, China, at the end of December 2019. The new virus is fast-spreading and is reported to have an average of 1 to 3 infection rate. [3] The virus is primarily spread by people who show symptoms. An individual can be infected before developing symptoms when there is close contact with an infected person's mouth or nose secretions (i.e.: saliva, respiratory secretions, or secretion droplets). These secretions are propelled onto surfaces or into the air when an infected person sneezes, coughs, or speaks. As measures for controlling the virus, the WHO recommends limiting contact with people infected with COVID-19, frequent hand cleansing, and wearing a mask when at least 1 meter of physical distance cannot be guaranteed [4].

Some of the most notable symptoms of the COVID-19 virus are flu-like and include a rise in body temperature (fever), tiredness, and dry coughs. As a precautionary measure, some public places implement temperature measuring at their entrances. Some also require proof of recent COVID-19 test results to ensure that no infected individual enters the premises. However, the virus is still rampant worldwide, with some countries seeing an increasing curve in cases and no sign of improvement with the absence of any foreseeable ready vaccination. There are currently 34,519,530 cases of COVID-19 reported worldwide as of the 2nd of October, of which there are 1,028,230 COVID-19 related deaths reported. [5] In the current situation, all proposed vaccinations face delays in production and distribution due to slow international deal-making. In addition, many countries, such as Sweden and Jordan, have seen increases in cases and face lockdown threats. [6] Consequently, some countries are mandating masks for all their citizens to prevent further spreading of the virus, making masks essential tools in today's world.

With the lack of therapeutic interventions of COVID-19, researchers are trying to enhance face masks to help the medical field minimize the spread of infections. Currently, there is ongoing research on how to make the masks used every day smarter. However, there are no finished products ready for consumers to use.

The project proposes a mask that helps citizens in COVID-19 affected countries continue living out their day-to-day lives without the fear of catching the new virus or spreading it. The proposed mask functions by monitoring the wearers' relevant vital signs and helping him/her practice proper social distancing.

1.2.1 Definition of terms

COVID-19: 'CO' stands for corona, 'VI' stands for virus, and 'D' for disease, '19' stands for the year of origin of the virus (2019). Formerly, this disease was referred to as '2019 novel coronavirus' or '2019-nCoV.'

Social Distancing: the practice of keeping away from other people as much as possible, or of keeping a certain distance from other people, to stop a disease from spreading to many people.

Oxygen Saturation: refers to the amount of oxygen that is in a human's bloodstream.

Respiratory Rate: the number of breaths a human takes per minute.

CHAPTER – 2 CONCEPTUAL DESIGN

2.1 SITUATION DESCRIPTION

The world is in the middle of a COVID-19 pandemic, governments, institutions, and communities around the world are grappling with the impact of COVID-19. 219 Countries and Territories around the world have reported a total of 126,180,069 confirmed cases, and a death toll of 2,769,326 deaths [7].

Governments work on tracking the pandemic, advising on physical distancing, masks and other preventive and control measures which could help in reducing the risk of coronavirus spread. Hence, COVID-19 has accentuated a trend to create more, not less, plastic trash. As the use of disposable masks, gloves and other protective equipment ascends.

Meanwhile, Health manufacturers are racing to develop and deploy safe and effective vaccines which work by training the body's immune cells to make antibodies. These antibodies help the immune system to fight COVID-19 [8]. The goal behind using vaccines is to prevent the infection of COVID-19, rather than to treat it.

2.2 DEFINING THE PROBLEM

The spread of the contagious COVID-19 disease worldwide is alarmingly fast, and there are instances of infected individuals showing delayed signs of symptoms. As a result, public health officials are facing difficulties containing the virus and are urging measures such as social distancing to mitigate the spread. Yet, citizens in overcrowded situations face difficulties practicing social distancing. The virus can affect the human body and cause a range of symptoms, in which initial information and evaluation of vital signs regarding a possible infection are crucial. Currently, the need is rising for a product that can help citizens to perform their normal day-to-day activities during the current global pandemic without worrying that they are unknowingly spreading the virus by not keeping their vitals in check or that they are not practicing proper social distancing.

2.3 PROJECT OBJECTIVES

The objectives below should all be achieved before the end of the project duration, and they include:

- Design a social distancing and vital signs monitoring lightweight mask.
- Model the mask structure with a cleanable front material and detachable straps that hold the sensors.
- Measure the user's vital signs (i.e., temperature and oxygen saturation).
- Build an application that tracks the users' vital signs and warns them of any abnormalities.
- Provide warnings to alert the user when another person is too close to maintain proper social distancing in order to decrease the spread of contagious diseases.

2.4 DESIGN REQUIREMENTS, SPECIFICATIONS AND CONSTRAINTS

2.4.1 Product Design Specifications (PDS)

Under this section, Table 1 details the product design specifications (PDS) to be followed in order to accomplish a product that meets customer needs. The PDS lays the groundwork for the engineering design process and ensures all relevant factors are accounted for by the end of the project duration.

Table 1 - Product Design Specifications (PDS)

Parameter	Design Specifications
Weight	50 grams – 150 grams
Size	• Mask width: 12 cm - 15 cm • Mask height: 17cm – 21cm • Adjustable straps
Material	• Lightweight • Cleanable • Affordable • Breathable • Comfortable • Eco-friendly
Customer	Citizens of COVID-19 affected countries

Table 1 - Product Design Specifications (PDS) *(continued)*

Safety	• Heat radiation from sensors does not exceed 25°C • No sharp edges • Non-toxic
Environment	• Water-resistant • Withstands harsh outdoor temperatures of up to 60°C
Privacy	Mitigating privacy risks associated with the collection and use of personal data.
Quality	Long-lasting (Range: 1– 2 years)
Performance	• Accurately measures and monitors vital signs of user and detects social distancing • Notify user of abnormalities through mobile application through sound alarm or notification message
Testing	Product testing trial results should effectively attain desired features and requirements
Installation	Standalone device
Ergonomics	User friendly
Standards and Regulations	IEEE 1118.1-1990 - Standard for Microcontroller ISO/IEEE 11073 Health informatics - Medical/health device communication standards [9]
Time Scale	Prototype should be complete by end of the 2021 academic year
Shipping	The product can be picked up from stores
Total Cost of Production	200 – 600 SAR

2.4.2 Design requirements

A critical step in proposing a project is to identify its design requirements and design specifications. Design requirements are functional attributes that enable the team to convert ideas into design features in terms of measurable performance. Identifying requirements in the world of business is important to set objectives to meet the customer needs in order to maximize profit and minimize expenditures. Below is a list of the requirements based on expected customer needs.

A. Lightweight
B. Affordable
C. User friendly
D. Fast measure
E. Optimal power usage
F. Accurate measurements
G. Safe to wear
H. Environmentally friendly

The above list of requirements must be ranked according to importance. The Pairwise Comparison Chart (PCC) is a way used for ordering the importance of objectives. The objectives are compared from the team's point of view to see the more important and the less important objective, but it does not mean that the least important objective will be discarded. To calculate the scores, a one in the row if it is preferred over the column is entered, and 0 if the column is preferred over the row. Then, nothing is entered if the objective is competing against itself. The row scores are added at the end to see the win score, and to see the lose score, the column scores are added.

Table 2 - Pairwise Comparison Chart (PCC) of requirements

Requirements	A	B	C	D	E	F	G	H	I	Total
A	-	1	1	1	0	1	0	0	1	5
B	0	-	1	0	0	1	0	0	1	3
C	0	0	-	0	0	1	0	0	1	2
D	0	1	1	-	0	1	0	0	1	4
E	1	1	1	1	-	1	0	0	1	6
F	0	0	0	0	0	-	0	0	1	1
G	1	1	1	1	1	1	-	0	1	7
H	1	1	1	1	1	1	1	-	1	8
I	0	0	0	0	0	0	0	0	-	0
Total	3	5	6	4	2	7	1	0	8	36

As shown in Table 2 above, the higher priority goes to "Safe to wear" with 8 points, and the least priority goes to "Environmentally friendly" with 0 points. Finally, the requirements are rearranged from highest priority to lowest priority in the numbered list below.

1. Safe to wear
2. Accurate measurements
3. Cleanable
4. Lightweight
5. Fast measure
6. Affordable
7. User friendly
8. Optimal power usage
9. Environmentally friendly

2.4.3 Design constraints

Under this subsection, the project's realistic constraints are set according to aspects such as time, safety, functionalities, economics, and quality. The project should not deviate outside of the set constraints in order to be considered successful, and the constraints should be considered in the design process of the project. Below is a list of all the constraints under their respective aspects.

Functional constraints

a. The design must detect the distance of at most 3 meters of other human bodies around the user.

b. The design material should withstand temperatures of 60°C for disinfection.

Economic constraints

a. The design must be less than 300 SR to manufacture.

b. The project must use components that are available in the local market.

Time constraints

a. The design should be completed in less than 1 year.

b. The application should detect abnormalities in less than 5 minutes.

Aesthetic constraints

a. The design's weight must not exceed 150 grams.

b. The design dimensions should not exceed 15x21cm (width x height).

Safety constraints

a. The amount of emitting radiation of the device must be less than 1.75 (W/k).

Quality constraints

a. The device should have a lifespan of at least 4 years.

b. The device should have battery replacement capabilities.

c. The device can be used for at least 8 hours per day.

2.5 LITERATURE REVIEW

The purpose of this literature review is to gain a clear understanding and background of the project's main components and technologies. The literature review inspects the current state of what is being researched in terms of preventing the spread of the COVID-19 virus: this includes research on wearable technologies for both vital signs monitoring and social distancing. The research related to previous applications of the project's design and techniques used to implement continuous vital signs monitoring and real-time social distancing will be examined under this literature review. In addition, similar projects that use masks as the main tools to implement either the vital signs monitoring, or the social distancing technologies are observed. The search terms “wearable sensors”, “real-time monitoring”, “vital signs”, “social distancing”, and “masks” were used to find trends and general information about similar systems.

2.5.1 Vital signs detection

Vital signs are measurements of the body’s most basic functions and are useful in assessing a person’s general physical health. COVID-19 infected people suffer from some problems that are directly related to their vital signs. High body temperature may be present, and the oxygen saturation can decrease due to damage to the air sacs’ walls in the lungs. Therefore, continuous vital signs evaluation and monitoring could help in providing initial information regarding a possible infection of COVID-19. Advances in sensors’ technology are making sensors smaller and cheaper; therefore, wearable devices are becoming more common due to the role they play in helping people track their health status regularly and comfortably. Each wearable device is equipped with microchip sensors that communicate wirelessly. This subsection aims to examine wearable devices’ overall generic architecture and some of the sensors and measurement techniques.

Some of the commonly used components in wearable devices are sensors and microcontrollers. Sensors are considered the core of wearable devices; they are needed to measure and monitor vital signs. Practically, sensors should be harmless, low cost, lightweight, adaptable to the wearer’s body [10]. In addition, microcontrollers are used in wearable devices in order to collect and control data from the sensors. The proposed project aims to measure body temperature and oxygen saturation. Therefore, some of the most successfully used techniques to detect these two vital signs will be summarized.

2.5.1.1 Microcontroller

A microcontroller, sometimes referred to as a microcontroller unit (MCU), is used in wearable devices as a control component. Any typical microcontroller has many elements on a single chip, including a processor, data and program memory, and input/output (I/O) peripherals. A microcontroller receives the wearable devices’ data from its I/O peripherals and stores them in its data memory. Then the processor accesses the data and uses the microcontroller I/O peripherals to communicate and apply the appropriate action. Microcontrollers used in wearable devices are often small in size, low in cost, and simple to program and reprogram [11]. An excellent example of a microcontroller optimized for wearables is the Texas Instruments MSP430FR2676TPTR microcontroller. It is a member of Texas Instrument's MSP430FR2676 16-bit capacitive-touch sensing microcontrollers, which contains a low-power peripheral that can sense touch through thick glass. The glass screens used on wearables must be thick and durable to withstand the punishment of regular use. Moreover, for a higher performance wearable, Maxim Integrated has the MAX32660GWE 32-bit microcontroller. The MAX32660 supports active mode and sleep mode, where the CPU is off while any enabled peripheral can run autonomously. This can be useful when the wearable is idle, and sensor data is logged and stored. Any active peripheral can wake the CPU into active mode. [12].

2.5.1.2 Oxygen Saturation Sensor

Measuring blood oxygen saturation can be achieved non-invasively by a pulse oximeter. The oximeter consists of two parts, the light-emitting diodes (LEDs) and a light detector (called a photodiode). The light-emitting diodes incident light is passed through the skin, then the photodiode detects and collects the light reflected from various depths underneath the skin. Then, the microprocessor calculates a value for the oxygen saturation [13] [14]. As shown in figures 1 and 2, many high-sensitivity optical sensors were developed to measure oxygen saturation accurately to be used in wearable devices. The first sensor was the SparkFun Pulse Oximeter and heart rate sensor sized at 25.4mm x 12.7mm. The second sensor was the Mikroe Oximeter Click sensor with a board size of (42.9 x 25.4 mm). Due to their small size, both sensors are suitable for use in wearable devices, which allows continuous monitoring of the oxygen saturation [15] [16].

Figure 1 - SparkFun Pulse Oximeter and Heart Rate Sensor [13]

Figure 2 - Mikroe Oximeter Click [15]

2.5.1.3 Body temperature sensors

According to the World Health Organization, a healthy person's normal body temperature remains around 36.5°C to 37°C [17]. Fever is an extremely common symptom in COVID-19 cases. A research done about the current development in wearable thermometers mentioned that "Temperature detection can be classified into two types: contact and non-contact measurements. Contact thermometers such as thermistors, and integrated circuits (ICs) measure the average temperature between the sensor and the skin surface" [18]. Meanwhile, another research mentioned that wearable devices' prominent sensors usually work in thermistor configurations [19]. Figures 3 and 4 show two examples of body temperature sensors. The first sensor is MAX30205 with a size of 14 x 21 mm, and the second is the LMT70, which has an ultra-small size of 0.88 mm by 0.88 mm. Both are contact sensors; thus, the measurement of body temperature is achieved when close contact is made between the chip and the subject/environment to be measured. The direct connection allows the microcontrollers to read the temperature of the area that the sensor is physically in contact with. Moreover, due to their small size, the two sensors could be added into wearable devices, either as a wrist-worn wearable, embedded clothing, or a sticky medical patch [20] [21] [22] [23].

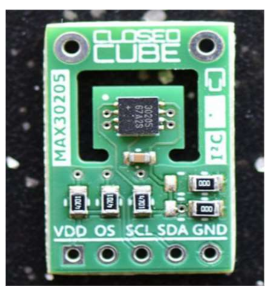

Figure 3 - MAX30205 Sensor [20]

Figure 4 - LMT70 Sensor [21]

2.5.1.4 Wearable Devices Examples

Under this subsection, the existing wearable devices in the market are observed. Wearable devices with detecting capabilities represent important sources of data generation. Early detection of physiological deterioration has been shown to improve patient outcomes. Due to recent improvements in technology, comprehensive outpatient vital signs monitoring is now possible. There are a number of wearable remote monitoring systems available, and they include the following examples.

Cosinuss One

The Cosinuss° One shown in figure 5 is an example of wearable devices that can continuously monitor some of the vital signs. The device is an in-ear wearable and can continuously measure heart rate, heart rate variability, body temperature, and arterial oxygen saturation of the blood from within the ear canal. The device is produced by a medical technology company called Cosinuss GmbH [24]. According to a case study conducted on the Cosinuss one, in order to monitor vital signs, many sensors were used, such as a resistance temperature sensor to detect the body temperature and an LED and photodiode to generate optical data and measure the pulse rate. Then the physiological data collected by the sensor is digitized and sent wirelessly, via Bluetooth, to a smartphone or sports watch. The data can be visualized and monitored via the Cosinuss° app or other 3rd party apps [25].

Everion Device

Figure 5 - Cosinuss One Device [25]

The wearable device Everion, shown in figure 6, is built by a Swiss start-up called Biovotion [26]. The device is used to collect vital signs data non-invasively, continuously monitor them, and supply actionable information (such as an alarm or vibration) that help it in health monitoring. Using several sensors in one single platform, Everion currently provides and measures 22 different parameters such as heart rate, skin temperature, respiratory rate, and blood oxygenation**.** The device contains no buttons or cables, making it more comfortable to wear around the wrist or on the upper arm [27].

Figure 6 - Everion Device

2.5.2 Social distancing

The term social distancing also called “physical distancing,” was first introduced in 2003 and became widely popularized as a result of the COVID-19 pandemic [28]. As mentioned in the background study in section 1.1, the WHO recommends social distancing as a critical factor in decreasing the rapid spread of the COVID-19 virus [4]. However, people often forget to keep a 2-meter distance in public places and find social distancing challenging to fulfill. As a result, there has been an influx of proposed methods in the past year to make social distancing more practical or smart. This subsection mainly focuses on Indoor Positioning Systems (IPSs) that determine an object’s position in a physical space continuously and in real-time [29]. This is because the project aims to have the functionalities of an IPS to apply social distancing. There should be real-time monitoring of the human bodies around the user, and the distance between the user and other people should also be known. Under this subsection of the literature review, the different technologies currently used to facilitate social distancing are analyzed and compared.

2.5.2.1 Bluetooth

The popularized approach for social distancing technology and contact tracing includes technologies already found on portable electronic devices. Many contact tracing apps use Bluetooth (BT) proximity sensing and have been deployed in most countries worldwide to track social distancing [30]. One of the benefits of using BT or, more specifically, Bluetooth Low Energy (BLE), is that it only consumes small amounts of power. In addition, it is a technology found in most smart electronic devices today. Bluetooth beacons, a small Bluetooth radio transmitter that continually transmits BLE signals [31], broadcast their unique identifiers to nearby portable mobile devices and trigger a location-based action on these devices; no paired connection with the mobile device is needed. As long as the user leaves the BT on their phone at all times, the user’s device can scan devices in the vicinity using onboard BLE and store information about the devices found. This information is shared with the official health authorities if the user is found to be COVID-19 positive so that the sets of at-risk populations can be isolated [32].

2.5.2.2 Ultra-wideband

Many applications already use Ultra-Wideband (UWB) positioning techniques, such as real-time indoor precision tracking for mobile inventory, locator beacons for emergency services, and indoor navigation for the visually impaired or blind. However, the use of UWB for proximity distance detection of social distancing is a newly developing idea. For UWB, Beacons are deployed, similar to BLE, together with some carried receivers. Standard positioning methods calculate the angle of arrival, time of arrival, time difference of arrival of the signal [33]. Researchers state that UWB is "the most promising technology for indoor positioning and tracking" [29]. Hence, UWB is one of the most accurate and promising technologies to realize accurate indoor positioning despite its high costs. Some applications that have used UWB for social distancing are appearing—for example, the SafeDistance device developed by Lopos. The system is a small and portable device that measures the distance to other SafeDistance sensors in real-time. It was designed specifically for employees in workplaces such as construction sites, hospitals, supermarkets, and public institutions. However, the product can be used in any other workplace environment. The user can attach the device, which is shaped like a small tag, onto a belt, pocket, or even a safety helmet. When the SafeDistance device detects another SafeDistance device, it vibrates and emits a sound signal to warn the user [34].

2.5.2.3 WI-FI

Another proposed solution suggests using Wi-Fi (Wireless Fidelity) signals, which can be used to detect people in the portable electronic device's vicinity, even through and around walls. One research describes explicitly a system that determines how many people are in an area based on the number of devices connected to the Wi-Fi in that vicinity, and it can work with a variety of Wi-Fi systems [35]. The system tries to prevent any possible social distancing breaches by allowing people to see how many people are in the area before entering it.

The previously mentioned technologies are usually paired with an application where the user can view alerts or new information. This will be further discussed in section 2.1.3.

2.5.2.4 Ultrasound and radio frequency

One of the methods found presently to facilitate social distancing includes proposed dedicated devices or a system of devices that function primarily to help the user keep a safe social distance from the people around them. A proposed solution from Namya Malik at Dartmouth College is a Social Distancing Sensor system. The system consists of multiple devices that communicate together through ultrasonic (US) signals and radio frequency (RF) signals. The proposed solution is purely a prototype and is not entirely accurate; however, it displays successful bi-directional ultrasound and radio frequency communication. It works when the first device transmits a radio frequency and ultrasound signal simultaneously using boards with fitted capabilities to switch between transmitting and receiving RF signals. The second device in receiving mode receives the RF packet and US signal at different times due to the signals' differing speeds. The receiving device then calculates the distance and beeps if it exceeds the set distance limit of 2 meters. This procedure is reversed and repeated so that both devices are aware if the distance limit is exceeded. [36]

Using either ultrasound sensors or radio frequency signals alone for distance measuring or positioning has been seen in multiple applications over the years. Even the combinational use of radio frequency and ultrasound has been seen before in indoor positioning before being utilized as a method for facilitating social distancing [37]. The stated benefit of combining RF and US signals lies in merging US signals' high accuracy to precisely find the room location and RF's high communication capacity for tracking multiple simultaneously moving bodies. Without the RF signal, the devices have no way of knowing when the ultrasonic sound wave from other devices was sent and therefore have no way of knowing the distance between them. [36] [37]

2.5.2.5 Infrared

On the contrary, some have proposed the use of infrared sensors as a means of expediting social distancing. The use of infrared sensors to measure distances is a popularized idea; however, utilizing infrared sensors to measure distances in relation to social distancing is a new idea that arose with the COVID-19 pandemic. By utilizing a PIR sensor, otherwise known as a Passive Infrared Sensor, a group of researchers designed a wearable device, known as the Novel Device, to detect human movement at a particular range. In figure 7 below, the structure of a PIR sensor is shown. The sensor solely depends on receiving infrared radiation from the human body to give alerts on the users' mobile device. Coupling the PIR sensor with a microcontroller (Arduino) allows the device to gauge the distance between the wearer and the other individual [30]. Although gauging the distance would not give a definite distance, it will estimate that an individual had entered the sensor's range. The researchers also noted that the system can not only detect humans in a range for social distancing but that the infrared will also be able to give information about the temperatures of the people around the user. A feature that the researchers note will help detect if any individuals around the user are COVID-19 positive.

Figure 7 - Structure of PIR Sensor [38]

However, others argue that the use of infrared for real-time positioning monitoring is not accurate, as they are prone to interference from sunlight and other thermal sources [29] [39].

2.5.2.6 Magnetic field

The newest research found proposes using a magnetic field proximity sensor in a wearable device to monitor social distancing. The research focused mainly on contact tracing, which is the act of figuring out who may have been recently in contact with a positively diagnosed person [40]. However, for this report, the focus from the research will be on mentions of using the sensor merely for real-time monitoring of the users distancing from other people. The paper's research claims that they are the first to use an oscillating magnetic field-based modality for proximity sensing. The oscillating magnetic field sensor is modeled as a compact, wearable, and highly accurate approximating sensing system. The workings behind the sensor rely on the fundamentals of magnetism. The signal intensity decreases rapidly as the distances increase; this rapid decrease has been one reason why oscillating magnetic field indoor positioning systems have not become widespread since huge currents, huge coils, and most of all, many transmitter coils are needed to cover large rooms. However, for proximity detection related to social distancing requirements of around 2m, this will not be a problem. With coils of size (2–3 cm diameter), which is reasonable in a wearable system and typical currents (not more than a half ampere), the field is virtually undetectable outside a range of 2–3 m while being present below those distances. The devices work by detecting the magnetic field radiating from another device worn by another user [41].

Table 2 below lists the advantages and disadvantages of each approach to social distance-related proximity detection, as seen from previous research.

Table 3 - Comparison of indoor positioning technologies

Approaches	Advantages	Limitations
Bluetooth (BT)	Ease-of-use(smartphone); low power consumption [41]	Limitation in user mobility; low accuracy [41]
Ultra-wideband	Excellent accuracy [32] [41]; effectively passing through obstacles [32];	High cost; base station requirement (challenge of UWB antenna placement) [33]
Wi-Fi	Reuse existing infrastructure; low infrastructure cost. [32]	Low accuracy; substantial battery consumption [32]
Ultrasound and radio frequency	Moderate cost; High accuracy; large proximity range [41]	Low robustness; environment dependency; [41]
Infrared	Low power consumption; low cost; widely used and proven [33]	Accumulating error [33]; prone to interference from thermal sources [29] [39]; more useful for detecting presence not distance [33]
Magnetic field	High accuracy; robustness [41]	Portability; current size of the hardware [41]

2.5.3 Mobile applications

A mobile application (also called a mobile app) is a software application developed to run on smartphones or tablets and is usually designed to perform specific tasks for mobile users. This section aims to provide examples of mobile applications that use technologies related to the proposed project. Below, two examples of mobile applications, along with their working principle, are introduced.

2.5.3.1 Vital signs monitoring application

The use of mobile applications in healthcare is becoming very prevalent in today's world. The number of healthcare applications in app stores worldwide has reached 318,000, and this number is increasing day by day [42]. However, one of the most popular uses of healthcare apps is to monitor vital signs (i.e., temperature, heart rate, and oxygen saturation). Carebook Technologies Inc. has developed an application called "My Vital | Covid-19" that allows users to monitor his/her vital signs by only looking into his/her phone's screen. The application measures three vital signs: heart rate, oxygen saturation level, and respiratory rate. When any of these vital signs become abnormal, the app will send alerts to the user and give him/her instantaneous tips based on his/her results. The application depends on a technique called photoplethysmography (PPG). PPG is an optical measurement method frequently used to monitor heart rate by detecting blood volume changes in microvascular [43] [44]. In contrast to the PPG technology used in clinical and hospital care requiring contact via a fingertip sensor, the app is based on a remote PPG (rPPG) that uses video of the user's face to read out the vital signs [43].

2.5.3.2 Social distancing application

As a result of the spread of COVID-19, many countries have enforced regulations to maintain social distancing between citizens to reduce infection prevalence. In the UK, citizens have to keep 2 meters between each other to maintain social distancing or at least 1 meter if precautionary measures are taken [45]. This has spurred mobile apps developers to find solutions that use mobile apps to help citizens maintain proper social distancing. London start-up Hack Partners developed an application called "Mind The Gap" to help workers maintain social distancing in their workplace [46]. The application aimed to measure social distancing between the users and alert them when their social distance is violated. There is no need for added hardware or internet connection because it is only based on ultrasound and Bluetooth to provide distance measurements. The app uses Bluetooth to detect nearby devices and Time of Flight (TOF) of ultrasound pulses to measure the distance between two devices [45]. Time of Flight (TOF) is a method to measure the distance between a sensor and an object by calculating the time difference between the signal's emission and the time it takes to bounce back [47]. This combination of using Bluetooth technology with audio measuring enabled the application to achieve accurate results to measure distances with a median absolute error of 8.5 cm [45] [46].

2.5.4 Use of masks as preventative measures

The purpose of this part is to gain a background on the importance of face masks in the medical field and how their development helped against contagious diseases. The following data was collected from different online resources that are related to the topic. Face masks are considered the first defense line against infections, which is a part of an infection control method to eliminate cross germs and viruses. So, social contacts are a key for cross-contamination, and the use of face masks seems to be critical to prevent the transmission of COVID-19 since there is no medicine that can offer a cure at this time. For now, scientists and engineers are trying to develop face masks to be smart and multifunctional to help in the lack of therapeutic interventions of some contagious diseases. Some universities are also going on the path of developing face masks, which are listed below.

2.5.4.1 Harvard University (Fluorescent Signaling Mask)

Harvard and MIT researchers are designing a face mask to produce a fluorescent signal when a person with the coronavirus breathes, coughs, or sneezes. If the technology proves successful, it could address flaws associated with other screening methods like temperature checks [48]. The design is in the early stage; the team is testing the used sensors' accuracy by detecting the coronavirus through saliva samples. In order to activate the face mask, there are some conditions: the first is the moisture that our bodies produce naturally through mucus or saliva. Second, experts need to study the virus's genetic sequence in order to detect the virus's existence. Once the virus is detected, the mask is designed to give a fluorescent signal within one to three hours, which can only be detected by a fluorimeter. One of the pros of the design is that it uses cheap sensors, and the fluorimeter itself costs $1 or less to manufacture. When it comes to cons, the virus must be known, and its genetic sequence must have been studied. So, the masks cannot detect new viruses, and it will take some extra time to develop it based on new infectious diseases that may occur in the future. The proposed project design will detect only the specified genetic sequence for the COVID-19 virus, which makes it limited to one type of infectious disease.

2.5.4.2 University of Kentucky (COVID-19 Detecting Mask)

A team at Kentucky University will create a membrane mask and other flat sheet materials with a more porous and spongy structure that will include charged domain and enzymes, which would capture and effectively deactivate SARS-CoV-2, the virus that causes COVID-19. The proteolytic enzymes in the membrane attach to the coronavirus's protein spike and separate them, deactivating the virus and preventing it from spreading [49]. The design is in the early stage and the process may take six months to finish the final product. The aim of the design is to detect the virus after the user is infected, but there are no preventive measures to protect the user from exposure to the virus. Unlike the COVID-19 Detecting Mask, the proposed project design will take preventive measures to protect the user by ensuring a social distancing in public places.

2.5.4.3 Cornell University (Vital Monitoring Mask)

A Cornell University team, made up of students, worked on a biomedical device innovation by designing a smart mask that can monitor vital signs. They used their experience with biosensors to develop the winning idea at the seventh annual AI Health Hackathon, Feb. 7-9: a "smart" respiratory mask that prevents the spread of airborne diseases while monitoring the wearer's vital signs [50]. The design is made of 3D-printed resin and it can monitor the respiratory rate, heart rate, blood oxygen, and body temperature. The design will also be connected to mobiles and apps and will be washable in order to clean it easily. The proposed project is related to the design discussed in this paper in that both of them can detect any abnormal conditions related to vital signs. However, the SDVM Mask should be able to ensure social distancing before the user's vital signs are in an abnormal condition based on the exposure of infection. As they say, "Prevention is better than cure."

Below in Table 4 is a comparative analysis of the mentioned mask applications in subsection 2.1.5. The table contains the advantages and limitations of each approach.

Table 4 - Comparative analysis of mask applications

Approaches	Advantages	Limitations
Fluorescent Signaling Mask	- Detects COVID-19 virus - More reliable than using body temperature scanners/thermometers.	- Requires handheld fluorometers to scan masks and detect the fluorescent signals. - Does not promote continuous tracking of the user's health status. - Takes time to detect virus (1-3 hours).
COVID-19 Detecting Mask	- Detects COVID-19 virus.	- No preventive measures to protect the user from exposure to the virus.
Vital Monitoring Mask	- Measures respiratory rate, heart rate, blood oxygen, and body temperature of the user. - Washable, easy to clean	- The 3D printed resin mask is bulky and uncomfortable. - Does not help in promoting social distancing.

2.6 ANALYZING ALTERNATIVE SOLUTIONS AND SELECTION

This part aims to compare different solutions of designing the SDVM mask to select the best alternative under the specified circumstances in the design requirements, specifications, and constraints. First, a morphological chart is used to generate alternative solutions by analyzing the main functions and listing the possible means of implementing each function. Then, three alternative solutions are selected by analyzing and comparing each function's means and then choosing one of the options. Finally, Pugh's technique is used to select the best solution out of the alternative solutions generated.

For clarification, the system is deconstructed to show each of its functions and features. These functions and features will be used to build the morphological chart. For more clarification, a function tree is used, as shown below in Figure 8.

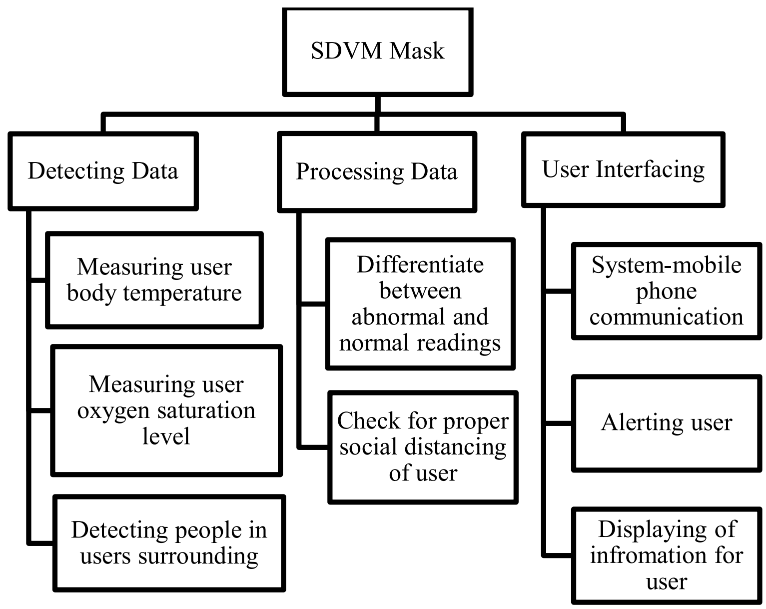

Figure 8 - Function Tree for the SDVM Mask

The design system comprises several technologies that work together to perform the system's main objectives listed under section 1.3. The first function is detecting data. It is branched out into measuring user body temperature, measuring user oxygen saturation, and detecting people in the user's surroundings, each of which requires its own means to be implemented. This function will aid the design in helping the user keep track of their health by measuring the relevant vital signs that indicate COVID-19 symptoms, and it will also help in enabling detection of human bodies around the user.

The second function of the design is processing data, where a microcontroller will be used to implement this feature. A comparison algorithm is used to differentiate between abnormal and normal readings for the body temperature and oxygen saturation readings. Also, to help the user keep a proper social distance at all times, the microcontroller will implement a comparison algorithm that assesses the user's distance from other bodies to guarantee proper social distancing.

The third function is user interfacing, which branches out into system-mobile phone communication, alerting, and displaying information for the user. The function will help in allowing the data transferring and communicating between the project design and the mobile phone application, utilizing the mobile phone application to display the user's information or alert the user.

2.6.1 Generating alternatives

To simplify the process of generating alternative solutions, a morphological chart is used, as seen in Table 5. The morphological chart shows the system's main functions and features on the left side with corresponding means to implement each function or feature on the right side. To select the appropriate means for each feature or function, the team referred to the literature review written in chapter 2.

For the first feature, social distancing measurement, the selected means were narrowed down to 4 options: Radio-Frequency Identification (RFID), Ultra-Wideband (UWB), Infrared (PIR Sensor), and Bluetooth Low Energy (BLE). When choosing the sensors for social distancing, their range, detection method, and size are the main concern. The range of the sensors should reach 2 meters, which is the required distance for social distancing. The sensors should also have a wide peripheral range and detect a reasonable portion of the user's surroundings.

For the vital signs monitoring function, the system will measure body temperature and oxygen saturation, which are both factors that indicate COVID-19 symptoms. The selected sensors for body temperature monitoring were: Non-contact Infrared Thermometer (GY-906), Contact Human Body Temperature Sensor (MAX30205), and Contact Temperature Sensor (LMT70). The sensors chosen for oxygen saturation monitoring were: Pulse Oximeter and Heart Rate Sensor (MAX30100), SparkFun Pulse Oximeter and Heart Rate Sensor, Mikroe Oximeter Click. When choosing the means for implementing the vital signs monitoring feature, the component's size and accuracy were considered, and the user's safety. Like the social distancing feature, the sensors used under vital signs monitoring have to be reasonably sized for a wearable device. Since the system will be worn as a mask, all the components considered have to fit onto the mask structure and be comfortable for the user in terms of weight and size. In addition, the sensors cannot use techniques or technologies that are not safe for the user when worn on the face. Finally, since the sensors will be measuring vital signs that indicate COVID-19 symptoms, the sensors have to provide highly accurate measurements.

The components and tools needed to establish a connection between each technology are observed in the systems communication feature. Since the system will contain multiple sensors and components, there should be a method of transmitting data and information. To begin, the microcontroller component will connect all the sensors together and perform the necessary algorithms to establish the data or information that will be communicated to the mobile phone application. The options chosen for the microcontroller were as follows: Maxim Integrated (MAX32660), Arduino Nano, Arduino LilyTiny, and Arduino Pro-Mini. When deciding on the microcontroller, the focus was put on the size of the microcontroller and the compatibility of the microcontroller with the sensors and components.

Finally, the mode of communication between the system and the user's mobile phone application was observed. The most convenient and widely used methods found were the following: Bluetooth Module, GSM Module, and Wi-Fi Module. Each module comes in different sizes and with different capabilities, which will be delved into in the coming section. The final feature or function inspected for the design was the mobile phone application's operating system or platform. When developing the mobile phone application, the operating system or platform to be used is also decided. The team narrowed the choices down between IOS, Android, and Linux.

Table 5 - Morphological chart

Function/Feature			**Means**			
			Option 1	**Option 2**	**Option 3**	**Option 4**
Data Detecting	Social Distancing Measurement		Radio-Frequency Identification (RFID)	Ultra-Wideband (UWB)	Infrared (PIR Sensor)	Bluetooth Low Energy (BLE)
	Vital Signs Monitoring	Monitors Body Temperature	Non-contact Infrared Thermometer (GY-906)	Contact Human Body Temperature Sensor (MAX30205)	Contact Temperature Sensor (LMT70)	

Table 5 - Morphological chart (*continued)*

Data Detecting		Monitors Oxygen Saturation	Pulse Oximeter and Heart Rate Sensor (MAX30100)	SparkFun Pulse Oximeter and Heart Rate Sensor	Mikroe Oximeter Click	
Data Processing (Microcontroller)			Maxim Integrated (MAX32660)	Arduino Nano	Arduino LilyTiny	Arduino Pro-Mini
User Interfacing		Operating System/Platform	iOS	Android	Linux	
		System-Mobile Phone communication	Bluetooth Module	GSM Module	Wi-Fi Module	

The morphological chart shown in Table 5 generates many possible alternatives that can be considered as feasible designs. Nevertheless, the alternatives were narrowed down to three alternatives based on how well the alternative will achieve the design's objectives, requirements, and constraints. Some of the means were not considered in the final alternatives, such as the Ultra-Wideband (UWB) and Contact Temperature Sensor (LMT70). These means were mainly not considered due to the lack of resources in the market needed to use them in the solutions. Also, the Maxim Integrated (MAX32660) and Mikroe Oximeter were excluded since they are a larger size compared to the other means thus making them more difficult to embed into the mask. The final three alternatives containing the best possible combination of options are listed below in Table 6.

Table 6 - List of generated alternatives

Function/Feature		**Alternatives**		
		1	**2**	**3**
Data Detecting	Social Distancing Measurement	Radio-Frequency Identification (RFID)	Infrared (PIR Sensor)	Bluetooth Low Energy (BLE)

Table 6 - List of generated alternatives (*continued*)

Data Detecting	Vital Signs Monitoring	Monitors Body Temperature	Non-contact Infrared Thermometer (GY-906)	Non-contact Infrared Thermometer (GY-906)	Contact Human Body Temperature Sensor (MAX30205)
		Monitors Oxygen Saturation	SparkFun Pulse Oximeter and Heart Rate Sensor	Pulse Oximeter and Heart Rate Sensor (MAX30100)	SparkFun Pulse Oximeter and Heart Rate Sensor
Data Processing (Microcontroller)			Arduino LilyTiny	Arduino Nano	Arduino Pro-Mini
User Interfacing		Operating System/Platform	iOS	Android	Linux
		System-Mobile Phone communication	GSM Module	Bluetooth Module	Wi-Fi Module

Each of the generated alternatives is discussed in detail and visualized with a block diagram in the following sections.

2.6.1.1 Alternative 1

For the first alternative, the RFID sensor was chosen to implement the social distancing measurement feature. Since RFID transmits radio waves from “tags” using an antenna to communicate with nearby readers, the RFID tags would have to be present on all individuals in the user’s environment to gauge the number of persons around the user accurately. Accordingly, this alternative is suitable for implementation in a controlled environment such as schools, workplaces, or factories, where all individuals inside the location are accounted for.

For vital signs monitoring, the mean for temperature measurement chosen was option 1, the non-contact infrared thermometer. With this mean, the sensor can also be utilized in contact with the skin. The advantage of using infrared is its high accuracy in detecting body temperature with an accuracy of 0.5°C. In addition, the sensor is appropriately sized to be placed on the mask. On the other hand, to implement the oxygen saturation measuring, the SparkFun pulse oximeter is used. The main difference between the options in this feature is the availability and size of the components. The SparkFun sensor is tiny, measuring at 1in x 0.5in, and can therefore be easily attached to a face mask; however, it is difficult to source on the current market, resulting in a higher price.

Under the systems communication feature, the chosen microcontroller for this alternative is the Arduino LilyTiny. The Arduino LilyTiny's most significant advantage is size and thickness. As a relatively new line of Arduino's, the LilyTiny is targeted for use in textiles and clothing; with its small size and slim compactness, it is ideal to be stitched on the mask. This alternative utilizes a GSM module to establish a connection between the system and the user's mobile phone application. The advantage of the GSM module is that it does not require the user to turn on any feature from the phone (i.e., Bluetooth or Wi-Fi). So, it will be able to communicate with the phone as long as it is switched on.

Finally, the operating system that will be used when programming the mobile phone application is iOS. The block diagram detailing the alternative's system is shown below in Figure 9.

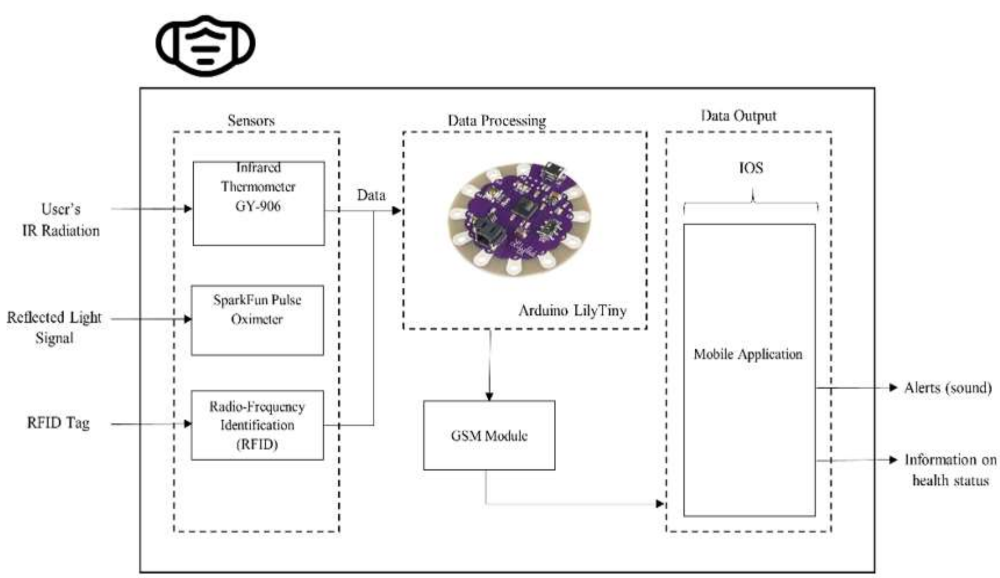

Figure 9 - Block Diagram of Alternative 1

2.6.1.2 Alternative 2

As for the second alternative, the passive infrared (PIR) sensor is utilized for implementing the social distancing feature. The sensor is able to identify the presence of humans by detecting the emitted infrared radiation from their bodies; this also gives the sensor the advantage of differentiating between human bodies and inanimate objects. By using the PIR sensor, the alternative has the advantage of detecting a person when he/she comes within the vicinity of the adjusted distance of at least 1.8m, which will help the user maintain sufficient social distance.

Moreover, for the vital signs monitoring feature, a non-contact infrared thermometer (GY-906) was chosen. The sensor has a small size, low cost, and high accuracy temperature readings that could also be taken in contact with the user whose temperature is being monitored. Additionally, for monitoring the oxygen saturation level, the Pulse Oximeter and Heart Rate Sensor (MAX30100) is utilized. The sensor is available in the local market, and it has a low cost and a small size with 5.6mm x 2.8mm x 1.2mm dimensions. [51]

For the systems communication feature, the alternative uses the Arduino Nano as the microcontroller. The Arduino Nano is an open-source prototyping platform based on flexible hardware and easy-to-program software; it is small, sized at 18x45 mm and weighs only 7g, which makes it a good option to be placed in a mask. Proceeding with the system to mobile phone communication, the Bluetooth module is chosen. The Bluetooth module can wirelessly transmit the data to the mobile phone, it has a low power consumption, and it is also available very cheaply in the local market. Finally, for implementing the mobile phone application, an android is used for the operating system/platform. The block diagram of the 2nd alternative can be seen below in Figure 10.

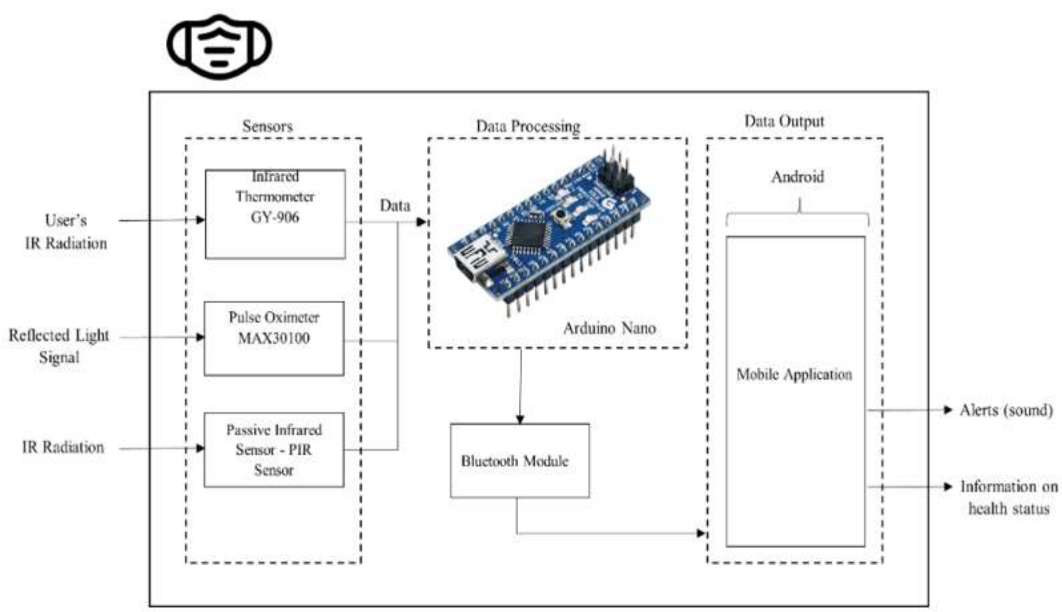

Figure 10 - Block Diagram of Alternative 2

2.6.1.3 Alternative 3

Regarding the 3rd alternative, Bluetooth Low Energy (BLE) has been selected to achieve the social distancing objective. BLE is a wireless network technology used for its cheaper cost in implementation compared to the other options in table 5 since it deals with applications that do not need to exchange enormous amounts of data.

Also, Contact Human Body Temperature Sensor (MAX30205) was selected to implement the body temperature monitoring. This device converts the temperature measurements to digital form using a high-resolution, sigma-delta, analog-to-digital converter (ADC) [52], and sensing temperature from 0°C to 50°C with 0.1°C accuracy [53], which is lower than GY906's that have 0.5°C accuracy [54]. SparkFun was selected in alternative 3 to implement the oxygen saturation measuring, mentioned in alternative 1 as a small component that measures at 1in x 0.5in. However, due to the lack of resources in the market, it costs a lot more compared to the other oxygen saturation sensors in table 5.

Moreover, Arduino Pro-Mini is selected as the microcontroller type to be used. While the Arduino Nano is a smaller variety of the widely popular Arduino Nano, the Arduino Pro-Mini is a smaller version of the ATmega328. They differ in how they can be programmed. For system communication with the mobile phone, Wi-Fi Module was selected in alternative 3, which has only meter-level accuracy, unlike Bluetooth that is centimeter-to-meter level with lower power consumption. In the end, Linux was selected as an operating system randomly. The corresponding block diagram for alternative 3 is shown below in Figure 11.

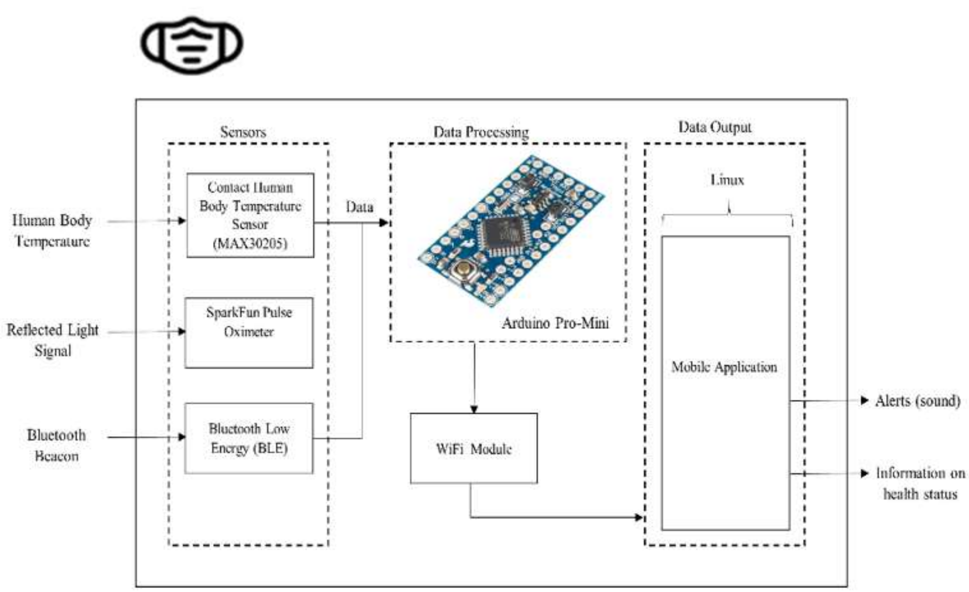

Figure 11 - Block Diagram of Alternative 3

2.6.2 Selecting an alternative

In order to select the best alternative, listing the pros (advantages) and cons (disadvantages) of each solution is implemented in Table 7. Pros and cons listing is a decision-making method used to achieve some level of awareness about potential consequences. The pros in Table 7 are listed based on how effectively the alternative achieves the design's requirement, like having high accuracy to achieve the accurate measurements requirement, using components with low power consumption to achieve the optimal power usage, and having a small-sized component to achieve the lightweight requirement. In addition, the component's availability in the market is also considered. Alternatively, the cons are based on how ineffectively the alternative is achieving the design's requirement and the unavailability of the components in the market.

Table 7 – Advantages and disadvantage of each solution

	Alternative 1	**Alternative 2**	**Alternative 3**
Pros	• High accuracy in measuring the body's temperature (0.1°C). • Arduino LilyTiny is easy to embed in the mask due to its small size and capabilities catered towards textile embedding. • The RFID is less prone to errors in detecting non-human bodies.	• High accuracy in measuring the body's temperature (0.1°C) • The Android operating system uses familiar program language to students (Java). • Bluetooth modules consume low power. • All components are available in the market.	• Data transfer to the user's mobile phone is very fast (about 3ms).
Cons	• The RFID tags would have to be present on all individuals in the user's environment to operate. • Some components are not available in the market.	• Bluetooth will lose connection in certain conditions (e.g., Bluetooth in the user's device is off).	• Wi-Fi Module consumes high power. • Wi-Fi Module has low accuracy. • Lower accuracy in measuring the body's temperature (0.5°C). • Some components are not available in the market.

Pugh's method is implemented to help in selecting the optimum alternative. Pugh's method helps engineers make design decisions by establishing a procedure to choose the best design from the considered designs. These considered designs or alternatives were generated from the Morphological Chart and are discussed in detail under the heading *Generating Alternatives.*

In Pugh's method, alternatives are compared in terms of how well they fulfill the requirements in comparison with the selected datum. The datum used for comparison is the following:

Datum: The Lab-on-Mask developed by scientists in Singapore measures user's vital signs, which could be health indicators associated with COVID-19. The design measures skin temperature, blood oxygen saturation, blood pressure, and heart [55]. This design has been selected due to its similarities with the SDVM design's mask structure and user vital signs measuring function. In addition, both designs are connected to the user's mobile phone application. Since there are many common features between the two designs, the Lab-on-Mask will be used as the basis of comparison for each of the alternatives.

Each alternative is compared to the described datum and assigned a +1, 0, or -1 according to its performance against the datum. For alternatives that perform better than the datum, they are assigned a point of +1. Contrastingly, an alternative that performs worse than the datum, is assigned a point of -1. If the alternative performs the requirement neither worse nor better than the datum, it is assigned a point of 0. Each requirement is then assigned a weight from a range of 1-5, where 1 is of lowest importance and 5 is of highest importance. These chosen weights are specified according to the ranks of the requirements of the PCC in Table 2.

Table 8 - Pugh's method

Requirements	**Weight**		**Design's Alternatives**		
			1	**2**	**3**
Lightweight	**4**	**Datum**	-1	-1	-1
Affordable	**2**		-1	0	0
User friendly	**2**		0	0	0
Fast measure	**3**		0	0	-1
Cleanable	**4**		+1	+1	+1
Optimal power usage	**3**		-1	0	-1
Accurate measurements	**4**		0	0	0
Safe to wear	**5**		+1	+1	+1
Environmentally friendly	**1**		0	0	0
Sum of the Products			**0**	**5**	**-1**

0: Same *+1: Better* *-1: Worse*

The alternatives were compared to the datum as could be seen from Table 8. all alternatives perform poorly in the *lightweight* requirement as a result of the SDVM mask design having extra components due to the additional function of measuring social distancing. The first alternative performed worse in the *affordable* requirement since it utilizes a GSM module, which has a higher cost in comparison to the Bluetooth module. All alternatives perform equally in the *user-friendly* requirement since the datum also uses a mobile phone application to display the user's information. In the *fast measure* requirement, alternatives 1, 2 received a 0, since in terms of the infrared sensor that measures the body's temperature, which is the same as the datum's temperature sensor. Alternative 3 uses MAX30205 that is much slower compared to the fast infrared sensor that has a 0.5s response time [56]. For the *cleanable* requirement, all alternatives utilize the same mask structure as the datum, a cloth mask. However, the SDVM mask will feature a detachable front material that can be individually cleaned. Alternative 2 received a 0 in the *optimal power usage* requirement, since similar to the datum, it utilizes a Bluetooth module for system-mobile phone communication, which consumes less power than the GSM and Wi-Fi modules. For the *accurate measurements'* requirement, all alternatives received a 0, since in terms of the pulse oximeter sensor in alternative 2, the datum also uses the MAX30102, which is in the same line of sensors as the MAX30100. All the alternatives performed better in the *safe to wear* requirement, since the datum design shows the connecting wires wrapped around the users face as shown in Figure 12 below, which could pose a hazard to the user. Finally, for the *environmentally friendly* requirement, all the alternatives received 0. Because similar to the datum, the alternatives will use a cloth mask structure which is reusable and recyclable.

Figure 12 - The Lab-on-Mask [57]

After finishing the alternatives comparison with the datum, the score of each alternative was calculated, and as the table shows, alternative 2 got the highest score. Therefore, it was selected.

CHAPTER – 3 PRODUCT BASELINE DESIGN

3.1 BLOCK DIAGRAM

Under this section, the detailed block diagram of the optimum solution is drawn and explained. The block diagram details the system's functionalities as blocks, and the output and inputs of each block are specified on the arrows. For more clarity, function blocks are organized further according to the type of function they perform. The block diagram is shown below in Figure 13.

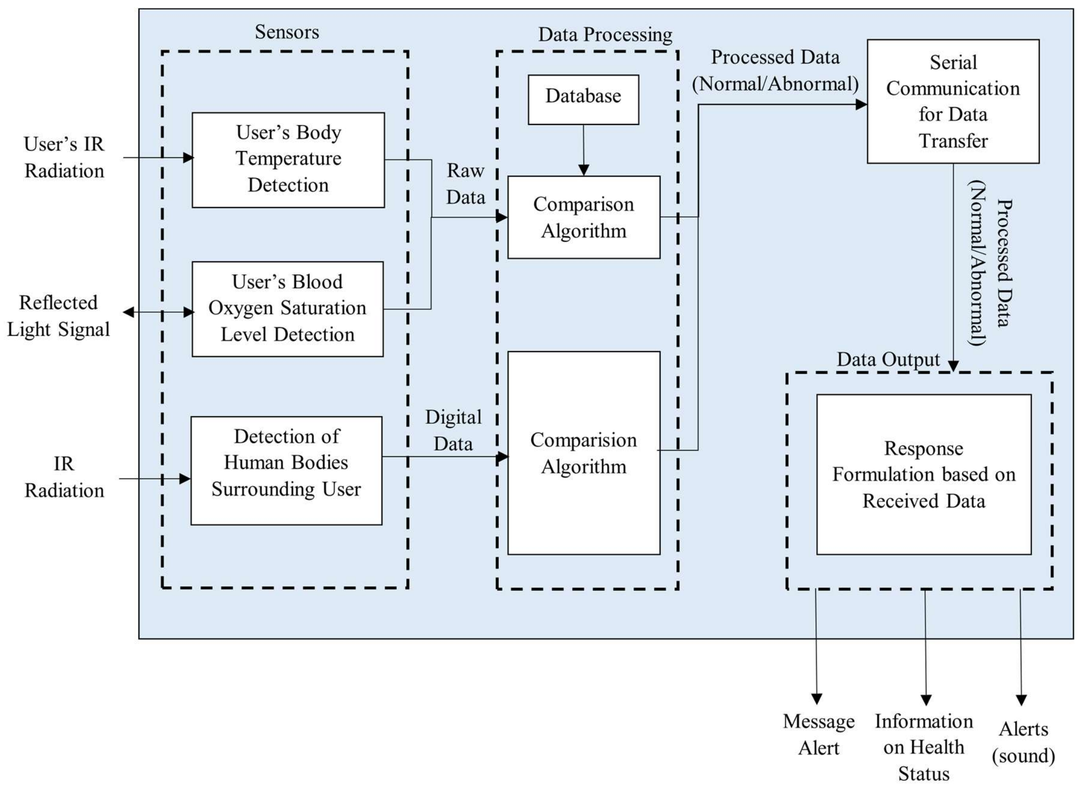

Figure 13 - Block Diagram for the SDVM Mask

As a start, there are three main blocks for the block diagram: sensors block, data processing block, and data output block. The sensor block contains three sub-blocks that will measure different types of data. The first sub-block represents the user's body temperature detection that detects the user's IR rays, which result from moving molecules inside the user's body. These moving molecules emit infrared radiation and directly correlate with a human's temperature. So, the sensor uses it as an input to perceive the temperature range that enters the data processing block as raw data. The second block represents the user's blood oxygen saturation level detection that operates on the red and IR light absorption characteristics of hemoglobin. So, the sensor uses the ratio between the absorption of red light and IR light from the hemoglobin to calculate the blood oxygen, and the output enters the data processing block as raw data. The third sub-block represents the user's surrounding human body detection that detects such infrared radiation levels to give information about close human body existence and transfers the information to the data processing block as digital data.

The Data Processing block contains sub-blocks with different types of algorithms. An algorithm is a series of instructions to help the system make decisions. When the sensors generate raw data like temperature and oxygen level, it will be processed by the comparison algorithm to decide if the temperature/oxygen level is in the normal range. Synchronously, the user's surrounding human body detector will output digital data that enters the comparison algorithm. The algorithm determines if there are any bodies in the sensor's programmed range based on whether the digital output is HIGH (body is present) or LOW (body is not present). The maximum range will be set to the safe limit for social distancing at 2m so that as soon as a body enters the user's range of 2m, the sensor will detect the body and produce a digital output of 1 (HIGH). The data is considered abnormal if a human body is detected, and if the temperature and oxygen saturation levels recorded are out of the normal range when compared. After differentiating between the abnormal and normal data, the microcontroller will send the processed data to the serial communication block.

The serial communication block will transmit the data to the user's mobile application; if the data is abnormal, it will trigger an alarm and warning message on the mobile phone to alert the user. Also, information on the health status will appear in the mobile application to show the user's temperature and oxygen level regardless of the data type so that there is constant monitoring of their vital signs.

3.2 SYSTEM DESCRIPTION

For the second section of chapter 3, the characteristics of the baseline design are discussed. The purpose of this section is to provide a thorough description of the proposed system through a circuit schematic, including the circuit components, and then delving into all the technical aspects of the system. The operating instructions needed to utilize the design are detailed, and the system's inputs and outputs are specified. Under this section, the estimated cost to build the system's design prototype is documented, and the impacts of the engineering solution are examined.

3.2.1 Circuit schematic

Before implementing the hardware design of the system, a visualization of the possible connection of the components is done using the fritzing software program [58]. The circuit schematic of the chosen design of the system is shown below in Figure 14. The system design prototype should be able to monitor the user’s vital signs, detect distance for social distancing, and communicate data to the user’s mobile phone, where the user will receive all alerts and information. The design will also be demonstrated using a cloth face mask to detail how the user can reuse the mask and keep it sanitary. The connection of each component in the system is detailed as follows.

To begin, the red wires represent the positive terminal of the input voltage (VIN), and the black wires represent the negative terminal of the input voltage (GND). The Arduino Nano microcontroller is the component that connects all the other sensors together. A 6V AAA battery combination is used to power the system since the datasheet specifies an operating voltage of 5V – 12V for the Arduino Nano, the Vin pin is also a regulator and will regulate any inputted voltage to 5V. The microcontroller has 8 analog input pins, some of which connect the vital signs monitoring components: The Pulse Oximeter MAX30100 and the Non-contact Infrared Thermometer GY906.

The Pulse Oximeter MAX30100 has 7 pins: VIN, SCL, SDA, INT, IRD, RD, and GND. However, only the VIN, SCL, SDA, and GND inputs will be utilized for the system's design. The MAX30100 has its own Arduino, as after testing the system with only one Arduino, it was noticed that the MAX30100 sensor was not compatible with the other sensors as it operated at a different baud rate. The VIN and GND pins are correspondingly connected to the 5V and GND inputs on the microcontroller. The SDA and SCL pins are connected to the analog input pins A4, and A5 of the microcontroller, which are dedicated SCL and SDA pins on the Arduino Nano. It should also be noted that the operating voltage of the MAX30100 ranges between 1.8 to 3.3V, however, the internal resistor of the MAX30100 was soldered and used so it was connected to the 5V pin.

The other Arduino is connected to Non-contact Infrared Thermometer GY906, PIR sensor, and the HC-06 Bluetooth module. For the Non-contact Infrared Thermometer GY906, there are 4 pins on the sensor. The VIN and GND pins, dedicated to powering the sensor, are consequently connected to 3.3V and GND inputs on the microcontroller. The other two pins, SDA and SCL, are connected to the analog input pins A4 and A5 of the microcontroller. Much like the MAX30100, the GY906 also operates around the range of 3.3V.

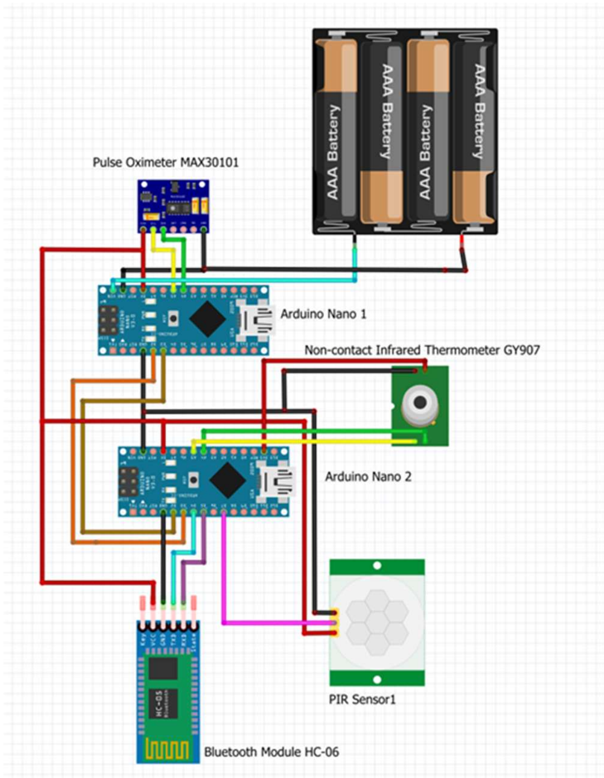

Figure 14 - Circuit Schematic of System Design Prototype

Regarding the PIR sensor wiring, the sensor has 3 output pins, the VCC, the GND, and the OUT. The VCC is the power supply for the sensor, and it is connected to the 5V pin on the Arduino, and the GND is connected to the ground of the Arduino. The PIR sensor has a digital output; therefore, the OUT pin is connected to the digital pin D7 of the Arduino.

Finally, for the Bluetooth module, there are 6 pins. The STATE, RX, TX, GND, VCC, and the EN or the (KEY) pins. However, the STATE and KEY pins will not be needed. The VCC and the GND pins are connected to the Arduino 5V and GND inputs pins. Regarding the RX pin (The Receiver), it is used to receive serial data, and it is connected to the Arduinos' TX1 pin, which corresponds to pin D5. For the TX pin (The Transmitter), using it allows the received data to be given out as serial data, and it is connected to the Arduinos' RX0 pin, which corresponds to pin D4.

To power the whole system, four 1.5V AAA batteries are used. The AAA alkaline batteries are inside an AAA battery holder that allows you to add 4 AAA batteries together. The batteries are connected to the VIN and GND pins, where the VIN pin will regulate the incoming voltage to 5V. The two Arduino's are also connected together through serial communication and through power pins (5V and GND). This way the battery needs only be connected to one Arduino, but it will still power the other Arduino. The batteries can be connected from any of the Arduino's and still work the same way. Finally, the serial communication is used so that the serial data from the MAX30100 can be sent to the other Arduino in order to be sent to the application through the Bluetooth module. This is done in a similar fashion to the Bluetooth module the RX pin (D2) of Arduino 1 is connected to the TX pin (D3) of Arduino 2, while the TX pin (D3) of Arduino 1 is connected to the RX pin (D2) of Arduino 2. The digital pins are to be specified and configured during coding.

3.2.2 Circuit components specifications

Table 9 shows the components specifications that are used in Figure 14 to demonstrate the design's circuit schematic. Component specifications often refer to a detailed description that achieves the design's requirements.

Table 9 - Circuit components specifications

Component	Picture	Specification
Arduino Nano	 [59]	**Microcontroller:** ATmega328P – 8-bit AVR family microcontroller. **Operating Voltage:** 5V **Input Voltage:** 7-12 V **Frequency (Clock Speed):** 16MHz. **SRAM:** 2KB **EEPROM:**1KB **PCP Size :** 18 X 45 mm **Weight:** 7g **Power Consumption:** 19mA [60]
Infrared (PIR Sensor)	 [61]	**Product Type:** HC--SR501 Body Sensor Module **Input Voltage:** DC 4.5-20V **Sensing Range:** Max 7 m **Delay Time:** 5-200s **Board Dimensions:**32mm*24mm **Angle Sensor:**<100 cone angle **Operating Temp:** -15 - +70 degree **Diameter:** 23mm [62]

Table 9 - Circuit components specifications (*continued*)

Bluetooth Module	 [63]	**Product Type :** HC-06 Bluetooth Module **Modulation :** Gaussian Frequency Shift Keying **Frequency:** 2.4 GHz ISM band **Emission power:** 4dBm **Sensitivity:** 84dBm at 0.1% BER **Speed:** Asynchronous: 2.1Mbps(Max) / 160 kbps, Synchronous: 1Mbps/1Mbps **Security:** Authentication and Encryption **Power supply:** +3.3VDC, 50mA **Working temperature:** -20 ~ +75 Centigrade **Dimension:** 26.9mm x 13mm x 2.2 mm [64]
Pulse Oximeter and Heart-Rate Sensor	 [65]	**Product Type:** MAX30100 **Operating Voltage:** 1.8-5.5V **Module Dimensions :** 18.8mm (L) x 14.4mm (W) x 3.0mm (H) **Interface Type:** I2C Serial Interface [66]
Non-contact Infrared Thermometer	 [67]	**Product Type:** GY906 **Body Temperature Range:** 32 to 42.5°C **Response Time:** 500ms **Power**: 2 AA batteries **Weight:** 177g **Dimension:** 160x82x42mm [68]
Battery	 [69]	**Product Type**: AAA Alkaline Battery **Product Brand**; Energizer **Capacity**: 1000mAh **Voltage**: 1.5V for each **Number of Modules**:4 [69]

3.2.3 Operating instructions

In order to use the mask properly, the following instructions should be followed by the user:

1- Wear the mask.

2- Turn on Bluetooth on the mobile phone.

3- Keep track of the alerts through the mobile phone.

3.2.4 Engineering standards

Engineering standards are crucial to ensure a project design is reliable and safe. Engineering standards are documents that define some methods, technical processes, and criteria. The documents are usually prepared by a group of experts and professionals. Table 10 below outlines the project utilized components and their respective engineering standards. Moreover, a description of each standard is provided.

Table 10 - Engineering standards

Components	Standards
Microcontroller	2001/95/CE
Body Temperature and oxygen saturation sensors	IEEE 11073 IEEE-P1912 IEEE 2700-2017
PIR Sensor	IEEE 2700-2017
Bluetooth Module	IEEE 802.15.6

IEEE 802.15.6™ Standard for Wireless Body Area Network (WBAN)

The proposed project design will be equipped with temperature and oxygen saturation sensors, which will continuously measure the body temperature and the oxygen level. The sensors will be placed inside a mask and will operate in close vicinity to the user's body. The IEEE 802.15.6 Standard provides a standard for Wireless Body Area Network (WBAN) for having a reliable, low power, and short-range wireless communication within the human body's surrounding area. [70]

IEEE 11073™ family of standards

The IEEE 11073™ family of standards consists of many parts under the general title *Health informatics -Personal health device communication.* The standard provides electronic data of the user's vital signs and device operational data. And it also enables communication between medical-related devices and external systems.
[70] [71].

IEEE-P1912™—Standard for Privacy and Security Architecture for Consumer Wireless Devices

The proposed project will contain the user body temperature and oxygen saturation data. Therefore, privacy and security are mandatory. The IEEE-P1912 standard provides a common communication architecture. The standard supports user privacy and specifies many approaches for end-user security. [70]

IEEE 2700-2017 - IEEE Standard for Sensor Performance Parameter Definitions

A standard methodology for defining sensor performance parameters is provided in the IEEE 2700-2017 standard. The performance parameters in the standard are defined with required units, conditions, and distributions for each sensor. The standard discusses many sensors, such as barometer/pressure sensors, hygrometer/humidity sensors, and temperature sensors. [72]

2001/95/CE General Product Safety (GPSD)

The 2001/95/CE General Product Safety directive provides many standards related to consumer products. The directive was established to protect consumer health and safety. [73]

3.2.5 Input/output specifications

The system receives three different inputs from both the user and the user's environment. The first input is the user's skin temperature, which is read using the non-contact thermometer. The second input, also from the user, is the oxygen saturation. This input is read using the pulse oximeter sensor, placed around the user's ears. The sensor will emit a light signal that bounces off the user's arteries and comes back to be read for how much of that light was absorbed. The last input is the infrared radiation of human bodies around the user. The infrared sensor used for the social distancing feature will detect the infrared radiation emitted from human bodies.

The outputs of the system will all come from the user's mobile phone application. On the mobile phone application, the user will receive two outputs. The first output is a sound alert and notification that warns the user when there is an anomaly with the vital signs readings or when the user is too close to another individual. The final output is the information or data that will be compiled and displayed for the user on the application so that the user can effectively monitor his/her health status.

3.2.6 Flowchart

A flow chart is a generic tool for describing a process, which is used to represent each step of a specific process in sequential order. Figure 15 is describing the SDVM process regarding the software design, which is a sequence of instructions allowing the Arduino to perform logical and arithmetical operations.

There are five basic symbols in the program flowchart, start, process, decision, and end. Each symbol represents a part of the software program connected sequentially through arrow shapes. The oval shape is in the first level and it represents the start part. The start part includes connecting the Arduino to the power source. The second level is a collection of rectangle shapes that represent the process of collecting the information from different kinds of sensors connecting to Arduino. The third level is including diamond shapes, which represent a decision after taking the information from the first level. The Bluetooth module will contain only process shapes without the need for making decisions for only connecting the smartphone to the Bluetooth. The fourth level represents the process after making the decision, either to communicate with the user to alert him about some abnormalities in the readings by message and vibration, or to go back to the first level for collecting information from the sensors again. The process doesn't include end, because Arduino will keep collecting information from the sensor as long as it is powered on. Except for the Bluetooth that has an oval shape that represents the End, because it will be connected to the smartphone once.

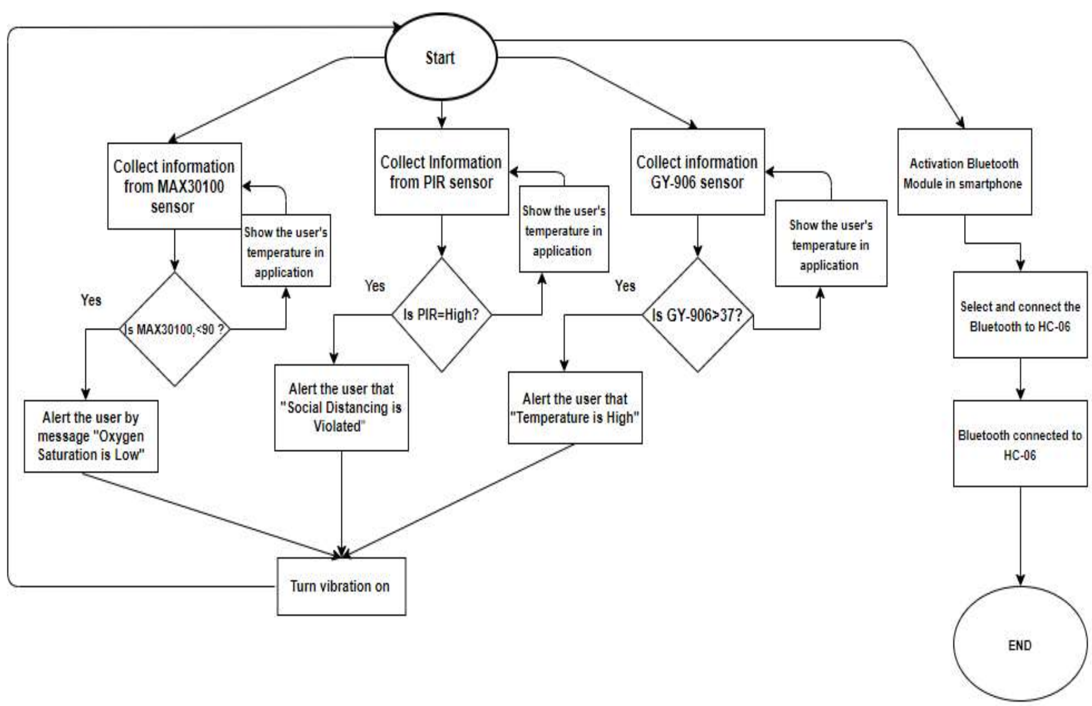

Figure 15- Design's Flow Chart

3.3 MATHEMATICAL MODELLING

In this subsection, mathematical modelling will be performed on the relevant subsystems of the design. The modelling will be done using the MATLAB and Simulink software. To begin, the raw data is imported serially from Arduino to MATLAB in order for it to be studied and exhibited. The mathematical model will help visualize the data and observe information that could help in the implementation and testing of the prototype.

3.3.1 Temperature Reading Delay Timing

The first subsystem to be modelled will be the temperature measuring block of the design, which will use the GY906 infrared sensor to measure the temperature. The temperature measurement should be accurate, and the sensors should show fast responsiveness since the readings will be continuously measured and in real-time. Additionally, slight deviations from any range of 0.5℃ to 1℃ in the temperature reading from the actual temperature will result in an inaccurate measurement that will not give proper results. To test this, the delay and overshoot of the temperature sensors data output are observed.

Below, the simple MATLAB code is shown that plots the graph in Simulink that shows the response of the temperature sensor in regard to time. The time unit used will be milli second (ms). The *temp* variable consists of the serial data imported from the Arduino and 952 readings were taken and a sample of it is shown below.

```
temp = [
24.23
24.27
24.27
24.23
.
.
.
25.37
25.41
25.43
25.37
];

time = (1:1:952)’;

signal = [time,temp];
```

Then, as shown below in Figure 16, Simulink is used to generate a signal and the signal is captured using a scope.

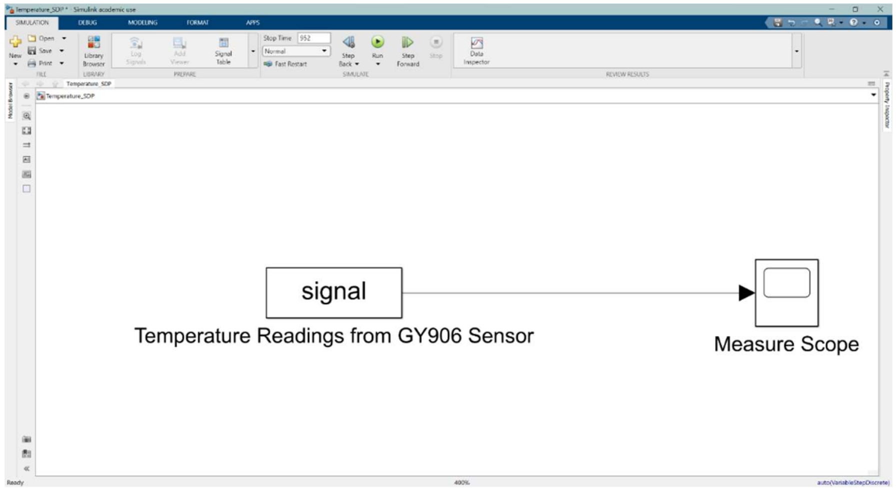

Figure 16 - Preview of Simulink Window for Temperature Sensor

Below in Figure 17, the output plot can be seen. The plot represents the data when the user places the sensor on his/her cheek and then removes it. As soon as the sensor is placed on the cheek there is an oberved overshoot at the 1000ms mark that gives a 45 °C reading, before it stablizes towards a constant reading of about 36°C. At the 6000ms mark, the user removes the sensor from their cheek and we observe that the readings reverts back to room temperature of about 25°C.

For both signifcant changes in the readings, there is an approximate 1800ms transient between each reading. This suggests the sensors overshoots anytime a foreign object is placed in front of it before it goes down to the correct reading. However, there needs to be a wait time of nearly 2 seconds (2000ms) before the readings reach a steady state.

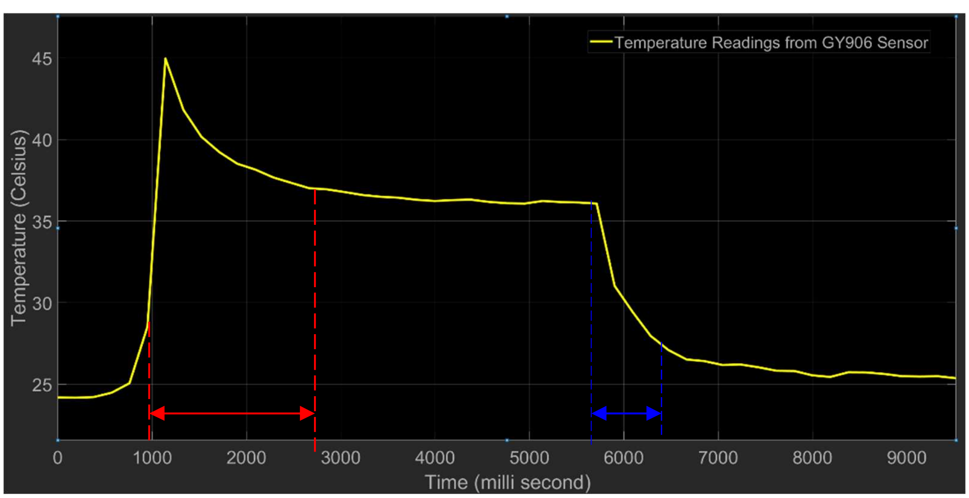

Figure 17 - Output Plot of Temperature Sensor Measurement

3.3.2 Blood Oxygen Saturation Reading Delay Timing

The second subsystem to be modelled will be the blood oxygen saturation measuring block of the design, which will use the MAX30100 sensor to measure the level of oxygen saturation in the user's blood. The blood oxygen saturation measurement of the design should be accurate and have quick responsiveness since the readings will be continuously measured.

Below, the simple MATLAB code is shown that plots the graph in Simulink shows the response of the blood oxygen saturation sensor in regard to time. The time unit used will be milli second (ms). A sample of the Spo variable, which consists of the serial data imported from the Arduino and 89097 readings, were taken and it is shown below. More readings are taken since the sensor was slower to respond as will be observed in the sample output in Figure 19 below.

```
Spo = [
0.00
0.00
0.00
.
.
98.00
.
.
0.00
0.00
0.00
];

time = (1:1:89067)';

signal = [time,Spo];
```

Then, as shown below in Figure 18, Simulink is used to generate a signal and the signal is captured using a scope.

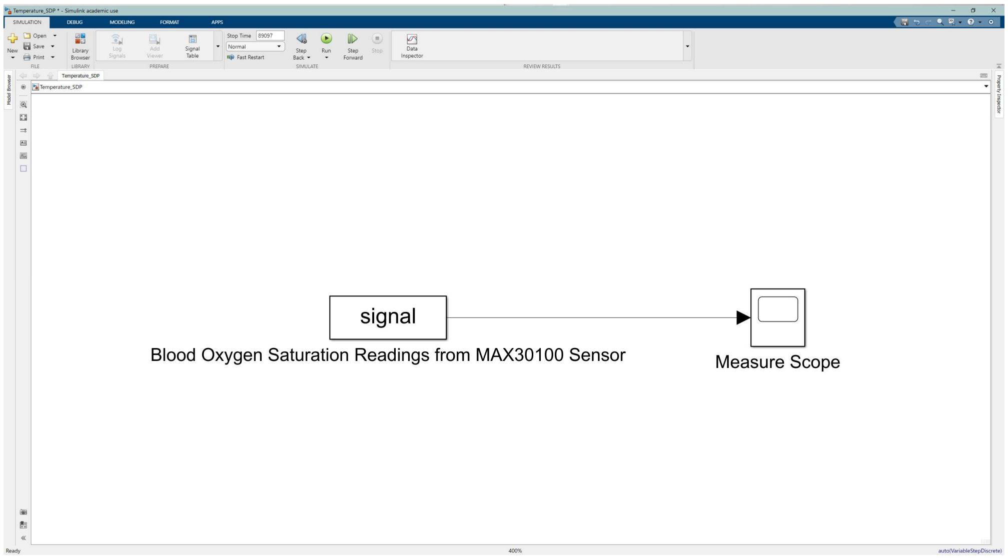

Figure 18 - Preview of Simulink Window for Blood Oxygen Saturation Sensor Measurement

Below in Figure 19, the output plot of the The plot represents the data of when the user places the sensor on their cheek and then removes it. As soon as the sensor is placed on the cheek, it takes approxiamtely 15000ms (15 seconds) before a reading is registered at approximately 94%. It takes approximately 7 seconds to stabilize to a reading of 98% for the next 12 seconds. At the 3.7 seconds mark, the user removes the sensor from their cheek and wears it again as soon as the sensor reaches 0 again after 0.3 seconds. It is observed that the sensor is able to output a reading again as soon as the user wears the mask again, however there is more oscillation for a longer time before it stabilizes. Finally as soon as the mask is removed, the sensor reverts back to 0.

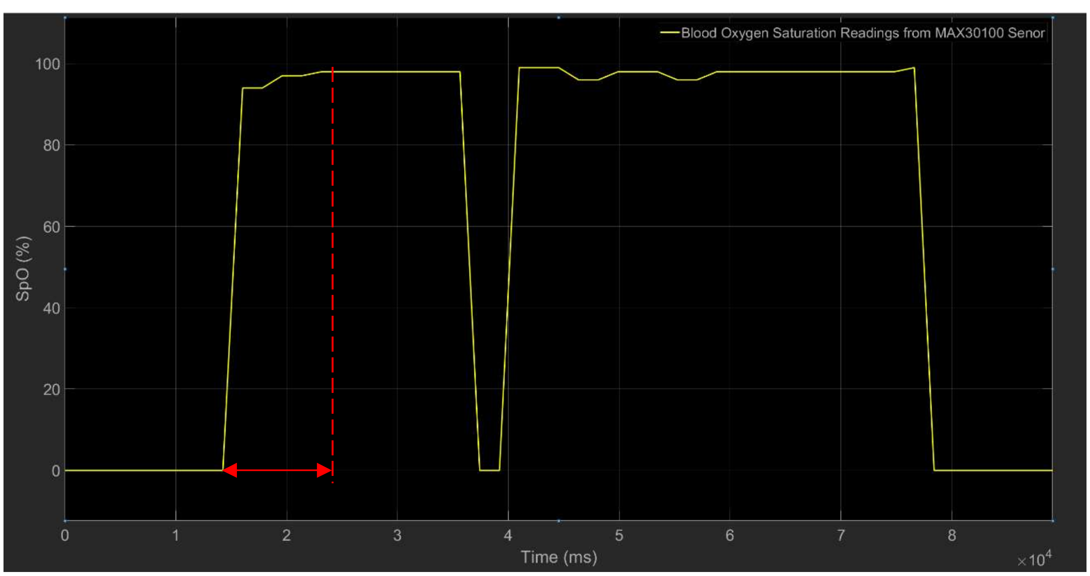

Figure 19 - Output Plot of Blood Oxygen Saturation Sensor Measurement

CHAPTER – 4 PRELIMINARY EVALUATION OF BASELINE DESIGN

4.1 TECHNICAL ASPECTS

The proposed baseline design of the SDVM mask comprises several technical aspects that cater towards the customers' requirements. Under this section, the system's various components will be observed in terms of how well they help satisfy these customer needs.

The SDVM mask is comprised of various sensors that need to be powered. When designing a product that requires power to operate and is to be used on a daily basis, one of the top priorities customers look for is efficiency, particularly in battery life [74]. When deciding on the power supply for the SDVM mask design, several options were observed in terms of size, cycle life, and commercial availability for replacement. Ultimately, the 4x1.5V Alkaline AAA batteries in a battery holder were chosen as the primary source of power. These batteries are advantageous because they last longer than other batteries, [75] which is beneficial for the customer regarding the mask being continuously used. In addition, should the batteries need to be replaced, the AAA batteries are low in cost and easily found in the market. In comparison to alkaline batteries, lithium batteries withstand harsh temperatures, are more suitable for high drain devices, and much lighter in weight. [76]

To have good performance, the SDVM mask uses fast measuring sensors, such as MAX30100, GY906, and the Infrared (PIR). The sensors are programmed to help the customer maintain social distancing and track vital signs on a regular basis. Meanwhile, the SDVM mask utilizes the BLE module for data communication with the customer's mobile phone, where the outputs of the sensors are displayed as information in a mobile application. The SDVM mobile application is a software application developed to run on smartphones and specifically on an Android operating system. The mobile application is user-friendly, easy to navigate, as well as visually appealing. The user can track his relevant data all day as long as he is wearing the mask, and easily check his vital sign without the need to visit the hospital. However, when social distancing is violated or abnormalities are detected by the vital signs' sensors, an alarm will be released to attract the user's attention. To provide a good user experience with the mobile application, the customer's need to interact with the app was considered. This happens when receiving a real-time warning if something goes wrong, for instance, if the user has broken the two-meter social distancing.

4.2 COST ANALYSIS

Cost analysis is one of the essential management tools in implementing a design project. It helps to decide if the project is sound, justifiable, and feasible by determining the budget of the prototype's components. Table 11 below represents a detailed estimation of the total cost of the proposed design. It specifies the required components to implement the prototype, the quantity needed, the price per unit, and any other expenses.

Table 11 - Total Cost Estimation

	Component	**Quantity**	**Cost/Unit**	**Total Price**
Hardware Components	Arduino Nano	2	SR59	SR118
	Bluetooth Module (HC-06)	1	SR52	SR52
	Infrared (PIR) Sensor	1	SR35	SR35
	Pulse Oximeter and Heart-Rate Sensor (MAX30100)	1	SR57	SR57
	Non-contact Infrared Temperature Sensor (GY906)	1	SR115	SR115
	Wires (Pack)	1	SR29	SR29
	Alkaline AAA Battery	4	SR5	SR20
	Cloth Mask (w/adjustable straps)	1	SR19	SR19
	Shipping Fees			SR39
Software	**Component**			**Total Price**
	Arduino IDE			Free
	MIT App Invertor			Free
Total Cost				SR484

The PDS specified that the total cost of production should not exceed SR600, and as shown in Table 11 above, the estimated cost of the project totals up to SR474, which falls under the constrained budget.

The most expensive components are the GY906 sensor, the Arduino Nano, and the MAX30100 sensor, as shown in Table 12. The market price of each of these components is listed in Table 12 below, and then the average price was estimated.

Table 12 - Market price

Component	Itqan Local Store	Amazon Global Market	Average Price
GY906	SR115	SR56.23	SR85.615
Arduino Nano	SR59	SR23.22	SR41.11
MAX30100 sensor	SR57	SR37.85	SR47.425

As could be noticed, the local store price for each component is comparatively higher than the global market price. Still, there are more factors to consider in the case of the global market, including shipment and import fees costs, the duration of the arrival time, which makes local stores more effective in implementing the project design.

During the ongoing pandemic, there is an increased use of face masks due to the significant role they play in preventing or reducing the spreading of COVID-19. The SDVM mask is designed to provide people with a mask that can detect social distancing and track their vital signs; therefore, turning the prototype into a commercial product would serve the common population, and by its feasible use and spike demand, it will affect and increase the local market profit and the global market as well since it is easy to operate, and its components are accessible nearly everywhere. Meanwhile, since the product is competitive in its field manufacturing it on the level of mass production will maximize its profit. Moreover, it would be very beneficial because the components would be bought in bulk at a lower cost, and it may provide higher customer satisfaction since its cost per unit is less, therefore the product could be sold at lower costs.

4.3 ENVIRONMENTAL IMPACT

Since coronavirus started, billions of masks are used each month globally, which the UN trade body, UNCTAD (United Nations Conference on Trade and Development), estimates will total some $166 billion in global sales this year [77]. The use of masks was without any restrictions on how to dispose of them safely, which may lead to an environmental crisis. Considering the plastic waste that can affect the ecosystems in the long term, and some animals can be killed either by the ingestion of plastic or entanglement. Accordingly, the SDVM design is made of a washable mask that can be recycled and used many times thus causing less harm to the environment.

Nevertheless, batteries represent one of the main components of the SDVM design that contain chemicals, thus improper disposal of batteries can be harmful on the environment. Improper disposal can lead to a release of corrosive liquids and dissolved metals that are considered as toxic exposition to animals and plants. Even if disposed of in landfill sites there are some possibilities that toxic materials can be released into groundwater. This has a direct effect on human health, according to the Agency for Toxic Substance & Disease Registry, as toxic metals found in batteries are known human carcinogens. Carcinogens are any substance, radiation, or radionuclide that acts as an agent that causes cancer [78]. Also, not only does the disposal topic need direct attention in environmental protection, but also the battery production that is associated with emitting carbon dioxide and other exhaust gas into the atmosphere, which will lead to climate change and global warming. But the good news is that nowadays the batteries are being recycled by reprocessing the crushed ones and manufacturing them to a new product, which the reclamation companies are responsible for. Some cities have dedicated household hazardous waste that accepts materials for safe disposal, which the customer may contact to recycle the wasted battery of the SDVM. For example: Arabian Plastic Compounds (APC) has a recycle program for electronic waste in Saudi Arabia.

4.4 IMPACT ON SOCIETY

The health sector in society is dealing with immense strain as a result of the COVID-19 pandemic. With critical cases of COVID-19 crowding local hospitals and intensive care units (ICU), many healthcare organizations all over the world have had to stop or cancel elective procedures to make room for the influx of patients. By assisting citizens in practicing proper social distancing, thus decreasing the spread of the COVID-19 virus, the proposed project will help decrease the load on the health sector.

There is also a concern in the health sector of health care workers contracting infections and spreading them amongst other patients. Some hospitals require their staff to make routine checkups more than once a day. The mask's vital signs monitoring function can be used in these scenarios to give healthcare workers a method for continuous checking of their vital signs to make the routine checkups more constant and time-efficient.

Many new challenges arose with the COVID-19 pandemic, but one of the most noticeable changes in everyday life is the mandating of wearing masks in public places. By introducing new features, the sense of the importance of the mask is increased and becomes a more valuable asset in day-to-day life. In addition, to get the full functionality of the SDVM mask, users will have to wear it properly on their faces, which could change the habit of some mask-wearers placing their masks below their noses or chins. Also, the social distancing aspect of the mask will change the perspective of distancing in a crowded area, giving citizens more confidence to go out and making public social lives possible even amidst a pandemic.

4.5 GLOBAL IMPACT

The proposed design aims to prevent the spread of the COVID-19 virus and any other airborne virus around the world by helping individuals in two ways. It will help users practice proper social distancing during a pandemic. In addition, it will allow the user to keep track of their health status and alert them in case of any abnormalities in their vital signs that could indicate that they are not safe to be in a public place. The global impact in the design is that by aiming to decrease the spread of the COVID-19 virus, the proposed system will help combat one of the modern world's biggest problems: the containment of the COVID-19 virus.

Furthermore, the design combines the functionalities of social distancing and vital signs monitoring in one system as a mask. This is a relatively new type of system that falls under the wearable devices category, a rising device technology. So, the proposed system encourages more innovation in this category.

Moreover, the social distancing function in the proposed project could help workers around the world maintain proper social distancing in their workplace and therefore do their normal day-to-day activities without worrying about spreading the virus among their co-workers. Alternatively, the vital signs monitoring function may reduce crowding in hospitals as it will allow people, who are undergoing periodic checkups for COVID-19 even if they do not have any symptoms, to keep track of their vital signs constantly and alert them in case of any abnormalities.

CHAPTER – 5 IMPLEMENTATION

5.1 VITAL SIGNS MONITORING

5.1.1 Oxygen Saturation Monitoring

To begin implementation, each sensor is first calibrated and tested alone before they are assembled. In the project design, MAX30100 Pulse Oximeter Sensor is responsible for monitoring Blood Oxygen. The sensor has two light emitting diodes: one is a red spectrum and the other one is infrared. Both the red and infrared lights are used by the sensor to measure oxygen levels in the blood. To read the sensor’s measured data, MAX30100 is related to Arduino Nano as the following: First, to power the sensor, its input voltage pin (VIN) is connected to the 5v pin in the Arduino and the GND pin to the GND. Then, to allow serial communication between the sensor and the Arduino the pins SCL & SDA of MAX30100 are connected to pins A5 & A4 of Arduino, respectively. The connection is illustrated in Table 13 and Figure 20 below.

Table 13 - MAX30100 and Arduino Nano connection pins

MAX30100	Arduino Nano
VIN	5V
SCL	A5
SDA	A4
INT	D2
GND	GND

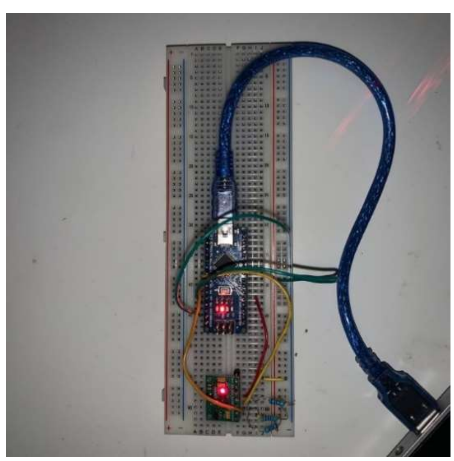

Figure 20 - MAX30100 Circuit Connection

While trying to interface the MAX30100 sensor with the Arduino, the sensor didn't work, and its light didn't turn on. By referring to the sensor datasheet and some online resources, it has been found that the sensor has a serious design problem. The MAX30100 IC uses 1.8V for VDD and this particular module uses two regulators to achieve this voltage. However, referring to the internal connection of the sensor in the datasheet, the SCL and SDA pins are pulled-up via the 4.7k ohm resistors to 1.8V. Which means that it won't work well with microcontrollers with higher logic levels. The problem could be solved in two methods. The first method is to remove the internal resistors from the board and attach external 4.7k ohm resistors to SDA, SCL and INT Pin instead. The second method is to cut the path in the place of the Red Cross and make a jumper as shown by the yellow line in Figure 21 below [79] .

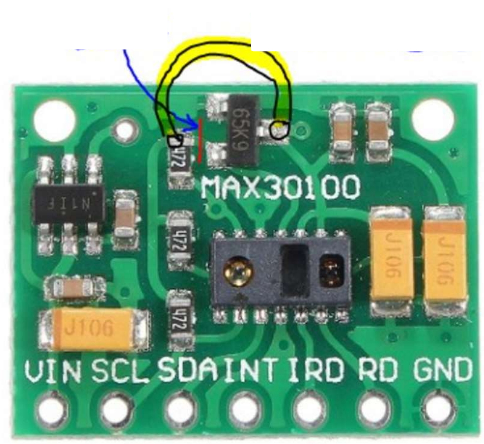

Figure 21 - MAX30100 Trouble Shooting

After finishing the connection, the code shown in Figure 22 below was used for interfacing the Arduino with MAX30100. First, the required library MAX30100 was downloaded and included in the code. The line PulseOximeter pox was used to initialize the PulseOximeter instance. And then, the setup block was used for the purpose of preparation. It is the first to be executed in the code and it is basically used to initialize and start the serial communication. The pox.setIRLedCurrent(MAX30100_LED_CURR_7_6MA); line sets the current through the infrared LED. After the setup block is executed, the loop block runs next. The loop block hosts the line pox.update(); which is used to update the sensor readings, the block also hosts the required statements to display the measured output repeatedly. Sample of the measured Output is shown in Figure 23.

```
#include <Wire.h>
#include "MAX30100_PulseOximeter.h"

#define REPORTING_PERIOD_MS     1000

PulseOximeter pox;
uint32_t tsLastReport = 0;


void setup()
{
  Serial.begin(115200);
  Serial.print("Initializing pulse oximeter..");

  if (!pox.begin()) {
    Serial.println("FAILED");
    for (;;);
  }
  else {
    Serial.println("SUCCESS");
  }
  pox.setIRLedCurrent(MAX30100_LED_CURR_7_6MA);
}

void loop()
{
  // Make sure to call update as fast as possible
  pox.update();
  if (millis() - tsLastReport > REPORTING_PERIOD_MS) {

    Serial.print("SpO2: ");
    Serial.print(pox.getSpO2());
    Serial.println("%");

    tsLastReport = millis();

  }
}
```

Figure 22 - MAX30100 Arduino Code

```
-> Initializing pulse oximeter..SUCCESS
-> SpO2: 0%
-> SpO2: 0%
-> SpO2: 0%
-> SpO2: 82%
-> SpO2: 82%
-> SpO2: 82%
-> SpO2: 95%
-> SpO2: 95%
-> SpO2: 96%
-> SpO2: 96%
-> SpO2: 96%
-> SpO2: 96%
-> SpO2: 96%
-> SpO2: 95%
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-> SpO2: 96%
-> SpO2: 96%
-> SpO2: 96%
-> SpO2: 96%
-> SpO2: 96%
-> SpO2: 96%
-> SpO2: 96%
```

Figure 23 - Sample Output of the Oxygen Saturation for the MAX30100 Sensor

5.1.2 Temperature Monitoring

For the GY906 temperature sensor, which is the sensor responsible for temperature measurement, the first trial included making sure that the sensor was picking up readings from its surroundings. The sensor pins are first soldered on each terminal of the sensor and then connected directly to the Arduino. The testing circuit, shown below in Figure 24 and Table 14, shows the connections.

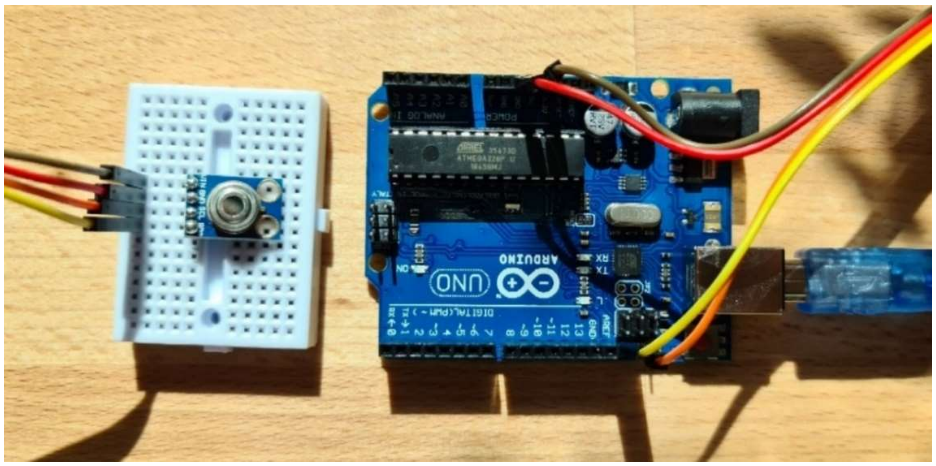

Figure 24 - Testing Circuit for GY906 Sensor with Arduino Uno

Table 14 - GY906 and Arduino Uno connection pins

GY906	Arduino Uno
VIN	3.3V
SCL	SCL
SDA	SDA
GND	GND

For testing purposes, the Arduino Uno was used as it was the only one readily available to the member performing the tests for the GY906 sensor. The Arduino Uno has the same terminals/pins, required for testing the sensor, as the Arduino Nano. The ADAFRUIT library is installed and included on the Arduino software, which is then used to program the sensor to give temperature readings onto the output terminal from the compiler. The temperature readings include the object radiating ultrasound waves directly in the sensor's line-of-sight, which in the case of the SDVM mask will be the user's cheek, and the ambient temperature, which is the temperature of the air around the sensor itself. The ambient temperature is useful only for diagnostic purposes, in the case of this design, only the object temperature is observed. The Figure 25 below shows the Arduino code to program the sensor.

```
temperatureTest §
#include <Wire.h>
#include <Adafruit_MLX90614.h>

Adafruit_MLX90614 mlx = Adafruit_MLX90614();

void setup() {
  Serial.begin(9600);

  Serial.println("GY906 test");

  mlx.begin();
}

void loop() {
  Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempC());
  Serial.print("*C\tObject = "); Serial.print(mlx.readObjectTempC()); Serial.println("*C");
  Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempF());
  Serial.print("*F\tObject = "); Serial.print(mlx.readObjectTempF()); Serial.println("*F");

  Serial.println();
  delay(500);
}
```

Figure 25 - Arduino Code to Test GY906 Temperature Sensor for Trial 1

Trial 1

The code was programmed to give a reading every 0.5 seconds. Below in Figure 26, examples of the outputs are shown. The first red block shows the reading when no object is directly in front of the sensor. The outputs show an average reading of 24.49℃, which is lower than the ambient temperature of an average of 25.6℃, indicating that there is no object directly in front of the sensor. In the second red block, an object (users' cheek) is placed directly in front of the sensor and gives an average reading of 33.3℃. In comparison, the test on the same object but using a digital thermometer gives a reading of 34.1℃. The digital thermometer is the most commonly used instrument to measure body temperature and is found in most households. The accuracy of digital thermometers is frequently indicated to be ±0.3℃. [80] [81] The difference is less than 1℃ but is not as up to par to the sensor's accuracy of ±0.5℃ [82]. Changes to the code will be made to remedy the inaccuracy for the purpose of the design's application. Finally, the final red block shows the readings returning back to the original temperature of an average of 23.47℃ after the object is removed from in front of the sensor.

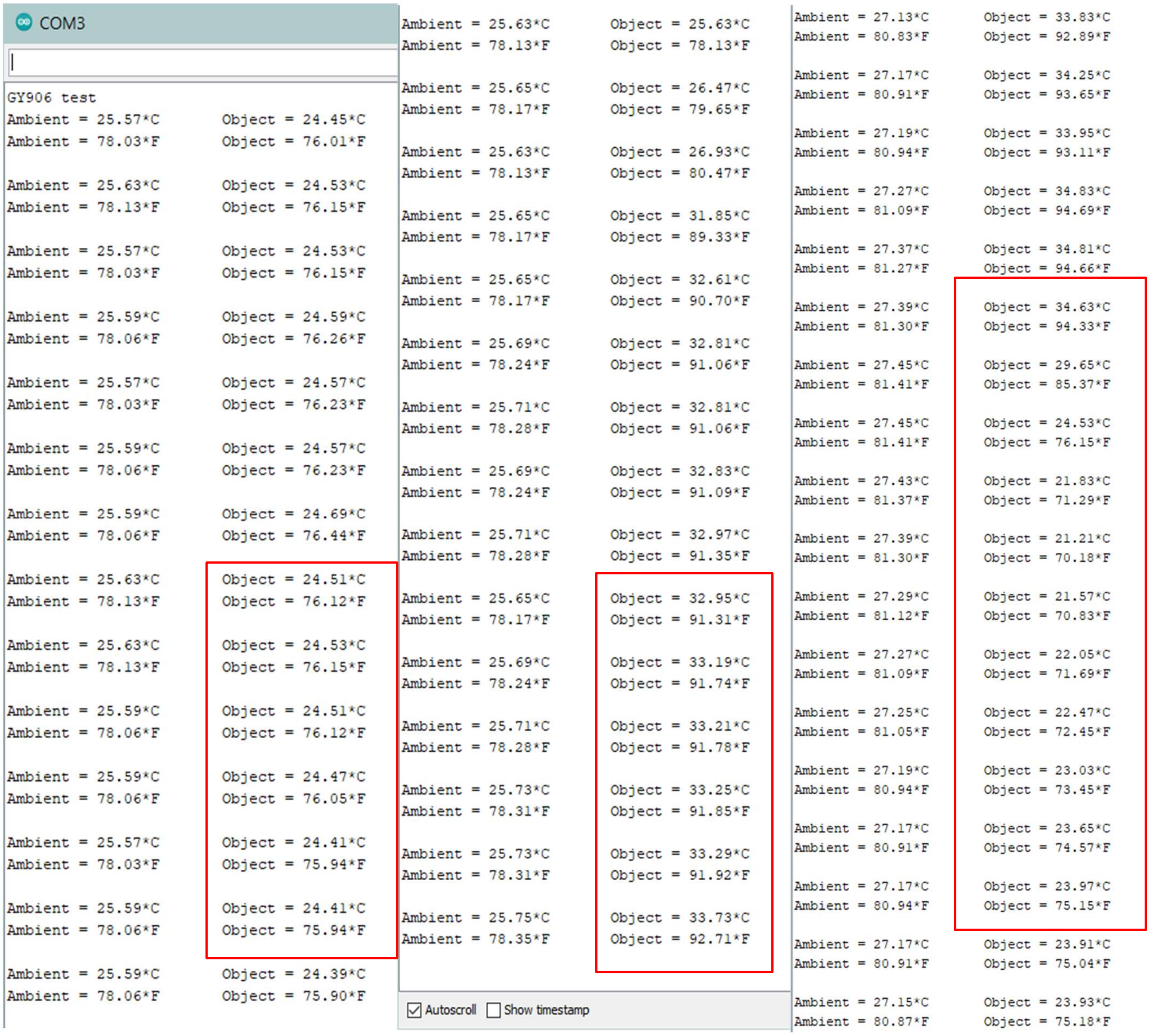

Figure 26 - Sample Temperature Readings for Trial 1

Trial 2

To remedy the inaccuracy shown in trial 1, the delay between each measured reading is changed from 0.5 seconds to 0.1 seconds by changing the last line of the code from delay (500) to delay (100) as shown in Figure 27 below. This gives more readings in one second. In trial 1, the code was giving 120 readings in one second, while in trial 2, the new code gave 600 readings in one second. This decreases the chances of uncertainties.


```
#include <Wire.h>
#include <Adafruit_MLX90614.h>

Adafruit_MLX90614 mlx = Adafruit_MLX90614();

void setup() {
  Serial.begin(9600);

  Serial.println("GY906 test");

  mlx.begin();
}

void loop() {
  Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempC());
  Serial.print("*C\tObject = "); Serial.print(mlx.readObjectTempC()); Serial.println("*C");
  Serial.print("Ambient = "); Serial.print(mlx.readAmbientTempF());
  Serial.print("*F\tObject = "); Serial.print(mlx.readObjectTempF()); Serial.println("*F");

  Serial.println();
  delay(100);
}
```

Figure 27 - Arduino Code to Test GY906 Temperature Sensor for Trial 2

The output in the serial monitor of the new code is shown below in Figure 28. The first screenshot shows the readings when no object is present in front of the object, not much difference will be observed here between trial 1 and trial 2. However, in the second screenshot we can observe the readings when the object (the users' cheek) is directly in front of the sensor. The readings now have an average of 33.36℃ and are compared to the temperature taken from the cheek using a digital thermometer, which is 33.4℃. We now observe an accuracy of 0.04℃, which is an improvement from trial 1. Finally, the last screenshot shows the readings when the object is removed from in front of the sensor. The temperature returns back to the temperature close to the ambient temperature.

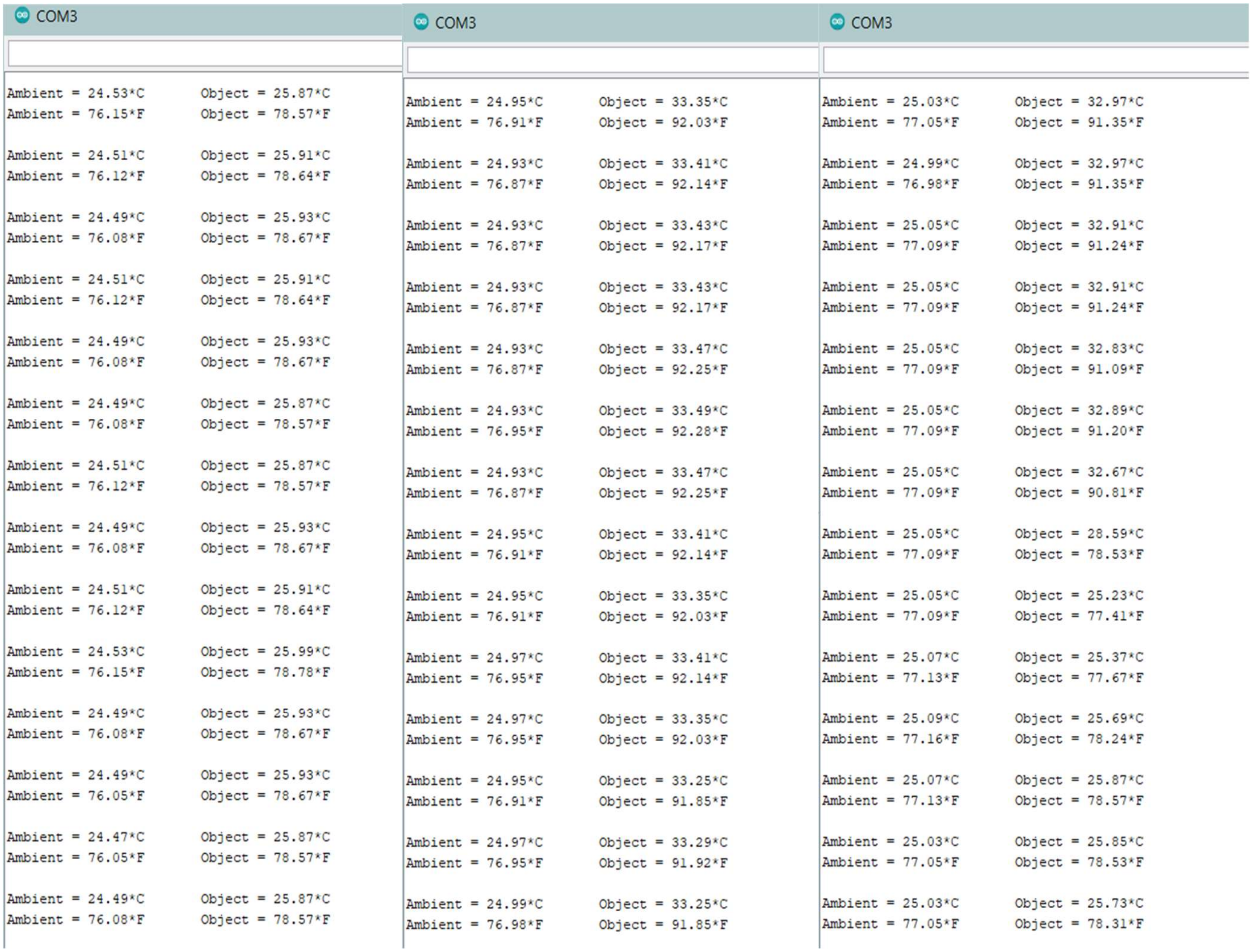

Figure 28 - Sample Temperature Readings for Trial 2

5.2 SOCIAL DISTANCING

In order to test if the PIR sensor detects motions, it was tested with an Arduino Nano. First, the VCC pin of the PIR is connected to the 5V pin of the Arduino Nano. Second, OUT pin of PIR is connected to D2 of the Arduino and then GND is connected to the Ground pin of the Arduino. Also, a LED has been used along with a 220Ω resistor to light up when the PIR sensor detects a motion. The LED is connected along with 220Ω resistor to pin D13 of the Arduino. Then, the Arduino software has been installed to upload the code that will be used to test the PIR sensor. Figure 29 and Figure 30 show the connection of the circuit and the Arduino code to test the PIR sensor, and the connection between PIR and Arduino Nano are summarized in Table 15.

Table 15 - PIR with Arduino Nano connection

PIR	Arduino Nano
VCC	5V
OUT	D2
GND	GND

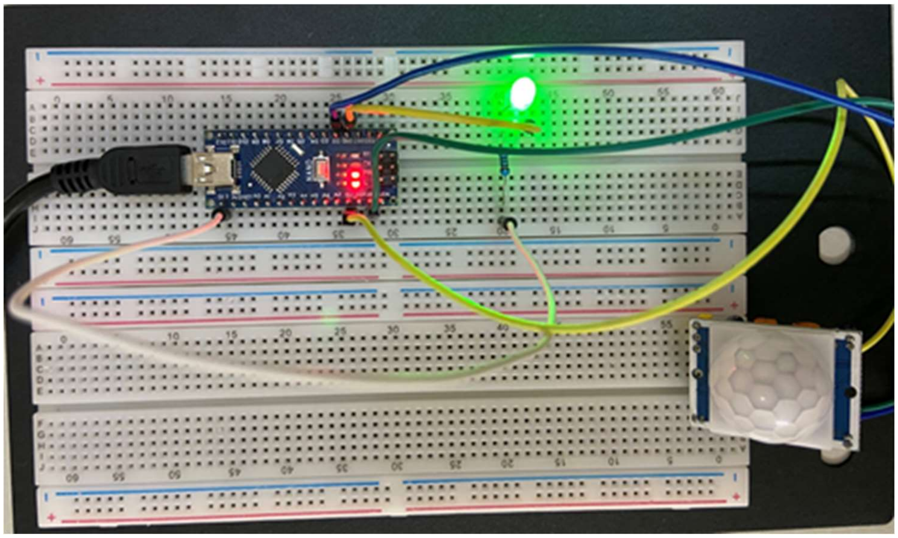

Figure 29 - Circuit Connection to Test PIR Sensor

File Edit Sketch Tools Help

PIR1 §

```
int LED = 13;              // the pin that the LED is attached to
int PIR = 2;               // the pin that the sensor is attached to

void setup() {
  pinMode(LED, OUTPUT);    // initalize LED as an output
  pinMode(PIR, INPUT);     // initialize sensor as an input
  Serial.begin(9600);      // initialize serial
}

void loop(){
  if (digitalRead(PIR) == HIGH) { // check if the sensor is HIGH
    digitalWrite(LED, HIGH);      // turn LED ON
    Serial.println("Motion detected!");
    delay(100);                   // delay 100 milliseconds
  }
  else {
    digitalWrite(LED, LOW);       // turn LED OFF
    Serial.println("Motion stopped!");
    delay(100);                   // delay 100 milliseconds
  }
}
```

Figure 30 - Arduino Code to Test PIR Sensor

The code was successfully compiled and uploaded on the Arduino Nano. Figure 31 and Figure 32 show the output on the Serial Monitor every 0.1 second when the sensor detects the presence of motion in less than 2 meters around it and the output when there is no motion in less than 2 meters of the sensor.

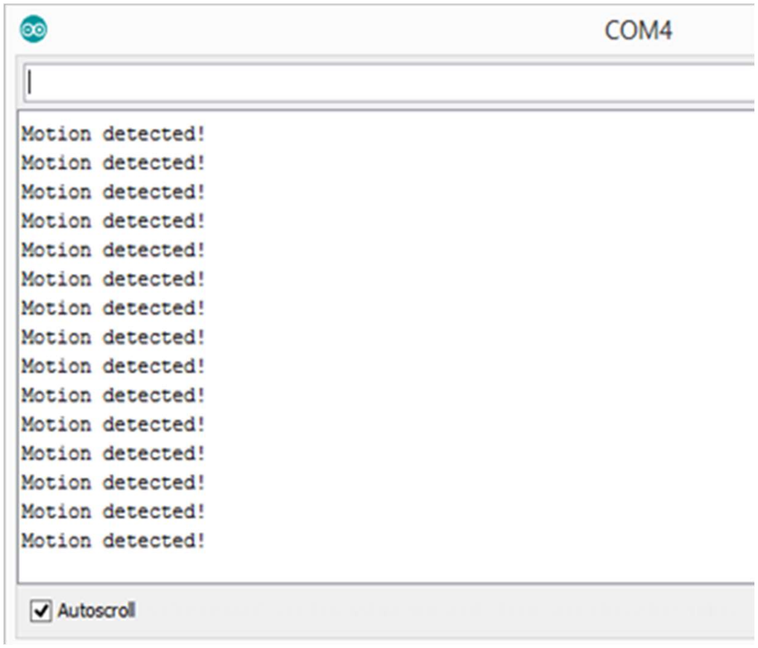

Figure 31 - Output of Code when Motion is Detected

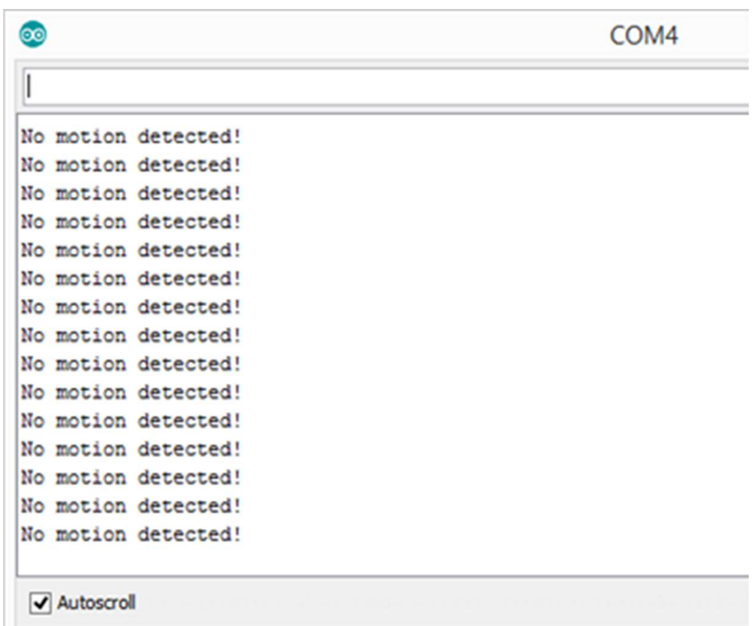

Figure 32 - Output of Code when No Motion Detected

After testing the mask, it was noticed that the PIR sensor can detect up to 7 meter, which will be a hindrance for the user's to detect motion even if it's not violating the social distancing. So, the sensitivity in the PIR was adjusted as shown in Figure 33 by moving the sensitivity adjustment clockwise to decrease the distance that should be detected by the PIR.

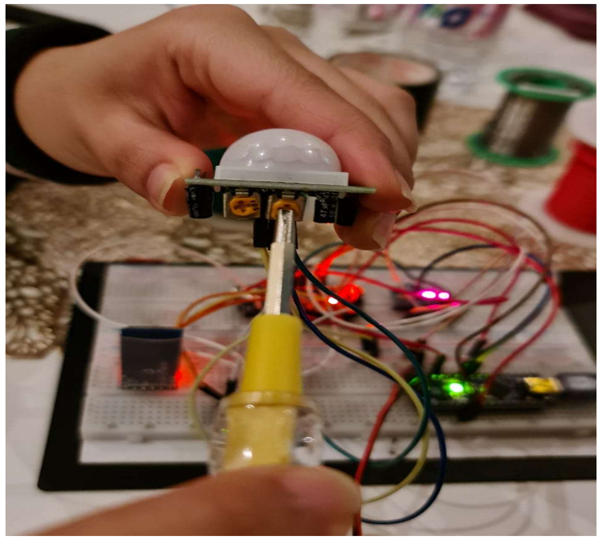

Figure 33 - Adjusting Sensitivity

Moreover, the team also noticed that the PIR is High once motion is detected and stays High for the time set by the potentiometer, and any movement during will not be detected or processed. Figure 34 shows two different results based on changing the potentiometer, which is the time delay adjustment in the PIR itself. The left output was based on adjusting it clockwise that will increase the time delay and stay high for longer time, than changing it anticlockwise as shown in the right side, which will make the High output stay for less time.

```
01:27:58.921 -> 0
01:28:00.959 -> 0
01:28:02.949 -> 1
01:28:04.980 -> 1
01:28:06.974 -> 0
01:28:09.000 -> 0
01:28:11.031 -> 0
```

```
01:28:47.237 -> 0
01:28:49.229 -> 1
01:28:51.257 -> 1
01:28:53.251 -> 0
01:28:55.258 -> 0
01:28:57.283 -> 0
01:28:59.275 -> 1
01:29:01.305 -> 0
01:29:03.333 -> 0
01:29:05.356 -> 0
01:29:07.351 -> 0
01:29:09.350 -> 0
01:29:11.387 -> 0
01:29:13.375 -> 1
01:29:15.411 -> 0
01:29:17.409 -> 0
```

Figure 34 - PIR Testing in Arduino Application

5.3 SYSTEM-USER COMMUNICATION

5.3.1 Bluetooth Module

Bluetooth Low Energy (BLE) is a low power wireless communication technology that can be used over a short distance to enable smart devices to communicate [83]. HC-06 is used as a Bluetooth module. The connections between Nano Arduino and HC-06 are shown below in Figure 35 and then summarized in Table 16.

Table 16 - HC-06 and Arduino Nano connection pins

HC-06	Arduino Nano
VIN	5V
TX	D2
RX	D3
GND	GND

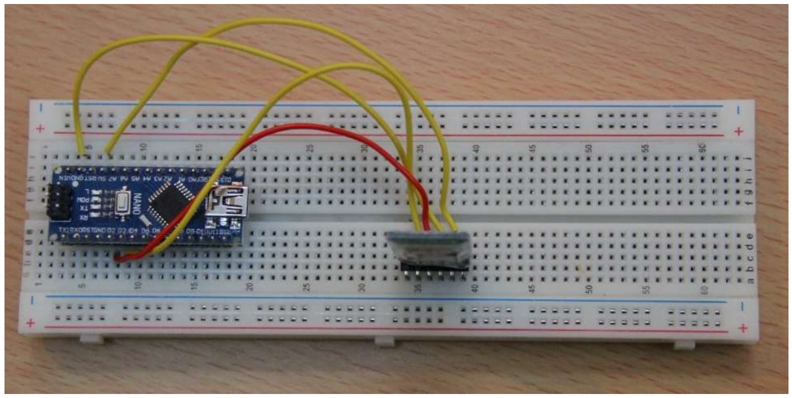

Figure 35 - Hardware Connection for HC-06 Circuit

To start communicating and transferring data, the code was uploaded using the Arduino that is installed earlier. The first challenge in the HC-06 implementation is that the Arduino Nano USB was not recognized, so there was a problem in uploading the code. However, after searching for ways online to achieve that, program CH340/CH341 was installed to help in the USB recognition, and then the code compiled and successfully applied on Nano Arduino in order to communicate with the Bluetooth module as shown in Figure 36.

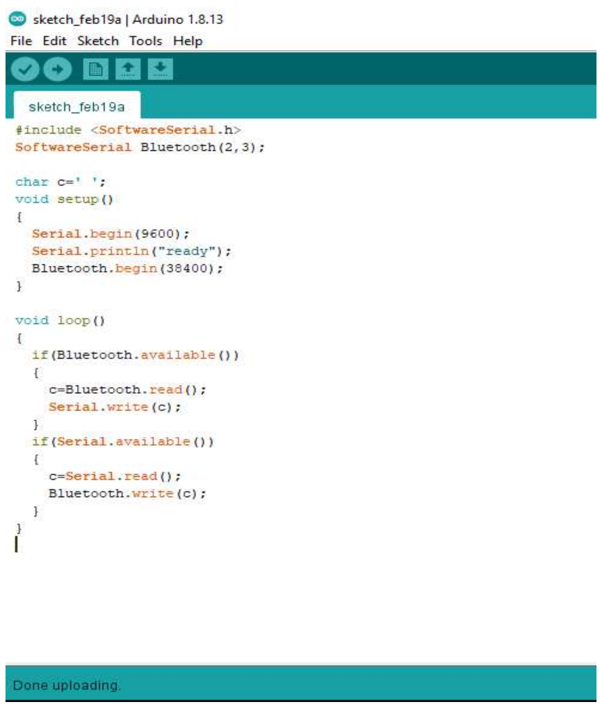

Figure 36 - The Code to Communicate with HC-06 is Uploaded Successfully

After opening the Serial Monitor as shown in Figure 37 below, “ready” message was shown to establish that Arduino is ready for communication at COM3 port. The transfer baud rate is 9600 by default, which is the data rate in bits per second (baud) for serial data transmission. Both NL & CR (New Line and Carriage Return) options were selected, which represent the ending characters appended to data sent to Arduino.

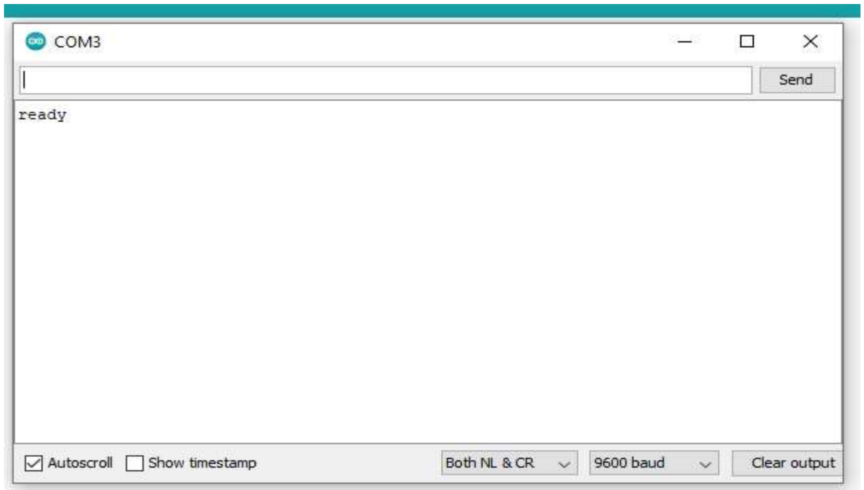

Figure 37 - Serial monitor window

AT commands mode is used to change the default settings of the Bluetooth module, like changing the device’s name, password, and role. The stranded pairing mode was on once the power source was plugged in using USB to connect it with the power source and to apply the code using the Arduino IDE. However, to enter the AT mode, the power source needs to be plugged in while holding down the reset button until noticing the HC-06 is blinking every 2 seconds as shown in Figure 38 instead of blinking rapidly, which demonstrates the AT mode of the module.

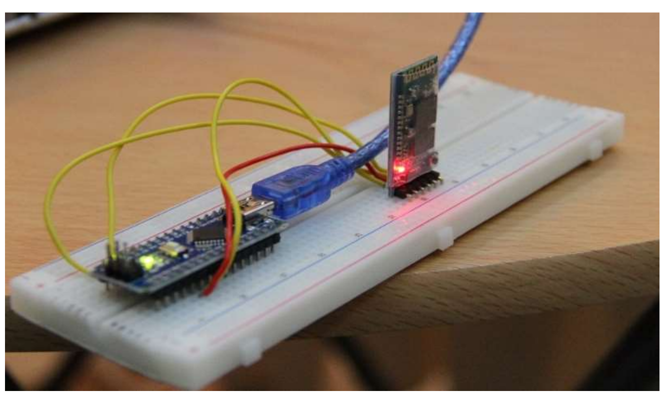

Figure 38 - Powering the Circuit Hardware

Figure 39 shows the response from HC-06 to Arduino Nano based on the AT command set that is shown in Table 17.

Table 17 - Detailed description of AT command

Command	Description of Command	Response	Parameter
AT	Test	OK	None
AT+UART?	Inquire Serial Parameter	+UART: Parameter 1,Parameter2, Parameter 3 OK	Param : baud rate(bits/s)=9600
AT+PSWD= 2020	Set Passkey	OK	Param: 2020 ”PASSKEY” Default: “1234”
At+PSWD?	Inquire Passkey	+PSWD:2020 OK	

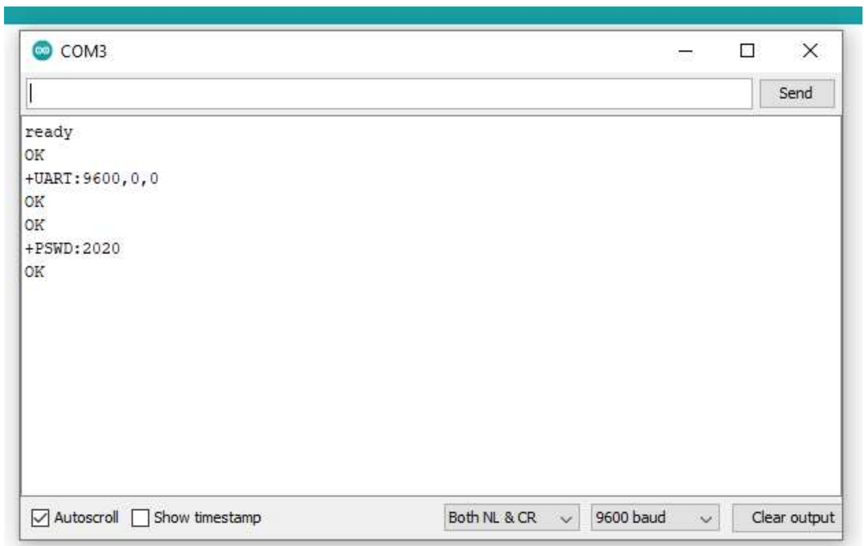

Figure 39 - HC-06 Responses on AT Commands

5.3.2 Mobile Phone Application

To build the mobile application that will receive the readings from the Bluetooth module and send alerts to the user, the MIT app inventor website is used. The MIT app inventor is a programming environment that allows anyone to build fully functional apps for smartphone or tablets in the form of a blocks-based tooling. For its ease-of-use it has been used to make the mobile phone application of the prototype. The homepage interface of the website is shown in Figure 40 below.

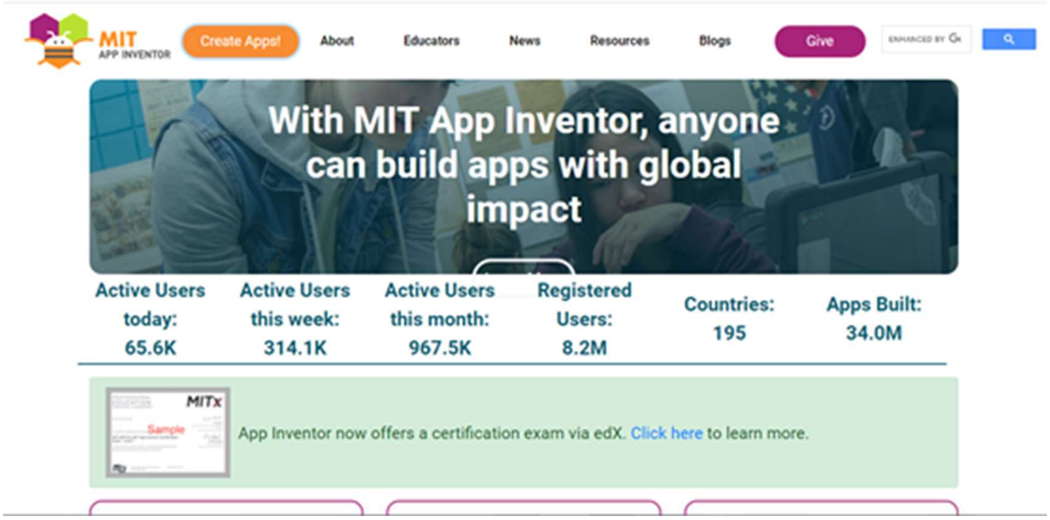

Figure 40 - The MIT App Inventor Website Interface [84]

As soon as the website is opened, there is an option at the top left corner (*Create Apps*) that will allow the designer to start creating the application, Figure 41 below shows the page that opens after clicking on *Create Apps*.

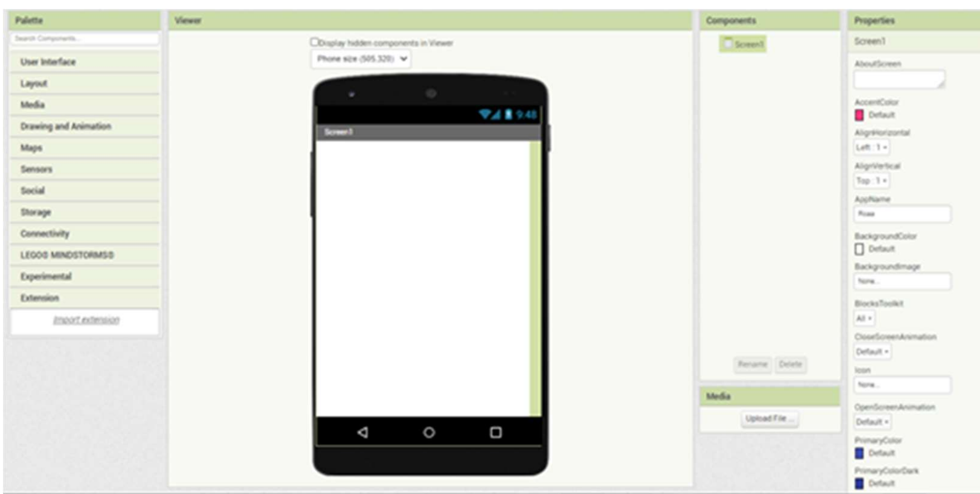

Figure 41 - The Interface After Clicking on *Create Apps*.

This page provides many options to build an application like user interface, layout, media, maps, sensors, connectivity, etc. Each of these options includes more detailed options. Starting with the user interface, a button for the Bluetooth has been added at the top of the screen by dragging and dropping the button component as shown in Figure 42. Also, a total of seven labels have been used: one for the Bluetooth button and the other six for the sensors and their reads.

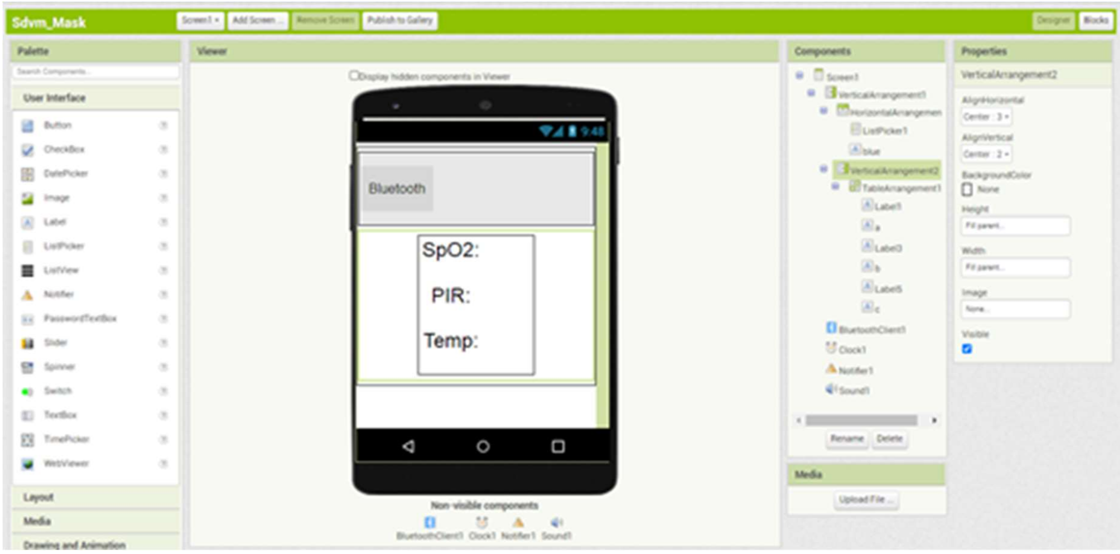

Figure 42 - Creating the Interface of the SDVM mask.

For the layout, vertical and horizontal arrangement options were used to arrange the overall design of the application. Then, the table arrangement option was used to arrange the sensors labels and their readings in tabular form. For the media option, the sound was added as a property inside the App, but it will be hidden in the application interface. From the connectivity selection, the Bluetooth client button was added to allow the user to choose from several options of the Bluetooth that are already connected to the user's mobile phone. Also, a clock has been added from sensors option to make the code runs continuously.

By clicking on the *Blocks* button that is in the top right corner, the website will open the page that will enable the application designer to start writing the code. First, the code for Bluetooth button has been written as shown in Figure 43. The first part of the code will allow the user to pick the Bluetooth that will be connected to the App from a list of Bluetooth names that are already connected to the mobile phone. Then, the second part will connect the App to the Bluetooth module selected by the user. The last sentence in the Bluetooth code below will make the Bluetooth button in the App invisible after it connects to the Bluetooth module chosen by the user.

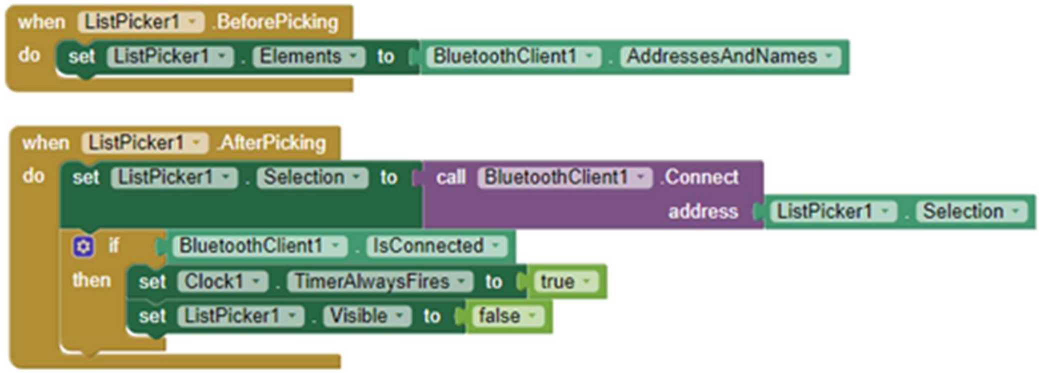

Figure 43 - The Bluetooth Button Code.

The other part of the code is *Clock1* which contains the (for loops) that will repeat the code continuously. The first condition added in this part is to check the connectivity of the App with Bluetooth. If there is a Bluetooth device connected to the App, the code will continue to run the other loops, and if there is not, it will close all the loops. The second loop will check the readings received from the Bluetooth module. If the readings are greater than zero, they will be accepted, otherwise, they will not be accepted. After receiving the readings, they will be saved as a line of inputs in the *global input* block. Then, the *global sdp* block is used to separate them into three readings by creating a list for them. Figure 44 and Figure 45 show the overall architecture of the Clock1 code.

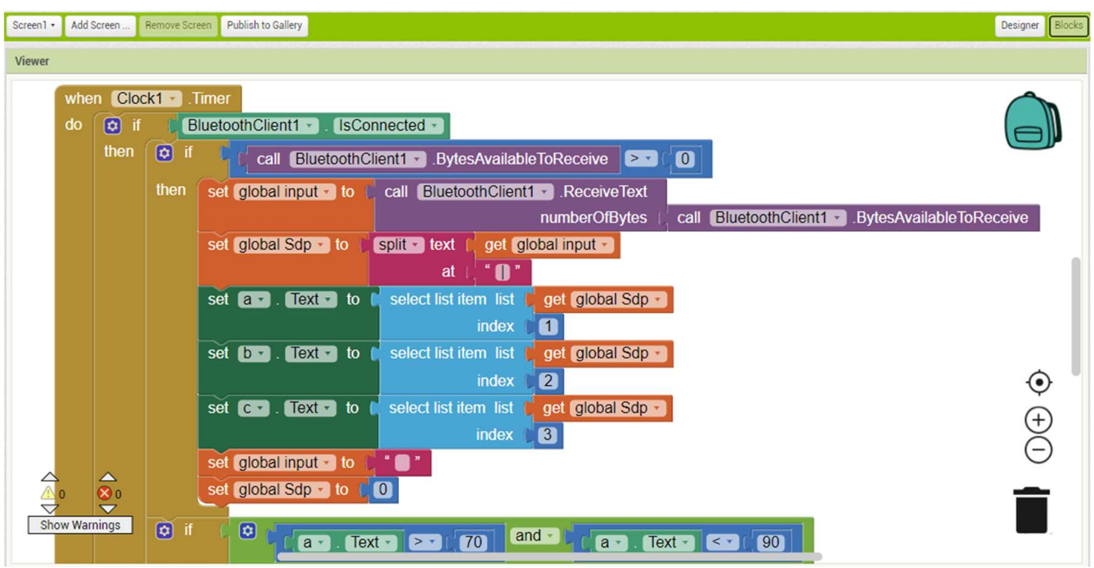

Figure 44 - The Clock1 Code.

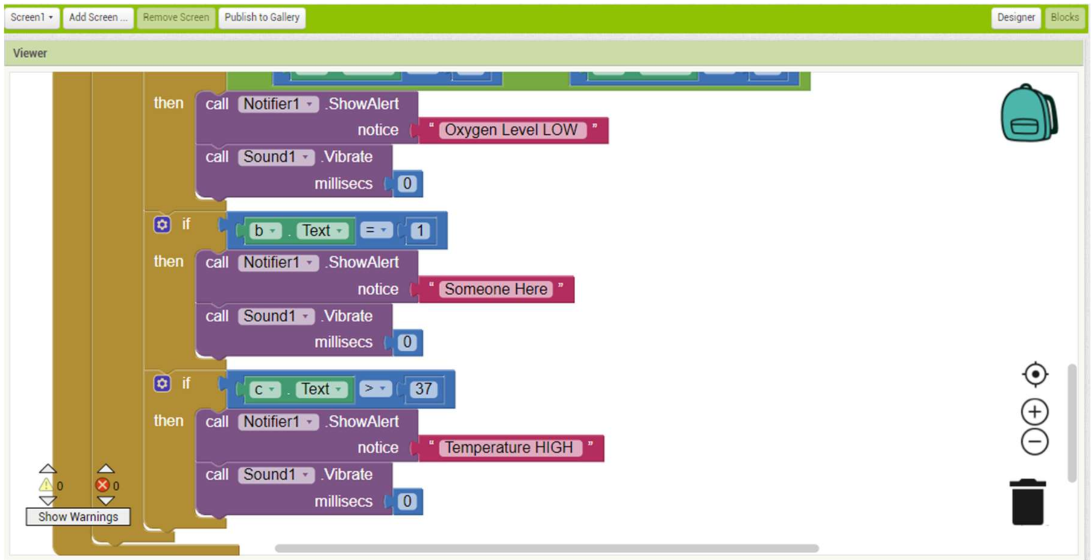

Figure 45 - The Clock1 Code (*continued*)

Figure 46 below shows the final user interface of the mobile phone application for the prototype. The leftmost image shows the interface as soon as the application is opened. Once the user clicks the *Bluetooth* button, they will be met with the interface shown in the middle screenshot. The list shows all the Bluetooth devices the mobile phone is paired to, the user will click on the HC-06 device to connect to the Bluetooth module of the mask prototype. Finally, the right most screenshot shows a sample output once the user is wearing the mask.

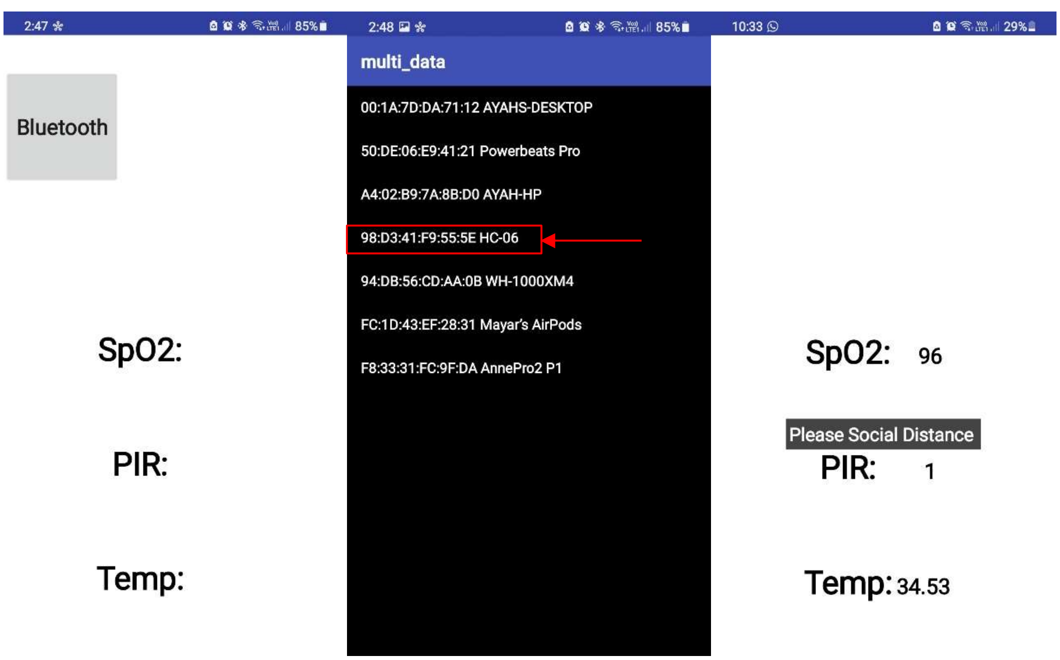

Figure 46 – Mobile Phone Application Final Interface

5.3 FINAL PRODUCT

The proposed system continuously monitors the user's vital signs such as: body temperature and blood oxygen saturation (SPO2), it also detects motions. Furthermore, based on the vital signs readings it is able to indicate whether the user is displaying COVID-19 symptoms, and should therefore get tested and self-quarantine. This feature could also be used for any airborne infectious virus that causes fever. It also helpful for health professionals that deal with critical care patients that are sensitive to infectious viruses and require their attendants to constantly monitor their own vital signs as to not spread it to their patients. The system provides precautionary measures by detecting motions to help the user adhere to social distancing, this could serve to continuously remind the users in cases where they violate social distancing that they should pay attention.

Figure 47 shows the hardware prototype, which is a mask to be worn by the user. In addition, the functions mentioned above will be integrated in the prototype to work simultaneously. The final product of the SDVM design has a PIR (Passive infrared sensor) that allows to sense motion within a specific maximum range, which is 2 meters, and angle (<120) [85]. PIR is located at the front of the mask to be facing the visual range of the user as shown below in Figure 47.

Figure 47 - The SDVM Design

Figure 48 shows the front view of the SDVM design that will be facing the user's face after removing the front cloth. The front cloth is made to protect the user's skin from the sensors pins and to make the mask neater. Under the front cloth, non-contact temperature sensor (GY-906) will be found on the left, while the oxygen sensor (MAX30100) that detect the pulse oximetry signals is located on the right. Both sensors are placed on cloth layer that is attached to the mask through Sew-On Snaps and to the back of the mask within a detachable string.

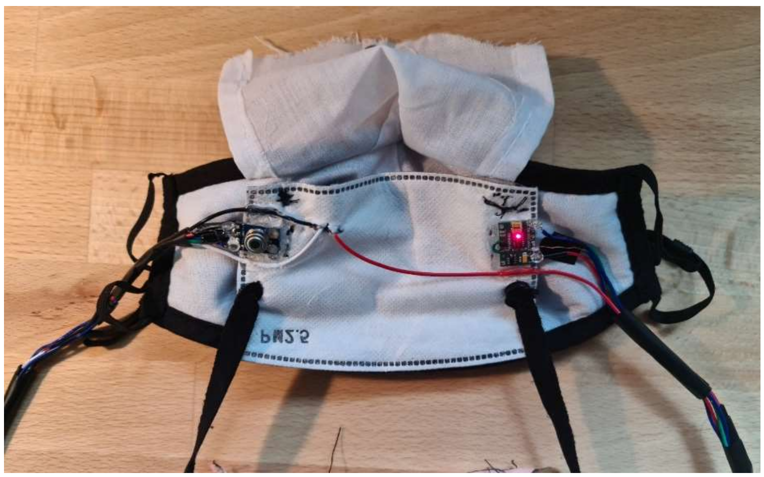

Figure 48 -The Front View of the SDVM Design Exposed

Figure 49 shows the back view of the SDVM design that has the Bluetooth module for transmitting data to the mobile phone application, two Arduinos to operate the logical operation and communicate with the Bluetooth module, and the 6V Batteries in their holder to power the system. One of the Arduinos is connected to the MAX30100 sensor, while the other Arduino is connected to PIR, Bluetooth, GY-906, and the batteries. The two Arduinos are connected together in more than one instance and this can be viewed in more detail in the circuit schematic under section 3.2.1 Circuit schematic. Moreover, the back part of the mask can be hidden within an extra cloth material and the detachable strings are connecting the electrical part with the cloth mask that can be detached to make the mask washable.

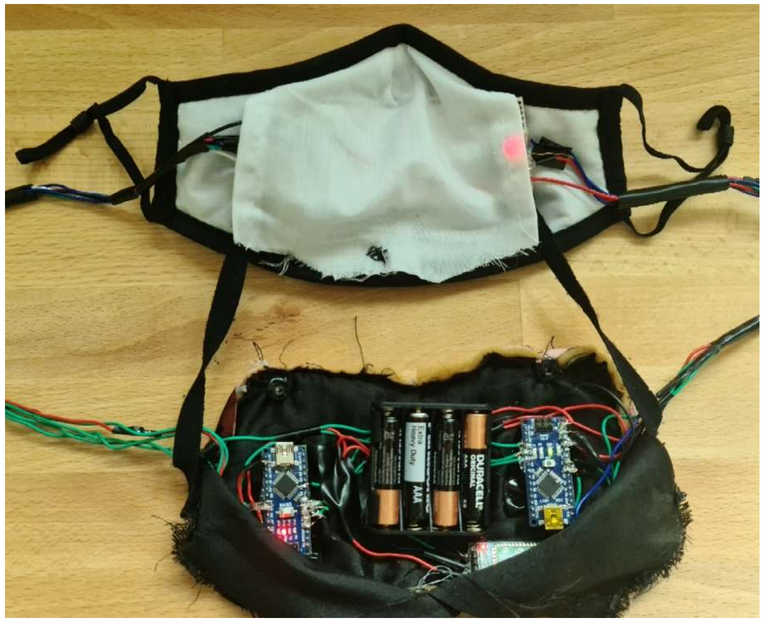

Figure 49 - The Back View of the SDVM Design Exposed

Once the prototype is activated and connected to the user's smartphone by Bluetooth, many actions will take place simultaneously. The Arduinos will collect information from the temperature sensor, oxygen sensor, and PIR to preform logical operations. At the same time, they will be transmitting data to the Bluetooth module. Based on the logical operation, notifications will appear in the application if there are some abnormalities in the data, for example: if body's temperature >37. The final prototype was tested to be working with the sensors able to measure readings even through the front cloth piece without any difference in readings with or without the front cloth piece.

Below in Figure 50, there are three sample outputs of the possible alerts the user might get. The first screenshot of the application shows the alert if the users oxygen level is low. While the second screenshot shows the alert when the user's temperature is too high (>37). Finally, the last screenshot shows when the user is not practicing social distancing and gives them an alert to place some space between himself/herself and the people around him.

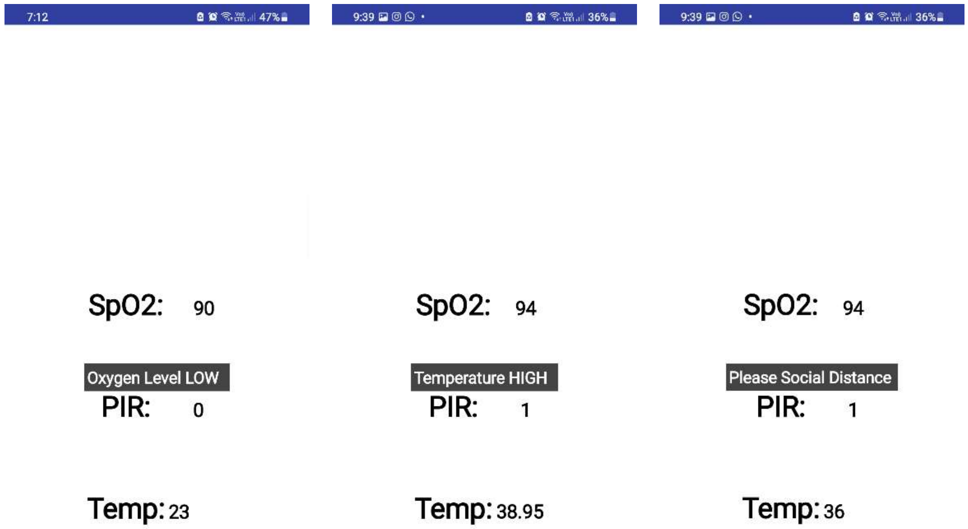

Figure 50 - Sample Outputs from Application

CHAPTER – 6 RESULTS, DISCUSSION, AND CONCLUSIONS

6.1 RESULTS AND DISCUSSION

In order to ensure an effective implementation, test analysis and identifying test conditions were made. Test analysis gives a generic idea for a large range of possibilities. Each subsystem of the product was conducted as per validation procedures found in Appendix A. This section will discuss the results obtained after testing the whole prototype. In addition, experimental uncertainties, and possible sources of error of some of the tests were addressed. The testing procedure was conducted on 5 different healthy volunteers (age range 12-45 years) to evaluate the effectiveness of the mask, so body's temperature, and oxygen saturation were measured.

6.1.1 Temperature Sensor Readings

As could be seen in Table 18, the reading of body temperature for each person was measured by using the MLX90614 sensor and a thermometer. The difference between the readings is significantly small which indicates that the MLX90614 sensor gave accurate measurements.

Table 18 – Body temperature measurement results using the MLX90614 sensor

Test Subject	Age	MLX90614 Body Temperature (C)	Thermometer (C)	Difference
Person 1	22	36.55	37.05	0.5
Person 2	45	34.91	35.04	0.13
Person 3	24	35.33	35.45	0.12
Person 4	18	35.67	35.74	0.07
Person 5	12	35.73	36	0.27

The graph in Figure 51 shows the temperature readings for each test subject over a time period of 10 seconds. By observing the plot and Table 18, it can be concluded that age does not factor into how the sensor takes measurements. There are also only slight variations in the overshoots and settling time for each test subject. However, a variable that has been observed to affect the reading is how close the test subject wears the mask to their cheek.

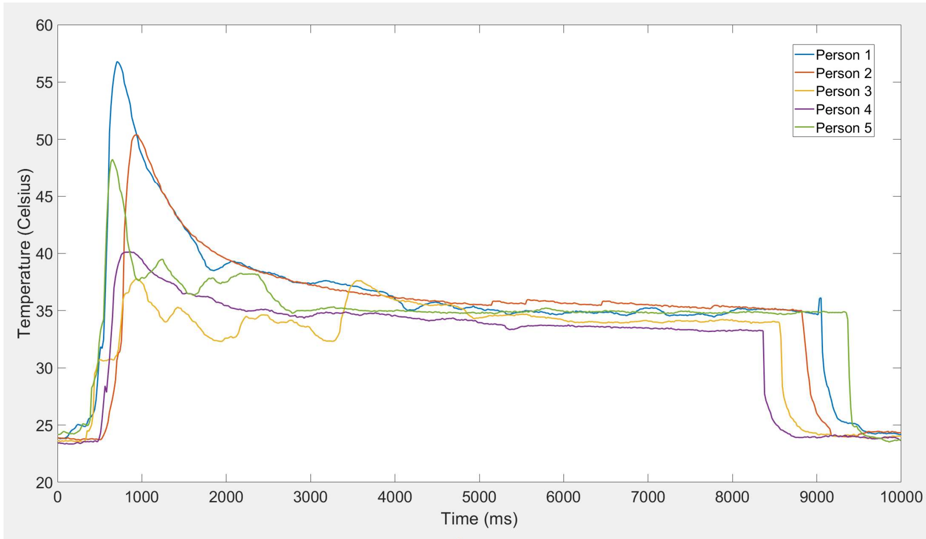

Figure 51 - Plot of temperature readings for each test subject

The plot above shows the different readings for each person who volunteered in the testing. As soon as the person wears the mask the reading increases highly reaching 57 C and takes from 500 to 1000 milliseconds to be nearly stable. The duration from 8500 to 9500 milliseconds is when the person takes off the mask. At that time, the sensor will be measuring the room's temperature that is shown as almost unchanged.

6.1.2 Blood Oxygen Saturation Sensor Readings

Table 19 - Oxygen saturation measurement results using the MAX30100 sensor

Test Subject	Age	MAX30100 Oxygen Saturation (%)	Samsung Oxygen Saturation (%)	Difference (%)
Person 1	22	93	98	5
Person 2	45	95	99	4
Person 3	24	97	98	1
Person 4	18	96	98	2
Person 5	12	98	99	1

As shown in Table 19, the measurement of oxygen saturation by the MAX30100 sensor was compared with the reading of the Samsung Pulse Oximeter. The MAX30100 reading was taken from the person's cheeks, while Samsung's sensor was reading from the person's finger. The smallest difference between the obtained test results was equal to 0 and the greatest difference was equal to 5. Based on the above testing there are some uncertainties in the MAX30100, which it can measure down to 93% that is considered a low level of oxygen saturation. While the Samsung sensor is reading 98% for the same person. This can be a result of the MAX30100 can be negatively impacted by excess motions and changes in temperature. Also, the temperature readings are highly dependent on the site that is measured from, thus some sites in the human body make it easier to obtain accurate readings.

6.1.3 Social Distancing Sensor Readings

The variables that will be tested for the social distancing (PIR) sensor are the distance the other person is from the user and how fast it will detect the other person. To observe this relation, Figure 52 shows the plot drawn where distance is varied at a specified interval. The distance increases every 30 seconds by 50 cm (except at the 2m mark). From a distance 50cm till 2.5cm the sensor is able to quickly detect the presence of another person, however reaching the 3m mark it takes the sensor slightly longer by about 10 seconds. Although this slight discrepancy does not affect the validity of the sensor since the sensitivity of the sensor was specified for around the range of 2m. Outside of the 2m range, there will be an expected delay and the sensor will not be able to detect as quickly as within the 2m range.

The sensor is also programmed to stay at HIGH , which indicated as 1 in Figure 52, for 20 seconds even if the other person is still standing in front of the user, this is so that the user does not continuously get a notification, they will only be notified for 20 seconds. So, the user will be notified only once for every person who enters their range. Figure 52 also , shows 0 reading as Low for PIR , which means no person is detected.

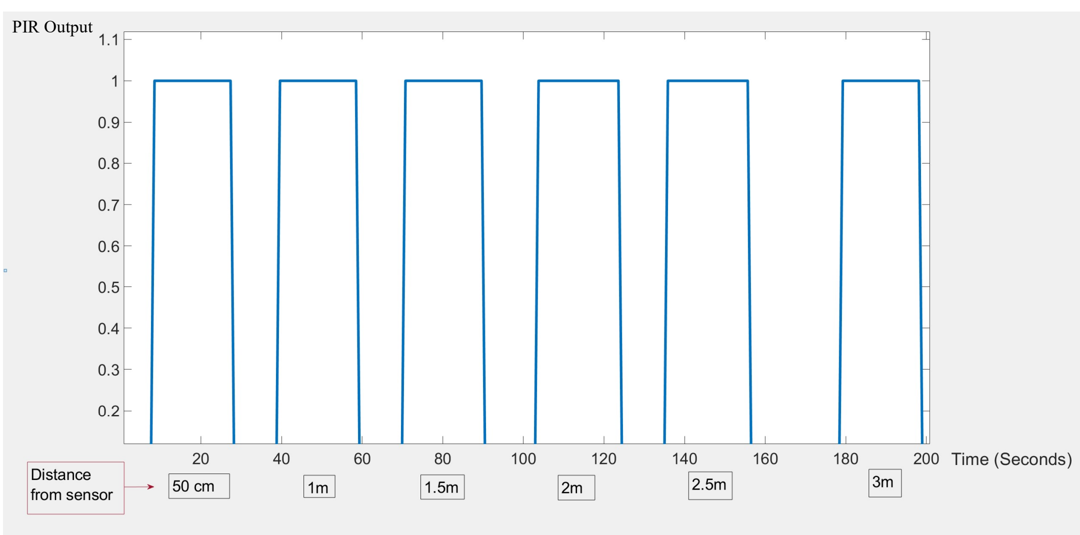

Figure 52 - Plot showing the relation between time and distance for the PIR sensor

A concern with the collected data from the PIR sensor is that even if the person moves away from the range of the sensor, it will still stay HIGH for 20 seconds. So, in Figure 52 shown above, at the 2m mark the situation was tested for the possibility that the other person moves out of range before 20 seconds. For this test, the other person moved out of range 10 seconds earlier, however, the sensor will still stay HIGH for the remaining 10 seconds.

6.2 EVALUATION OF SOLUTIONS

After the implementation of the overall system, the proposed solution was evaluated based on the objectives and the customers' needs which were specified in earlier sections.

The SDVM mask is a lightweight disposable mask with a cleanable front material structure. The mask is capable of tracking the user's social distancing and measuring the user's temperature and oxygen saturation. Furthermore, as shown in the previous section, the temperature readings were outputted continuously every 1 millisecond and blood oxygen saturation every 10-12 seconds. The mask is user-friendly and is provided with an application that tracks the users' vital signs and warns them of any abnormalities. In addition, the optimal power usage was silicified since the used AAA batteries should last up to 3-6 months. Also, the mask is environmentally friendly for the reason that it is sustainable, washable, and reusable [86].

Regarding the technical mistakes, after assembling the sensors the MAX30100 sensor stopped giving readings. By referring to the sensor's datasheet it has been found that the sensor's readings can be negatively impacted by excess motion and temperature changes. Also, it could be a problem of compatibility between the MAX30100 library and other sensors. To solve this problem two Arduinos were used in the prototype. One for the MAX30100 and the other for the rest of the sensors. Moreover, the steady-state for the temperature sensor was not achieved until a few seconds after it was initiated. It usually gave a high-temperature reading at the beginning and after some time it gave the correct reading. This happened also with the MAX30100 sensor. Sometimes it needs a warm-up period before it starts giving any readings. Concerning the PIR sensor, sometimes when it detects a person and goes HIGH it stays HIGH for a while before it goes back to LOW. For future improvements, it is suggested that the mask could use 3 PIR sensors instead of 1 to cover a wider range and help more in tracing social distancing.

Keeping the user secure and safe while using the mask was the most important concern set into consideration when designing the SDVM mask. The team must provide and maintain a safe design without health risks, by implementing suitable control measures. This can be achieved by applying several measures to the design itself, which is mentioned below.

- The mask used a reliable power source.
- The team ensured that the electrical components inside the mask are properly grounded.
- The team ensured that the electrical components and wires are heavily protected.
- Recyclable fabric material to make sure of the safety of natural ecosystems and human health.
- The team used the lightest electrical components to decrease the mask weight.

6.3 CONCLUSIONS

In the conclusion of the project, the implemented prototype was able to model the desired outputs of the system and meet customer needs and requirements. The main objectives of the prototype were for it to be able to help the user monitor their health through their vital signs, and additionally, it should help the user maintain proper social distancing in cases where the user finds himself in an overly crowded area. The application also serves its purpose in being a user friendly and simple manner for the user to check the necessary updates or information on their health or social distancing status and receive notifications in case of any abnormalities in their readings. The project delves into the area of research that deals with health monitoring, wearable devices, and object detection.

In order to make the prototype a finished product that can reach markets, certain improvements are suggested, and they are as follows. The MAX30100 sensor for reading oxygen saturation was not very accurate at times and in a product made for the market, a more reliable, but more expensive, sensor should be used. The product will be more expensive than the prototype, but the use of the more expensive and reliable sensors will make it a more dependable market ready product. Whereas for the purpose of our prototype, the sensor was able to serve its objective in demonstrating the required output. The infrastructure of the mask can be positively improved to be more comfortable for the user. Although the current placement of the sensors is the most optimal infrastructure that the team was able to achieve, if the sensors are improved, then the mask infrastructure can also be greatly improved. Some suggestions might include making the band behind the head slimmer.

Finally, the SDVM mask is a system that arose from the needs voiced during the current COVID-19 pandemic, which has drastically changed the way of life for many around the world. One of the adopted practices as a result of the pandemic is wearing a mask and social distancing: the mask will help make applying these practices easier and help the user feel more confident when going out in public to proceed his daily life with more safety. The social distancing feature of the mask will make the user always aware and remind them to always maintain their social distance. The mask is persistent so that the user is always social distancing especially during recent times when people have become more lenient with social distancing and wearing their masks. The goal of the project was to design a mask that will help going through pandemics with less difficulties and more safety, but also help anyone who has a need to always monitor their vital signs and stay distant from those around them.

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APPENDIX – A: VALIDATION PROCEDURES

EXPERIMENT 1 – TESTING THE ACCURACY OF THE PULSE OXIMETER

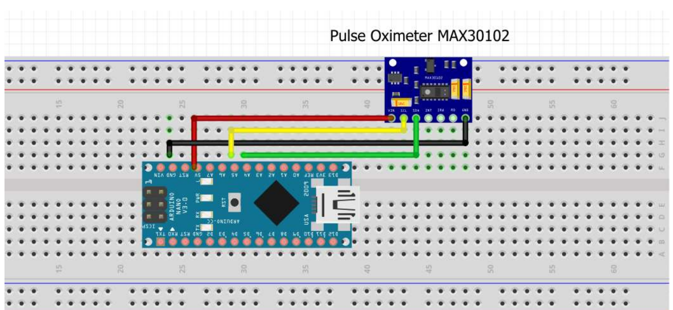
OBJECTIVE

To obtain the testers oxygen saturation from their cheek using the MAX30100 pulse oximeter sensor.

VARIABLE

Oxygen saturation of the tester from their cheek.

CIRCUIT



TOOLS

- MAX30100 Pulse Oximeter
- Arduino Nano
- Wires
- Arduino IDE
- A to Mini-B type USB Connector

WORK PLAN

- First, the circuit is connected as shown above
- The tester places the MAX30100 on their cheek
- Readings are taken from the Arduino IDE serial monitor and recorded
- Compare validity of readings by comparing them to the normal range of (95-99%)

ENVIRONMENTAL/SAFETY ISSUES

None

EXPERIMENT 2 – TESTING ACCURACY OF TEMPERATURE SENSOR

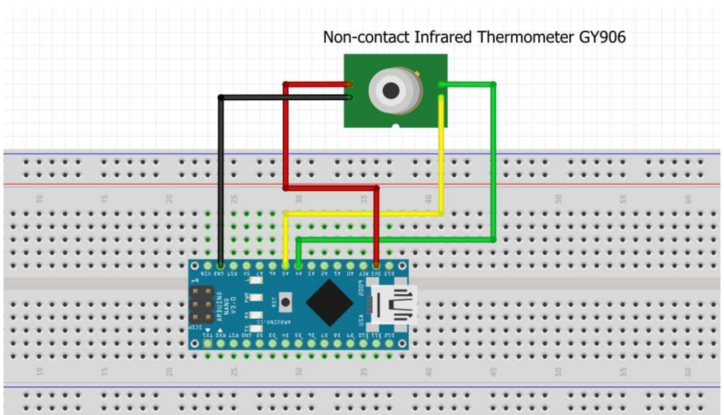
OBJECTIVE

To obtain the testers skin temperature through their cheek using the non-contact infrared thermometer GY906 and observe the results to determine sensor accuracy

VARIABLE

Skin temperature of tester from their cheek

CIRCUIT



TOOLS

- Non-contact infrared thermometer GY906
- Arduino Nano
- Wires
- Arduino IDE
- A to Mini-B type USB Connector
- Digital Thermometer

WORK PLAN

- First, the circuit is connected as shown above
- The tester places the GY906 on their cheek
- Readings are taken from the Arduino IDE serial monitor and recorded
- Compare validity of readings by comparing them to the readings from the digital thermometer.

ENVIRONMENTAL/SAFETY ISSUES

None

EXPERIMENT 3 – TESTING ACCURACY OF PIR SENSOR

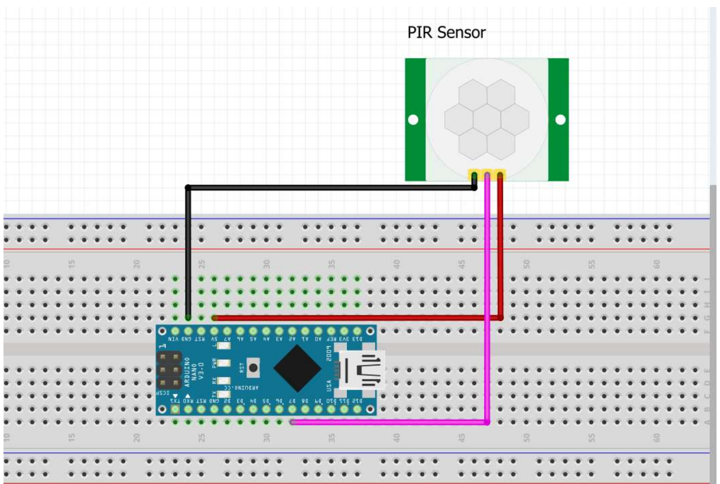
OBJECTIVE

To test that the PIR sensor can detect the presence of someone in front of the tester correctly and in a timely manner.

VARIABLE

Person passing past or standing in front of the PIR sensor.

CIRCUIT



TOOLS

- PIR Sensor
- Arduino Nano
- Wires
- Arduino IDE
- A to Mini-B type USB Connector

WORK PLAN

- First, the circuit is connected as shown above
- The tester holds the PIR sensor facing in front of them
- Another tester should pass by or stand in front of the sensor.
- The timing and validity of the results are recorded.

ENVIRONMENTAL/SAFETY ISSUES

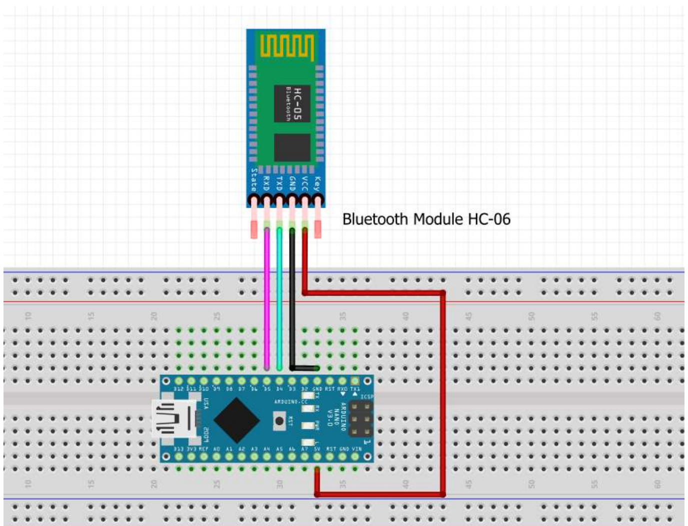
None

EXPERIMENT 4 – TESTING ACCURACY OF BLUETOOTH MODULE

OBJECTIVE

To test that the Bluetooth module is able to successfully transmit data from the Arduino serially.

CIRCUIT



TOOLS

- Bluetooth Module HC-06
- Arduino Nano
- Wires
- Arduino IDE
- A to Mini-B type USB Connector

WORK PLAN

- First, the circuit is connected as shown above
- The tester should send a message through the serial monitor
- If the message is received and sent the Bluetooth module should print a response to show so.

ENVIRONMENTAL/SAFETY ISSUES

None

EXPERIMENT 5 – TESTING VALIDITY OF READINGS FOR PROTOTYPE FROM APPLICATION OF SDVM MASK

OBJECTIVE

Verify that the final prototype is measuring and displaying readings correctly from the mobile phone application while a tester is wearing the whole prototype.

VARIABLE

Observed readings from mobile phone application such as temperature, blood oxygen saturation, and social distancing (PIR).

CIRCUIT

Shown in Figure 14 and final protoype is shown in Figure 47.

TOOLS

- PIR Sensor
- MAX30100 Pulse Oximeter
- Non-contact infrared thermometer GY906
- Bluetooth Module HC-06
- Arduino Nano
- Wires
- Arduino IDE
- Android phone with SDVM Mobile Phone Application
- A to Mini-B type USB Connector

WORK PLAN

- First, make sure that the Android mobile phone device is paired with the Bluetooth module of the SDVM mask prototype.
- After pairing, open the application on the mobile phone and select the HC-06 Bluetooth module from the list of paired devices.
- Make sure the tester is wearing the SDVM mask prototype.
- As soon as the mask prototype and mobile device are connected, the readings from the tester should be displayed on the application.
- Record the readings.
- Repeat the test on different test subjects.

ENVIRONMENTAL/SAFETY ISSUES

None

APPENDIX – B: SELF ASSESSMENT CHECKLIST

E for exemplary, S for satisfactory, D for developing, or U for unsatisfactory.

Student Outcome (SO)	**Key Performance Index (KPI)**	**Members Self-Assessment (E, S, D, or U)**			
		Alia	**Ayah**	**Bayan**	**Roaa**
1	1.1 Problem Identification	E	E	E	E
	1.2 Problem Formulation	E	E	E	E
	1.3 Problem Solving	E	S	E	E
2	2.1 Design Problem Definition	E	E	E	S
	2.2 Design Strategy	E	E	S	E
	2.3 Conceptual Design	E	E	E	E
3	3.1 Effective Written Communication	S	E	S	S
	3.2 Effective Oral Communication	S	E	S	S
4	4.1 Recognition of Ethical & Professional Responsibility	E	S	E	E
	4.2 Consideration of Impact of Engineering Solutions	E	S	E	E
5	5.1 Effective Team Interactions	E	E	E	E
	5.2 Use of Project Management Techniques	E	E	E	E
6	6.1 Developing Appropriate Experiment	E	S	E	E
	6.2 Conducting Appropriate Experiment	E	E	S	S
	6.3 Analysis and Interpretation of Experiment Data and Drawing Conclusions	E	E	E	E
7	7.1 Effective Access of Information	E	E	S	E
	7.2 Ability to learn and apply new knowledge independently	E	E	E	E