

Developing a Wearable Device that can Monitor the Onset of Covid-19

Sameen Ahmad under the supervision of Cameron Morley

Table of Contents

Abstract	3
1. Introduction	3
2. Background Information	3
2.1. Vital Signs	3
2.2. Environmental Impacts	4
2.3. Limitations of existing wearable devices	4
3. Wearable Device	6
3.1. Solution	6
3.2. Features	6
4. Process	6
Table 1. List of Materials	7
4.1. Function	7
4.3. Device Assembly	8
5. Next Steps	10
5.1. Testing	10
5.2. Sources of Error	10
5.3. Future Improvements	11
6. Product Outlook	11
6.1. Cost	11
6.2. Benefits	11
6.3. Audience	12
7. Conclusion	12
Acknowledgements	12
References	12

Keywords: wearable devices, heart rate, temperature, blood oxygen saturation Covid-19

Abstract

Over the course of the pandemic, hospitals nationwide have spent more than \$3 billion on personal protective equipment (PPE) for both workers and patients alike, imposing a serious financial strain on hospitals.^[1] Moreover, disposing of PPE creates waste that significantly pollutes the environment. Wearable devices have been developed to decrease the necessity of PPE as an alternative to recording vital signs, however they are susceptible to flawed readings and don't perform well on all individuals. Here, I investigated creating a wearable device that could autonomously measure the vital signs that are largely indicative of the onset of Covid-19. The device is a wrist and finger monitor capable of recording the heart rate, blood oxygen saturation, and temperature of patients in a non-invasive manner. The device is constructed by connecting a MAX30102 and MCP9808 sensors to an Arduino Uno. After future developments, it would record the data in a web application for workers to monitor, which could easily be shared through a Bluetooth connection. These sensors would also be linked to an OLED display and an HC-05 Bluetooth module to present and store the updated readings. This device holds prospects for significantly reducing the costs of supply chain goods for hospitals so that more funds can be allocated toward research. It'll also aid in reducing the ecological footprint of hospitals across the world. The device would be easily accessible to low-income communities, lessening the health crisis in developing and underdeveloped nations.^[2]

1. Introduction

Nurses and hospital staff typically check each of their patients' vital signs once, if not several times, throughout the day. Especially due to the spread of infectious diseases and quarantine practices, workers are required to suit themselves in a new set of standardized attire before testing and recording vital signs. This rapidly exhausts the supply of PPE in hospitals and increases their demand, leading hospitals to spend a significant amount of money on supplies. Further, with the recent surge in cases, hospitals have reached or exceeded their capacity with patients. There is also a shortage of staff and resources, so recording the vital signs of each patient has become a cumbersome and tedious task. These conditions are further strained in underdeveloped countries due to economic inequality and are likely to instill severe impacts because of the lack of sufficient infrastructure.^[3]

2. Background Information

2.1. Vital Signs

The four main vital signs utilized in hospitals include heart rate, respiratory rate, blood pressure, and temperature.^[4] Heart rate is defined as the number of times the heart beats per minute. In hospitals, it is typically taken by gently pressing one's finger on the wrists or side of the neck of the patient and counting the number of beats heard.^[5] A stethoscope is often supplemented to provide more accurate measurements. Electrocardiogram tests have also been developed, which measure the heart's electrical

signals through sensors placed on the chest produced when the heart beats.^[6] Respiratory rate is the number of breaths taken each minute. This is usually measured by counting the number of times the chest rises and falls when the patient is at rest. It is often important to take these measurements unannounced in the common case that the patient may subconsciously alter their respiration rate. Although, respiratory rate is not a reliable measurement for oxygen saturation. Respiratory rate and oxygen saturation actually possess a low correlation and aren't an accurate indicator for Covid-19 detection. Therefore, I decided to utilize blood oxygen saturation measurements instead of respiratory rate. Blood pressure is the force of the blood pushing against the heart's arteries as the heart contracts and relaxes. Blood pressure is most commonly measured using an aneroid monitor or an electronic sphygmomanometer that consists of an inflatable cuff strapped around the arm of the patient. After the cuff inflates and deflates, the monitor provides a reading of the systolic pressure and the diastolic pressure, which are the numbers on the top and bottom, respectively. Systolic pressure measures the pressure inside the artery when the heart is contracting, while diastolic pressure displays the pressure when the heart is relaxing.^[7] To record temperature, hospitals have used electronic thermometers that are typically placed in the mouth or ear. A noncontact method has also been popularized that uses infrared sensors to record the heat emitted when aimed at one's forehead.^[8] Through ongoing research, the signs that have been determined to have a significant probability of indicating the onset of Covid-19 include heart rate, blood oxygen saturation, and core body temperature.^[9]

2.2. Environmental Impacts

The onset of the pandemic has caused a surge in sales for PPE and prices have also increased as distributors struggle to keep up with the nationwide demand.^[10] To prevent the transfer of infections between patients when recording vital signs, hospital staff must repeatedly dispose of and equip themselves with a new set of surgical scrubs, washable footwear, facemasks/shields, gloves, and oftentimes safety goggles.^[10] These items are most commonly composed of plastic and polyethylene and contribute tonnes of waste when discarded.^[10] They release harmful emissions to the environment that are ultimately toxic to humans and can worsen global warming through the release of greenhouse gasses.^[10] Some of the detergents used to coat the PPE are also carcinogenic and contain chemicals that can pollute waterways if improperly disposed of.^[10] These items also often have to undergo a disinfection process to ensure that they are devoid of bacteria.^[10] While the CDC has called on hospitals to make rational use of PPE in efforts to conserve its supply, the severe demands and environmental impacts of this equipment continue to persist.^[10]

2.3. Limitations of existing wearable devices

While wearable devices have grown increasingly popularized with the development of the Apple Watch and Fitbit, these devices face several shortcomings. Many of these devices use photoplethysmography (PPG) technology to measure heart rate that relies on green LEDs or infrared light that radiates into the skin, interacts with the blood cells, and then reflects into an optical sensor to provide a reading (**Figure 1**). The quantity of reflected light is a function of blood volume, skin absorbance, and light scattering. Light absorbance can change with skin color, presence of tattoos and higher body mass index due to the Beer-Lambert Law, which states that more light is absorbed at greater concentrations of blood so less light

is reflected. However, green LED is more readily absorbed by skin with more melanin because it has a shorter wavelength, which blocks the light and prevents it from being reflected into the optical sensor, creating false and inconsistent readings.^[11] A similar issue is observed by individuals with a high body mass index since thicker skin layers result in higher signal loss. Increased absorbance with these factors leads to less reflected light and detected signal by the optical sensor. Green LED is useful for individuals with lighter skin and lower body mass indexes despite its shorter wavelength.^[12] However, infrared light (IR) possesses a longer wavelength and penetrates through all skin tones.^[12] The solution to reducing scattering and absorbance is to use IR, however, these measurements are more prone to higher signal-to-noise ratios than their green light counterparts.^[12] Also, wrist heart rate sensors are often disrupted due to the effects of surrounding ambient light entering the optical sensor. The wrist is also prone to high optical noise, low blood perfusion, and is highly susceptible to motion artifacts due to hand movements. To prevent these issues, I propose to use IR red light while embedding additional features into the monitor to prevent signal interference. Additionally, the device will take heart rate and blood oxygen saturation measurements at the finger, less susceptible to the disruptions at the wrist.

Additionally, issues can arise if the sensors are not in the correct position or aren't pressed sufficiently against the skin. Several wearable devices also take pulse oximetry measurements that rely on reflectance mode, which is less accurate than the transmission mode where the light source and detector are separated by the skin, allowing the sensor to measure the light directly after passing through one's finger. Reflectance mode can cause the light to be more dissipated and is more vulnerable to ambient light than transmission mode. Temperature monitors that rely on IR can also be disrupted by the ambient air temperature. They also provide measurements for the surface body temperature, which can easily fluctuate due to environmental changes, instead of the core body temperature.

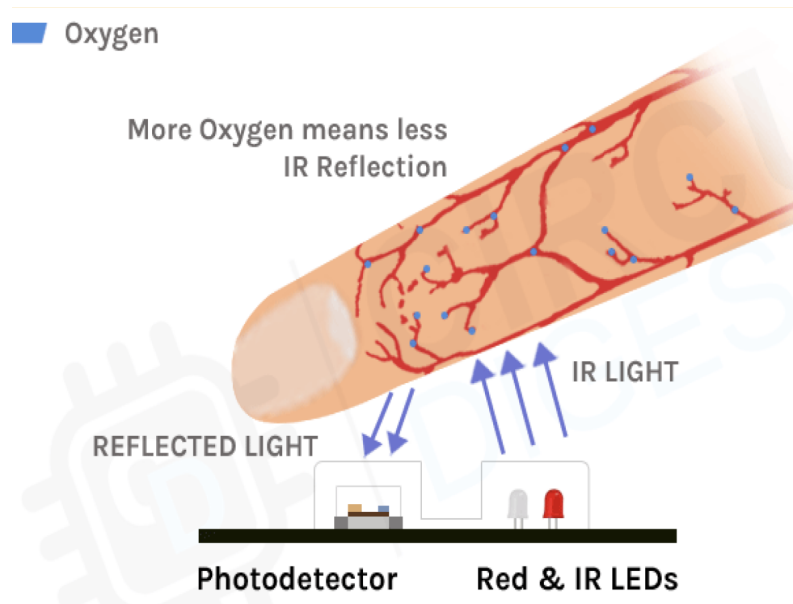


Figure 1. Interactions of light with the blood in one's finger to determine heart rate through photoplethysmography, adapted from Circuit Digest, 2022^[13]

3. Wearable Device

3.1. Solution

In efforts to create a device that achieves a high level of accuracy, the wearable uses PPG technology to record heart rate and blood oxygen saturation at the fingertip. These sensors will be connected to an OLED display located at the wrist to display the readings of one's vital signs. At the wrist, temperature sensors are also embedded. The information presented in the OLED display will be accessible for distance monitoring through an app that relies on a Bluetooth connection. Readings from the OLED would be sent to the interface, where trends could be monitored in real time. Users would be alerted through their web application when their readings fall out of their standard range, and can also choose to notify hospital staff or any, who possess shared access to the user's readings. The information of each user would be stored in a database on the cloud, where it could be shared with relatives or hospital staff to monitor.

3.2. Features

I investigated the use of infrared light instead of green light because infrared light is more effective at penetrating through all skin colors, providing more accurate readings. Therefore it is less biased against darker skin colors, but it is more susceptible to errors due to motion artifacts or ambient light. The MAX30102 sensor was selected because it can emit green light, infrared light along with red light, supplying many possibilities for testing. Also, the sensor contains low-noise electronics and ambient light rejection features. It possesses an accuracy of 97.11% and 98.84% for heart rate and blood oxygen saturation, respectively, according to a study conducted by IJEECS.^[12] For the temperature measurements, the MCP9808 sensor was chosen due to its high precision. It possesses an accuracy within 0.25 degrees Celsius and requires low power consumption. These two sensors are the main components for recording and transmitting the data required for the wearable device.

4. Process

Name	Quantity (x)	Link	Cost (t)
Arduino Uno	1	Arduino UNO REV3 [A000066]	\$28.50
MAX30102 Blood Oxygen and Pulse Detection Sensor	2	2Pcs Heart Rate Sensor Module MAX30102 Blood Oxygen Sensor Pulse Detection	\$10.99

MCP9808 Temperature Sensor	1	Amazon.com: Adafruit MCP9808 High Accuracy I2C Temperature Sensor Breakout Board [ADA1782]	\$12.45
HC-05 Classic	1	Amazon.com: DSD TECH HC-05 Classic Bluetooth 2.0 Serial Wireless Module for UNO R3 Nano (Basic Version)	\$9.99
OLED display	1	Amazon.com: waveshare 1.5inch RGB OLED Display Module, 128x128 Pixels Displaying 65K Colors, Compatible with Raspberry Pi Arduino STM32, SPI Interface	\$18.59
Jumper Wires	1 pack of 120	120 Pin Dupont Jumper Wires, 20cm Wire Length (40Pin Male to Female, 40Pin Male to Male, 40 Pin Female to Female)	\$5.99
Battery	x(t)	Duracell N 1.5V Alkaline Battery, 2 Count Pack, N 1.5 Volt Alkaline Battery, Long-Lasting for Medical Devices, Key Fobs, GPS Trackers, and More	\$5.49
Battery Pack	x(t)	Corpcio 6 x AA Battery Holder with Standard snap Connector 9V Output Type BH363	\$5.49

Table 1. List of Materials

4.1. Function

When the device is worn, the MAX30102 sensor emits red and infrared light into the finger (**Figure 2**). Based on the abundance of light absorbed, it calculates one's heart rate and blood oxygen saturation using PPG. Using the serial plotter, the sensor also depicts a graph of one's heart rate after calibrating. Simultaneously, the temperature sensor should be placed flush against the wrist where it can detect the amount of temperature emitted. The values of each sensor are constantly overridden several times within a second as new readings are received. These readings will also be updated on the wrist monitor and the web application, where the user can easily observe and share their vital signs patterns

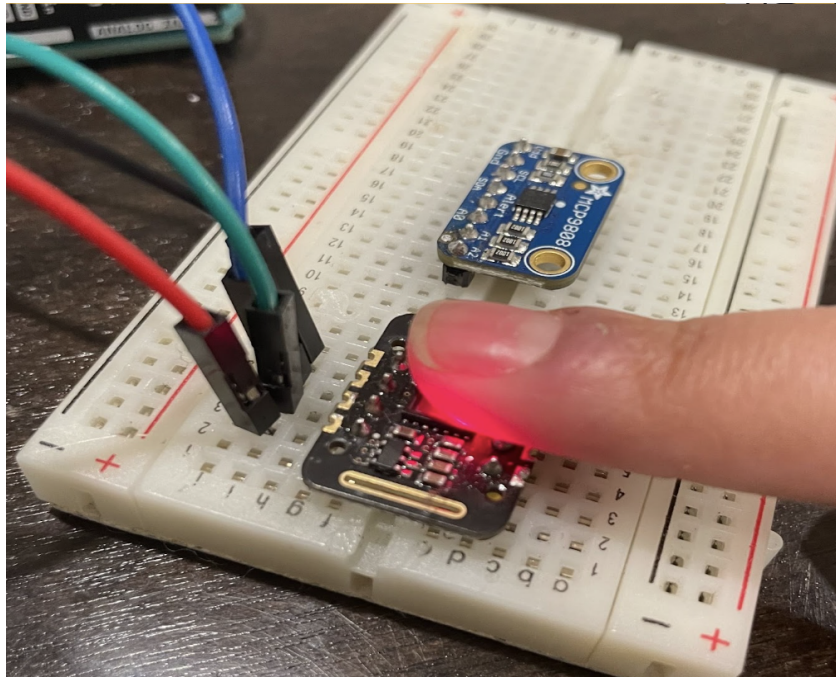


Figure 2. Heart rate sensor in operation besides the temperature sensor

4.2. Design

The MAX30102 sensor is placed on the right middle finger, which has been proven to have a statistically higher accuracy for pulse oximetry. Blood gathers more densely at the fingertips, reflecting more reliable measurements than sensors placed at the wrist, a location of lower blood perfusion and highly vulnerable to motion artifacts. The temperature sensors are placed at the wrist rather than the fingertips. This is because temperatures taken at the body's extremities (fingertips or toes) doesn't display an accurate representation of one's core body temperature, which fluctuates as it travels through the body. The MAX30102 sensor would be secured in place, in a module that replicated the form of a finger clip/band. It would exclude the interference of external light sources, allowing only the light emitted from the sensor to come in contact with the finger. This module would need to be suitable for the sizes of several finger sizes and comfortable for long use. It would also need to prevent severe impediments to one's range of motion. Similarly, a casing would need to be designed that can host the Arduino Uno, OLED display, HC-05 Bluetooth module, and the MCP9808 sensor, where the sensor had direct contact with one's wrist. The case should manage the use of space effectively to allow the components to be secured compactly.

4.3. Device Assembly

The main commands of the device would be administered by the Arduino Uno powered by a 5V or 3.3V battery while programming in C++. To program each of the individual sensors, first, download their respective libraries to access the sample code. After calling the proper libraries, a few lines of code

truncate the sample data, define variables, and initialize the serial monitor/plotter. The MAX30102 sensor performs calculations to measure the heart rate and blood oxygen saturation until a new sample is collected and the initial values are overridden. One can also adjust the sample average, sample rate, and pulse width variables to achieve greater accuracy. The temperature sensor functions similarly, though it makes calculations to display the temperature in Celsius and Fahrenheit. It also shuts down the sensor periodically to reduce power consumption.

```
red=52519, ir=9392, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=52481, ir=9362, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=52553, ir=9329, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=52517, ir=9301, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=52568, ir=9307, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=52589, ir=9299, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=52560, ir=9232, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=52298, ir=9030, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51894, ir=8969, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51930, ir=8949, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51984, ir=8921, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51931, ir=8916, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51980, ir=8888, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51989, ir=8829, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51998, ir=8812, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51879, ir=8673, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51571, ir=8652, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51657, ir=8654, HR=83, HRvalid=1, SP02=100, SP02Valid=1
red=51762, ir=8689, HR=83, HRvalid=1, SP02=100, SP02Valid=1
```

Figure 3. Heart rate and blood oxygen saturation readings from MAX30102 sensor shown on Arduino Uno's Serial Monitor

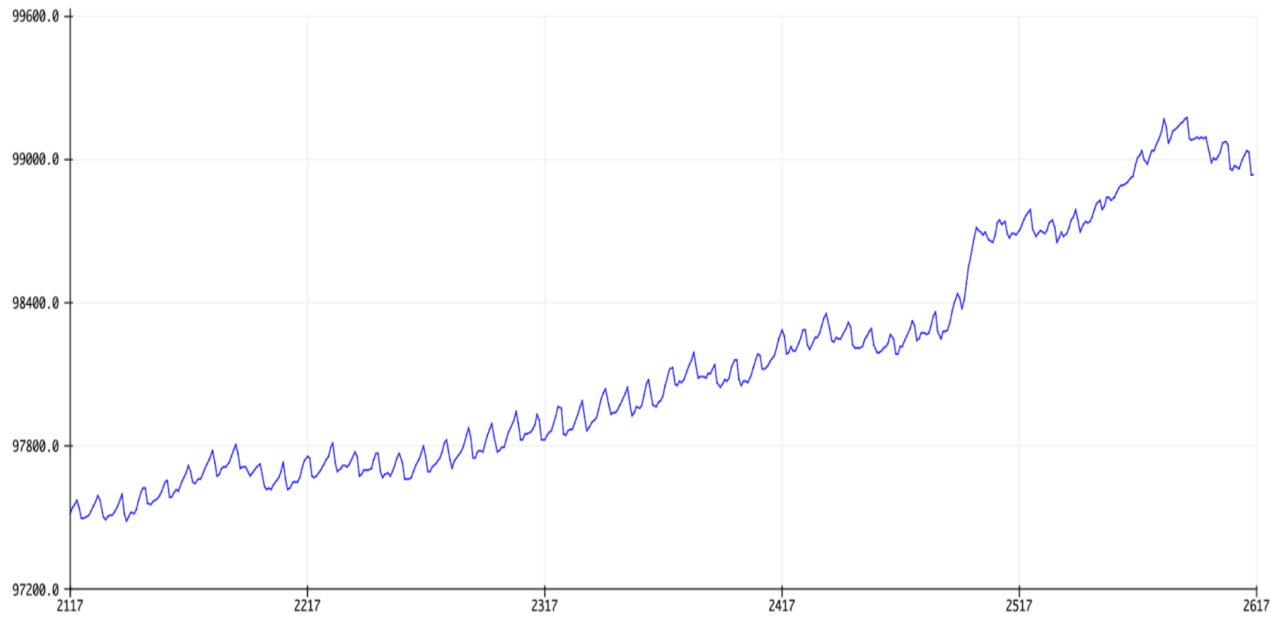


Figure 4. Heart rate graph from MAX30102 as shown on Arduino Uno's Serial plotter

5. Next Steps

5.1. Testing

When the MAX30102 sensor was tested, it displayed the ratio of the red and infrared light reflected, heart rate, blood oxygen saturation along with whether the values were determined to be valid or not (**Figure 3**). The sensor depicts a binary indicator to determine measurement validity, where “1” indicates a valid signal and “0” for an invalid signal. Additionally, one can also view a graphical representation of their heart rate using the Serial Plotter (**Figure 4**).

Following the construction of the prototype, each of the features of the device will be cross-tested with widely available point solutions from body temperature, pulse rate, and blood oxygen saturation. The goal is to achieve an accuracy rate within 95%.

5.2. Sources of Error

Often, the heart rate and blood oxygen saturation readings reported by the sensor fluctuate greatly when an unideal amount of pressure is exerted, providing inconsistent and unreliable readings. Also, when

viewing the Serial Plotter for one's pulse rate, the dips in the graph are initially unrecognizable until the graph calibrates itself, often taking several seconds upon initialization (**Figure 4**). Active measures may also need to be taken to ensure that excessive movement doesn't skew the readings from the light sensor.

5.3. Future Improvements

Employing a transmission mode instead of a reflectance mode for the MAX30102 module may provide more accurate results. In theory, this may be executed by utilizing two MAX30102 sensors and carefully disabling the emitting diode or photodetector of each, without damaging any of the remaining components. Additionally, replacing the Arduino Uno with an Arduino Nano would also allow for more compact electronics. A more advanced approach would entail designing a custom printed circuit board embedded with the required electronic pieces.

Upon completion, the device would first need to succeed in gaining approval from legal agents for credibility before mass production. The device will be classified as a class 2 medical device and must be approved by the FDA. The FDA approval process for class 2 medical devices is 60 days.

6. Product Outlook

6.1. Cost

The wearable device is notably cheaper than the charges of an extended stay at a hospital. If these devices are produced on a massive scale then their price may also reduce in bulk. A typical oximeter (a device that can often measure both heart rate and blood oxygen saturation) costs \$15, a blood pressure monitor costs \$50, and an oral thermometer costs \$5. The total cost of the point solutions is about \$70. Our goal will be to drive the cost for the entire solution to \$50. The benefits this will cause will primarily be in developing countries, which have a median annual wage of less than \$600. Countries starved of resources equipped with affordable vital sign monitors will allow clinicians to quickly diagnose their patients and save more lives.

6.2. Benefits

The wearable device has the potential to significantly reduce the money and waste associated with PPE. It will allow for the early diagnosis of Covid-19 or related illnesses so that proper action can be taken against the virus quickly, saving lives and preventing longer-lasting damage. The device is also easily accessible to low-income communities and can readily be replicated cost-effectively, lessening the economic disparity and health crisis in developing and underdeveloped nations.

6.3. Audience

The prototype will serve hospital staff and patients in both developed, developing, and underdeveloped countries. The device will address the health disparity in lower-income communities and serve to monitor the well-being of individuals who can't afford medical treatment or don't have easy access to hospitals.

7. Conclusion

The proof of concept of this device holds many future implications of success and benefits. The device, in essence, relies on the MAX30102 and MCP9808 sensors to gather data. Early iterations of this device only consider a few vital signs, but I hope to integrate additional metrics including blood pressure. Several steps remain in producing a prototype, testing for its credibility as compared to industry standards, and refining the finer details to ensure ease in usability. The wearable device holds high prospects of significantly reducing the negative impact of the virus and encouraging fairer healthcare access to underprivileged communities. The user-friendly and cost-effective nature of the device will prompt it to be popularized quickly, generating a notable effect.

Acknowledgements

Paper was produced under the supervision of Cameron Morley through the Polygence program.

References

- [1] Muoio, D. (2021, October 12). *Hospitals have spent more than \$3B on personal protective equipment since COVID-19 began*. Fierce Healthcare. Retrieved November 3, 2022, from <https://www.fiercehealthcare.com/hospitals/hospitals-have-spent-over-3b-personal-protective-equipment-since-covid-19-began-premier>
- [2] Steuart, R., Huang, F. S., Schaffzin, J. K., & Thomson, J. (2020, May). *Finding the value in personal protective equipment for hospitalized patients during a pandemic and beyond*. Journal of hospital medicine. Retrieved November 3, 2022, from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7204998/>
- [3] United Nations. (n.d.). *Top economists warn covid-19 impacts will be severe and long-lasting for developing countries*. United Nations. Retrieved November 4, 2022, from <https://www.un.org/en/desa/top-economists-warn-covid-19-impacts-will-be-severe-and-long-lasting-developing-countries>

- [4] John Hopkins University . (2022, June 14). *Vital signs (body temperature, pulse rate, respiration rate, blood pressure)*. Vital Signs (Body Temperature, Pulse Rate, Respiration Rate, Blood Pressure) | Johns Hopkins Medicine. Retrieved November 4, 2022, from <https://www.hopkinsmedicine.org/health/conditions-and-diseases/vital-signs-body-temperature-pulse-rate-respiration-rate-blood-pressure>
- [5] American Heart Association. (2022, October 18). *All about heart rate (pulse)*. www.heart.org. Retrieved November 4, 2022, from <https://www.heart.org/en/health-topics/high-blood-pressure/the-facts-about-high-blood-pressure/all-about-heart-rate-pulse>
- [6] NHS. (n.d.). *Electrocardiogram (ECG)*. NHS choices. Retrieved November 4, 2022, from [https://www.nhs.uk/conditions/electrocardiogram/#:~:text=An%20electrocardiogram%20\(ECG\)%20is%20a,heart%20each%20time%20it%20beats](https://www.nhs.uk/conditions/electrocardiogram/#:~:text=An%20electrocardiogram%20(ECG)%20is%20a,heart%20each%20time%20it%20beats)
- [7] Centers for Disease Control and Prevention. (2021, September 27). *Measure your blood pressure*. Centers for Disease Control and Prevention. Retrieved November 4, 2022, from <https://www.cdc.gov/bloodpressure/measure.htm#:~:text=First%2C%20a%20health%20care%20professional,will%20measure%20your%20blood%20pressure>
- [8] The University of California . (2020, October 6). *Temperature measurement*. ucsfhealth.org. Retrieved November 4, 2022, from <https://www.ucsfhealth.org/medical-tests/temperature-measurement>
- [9] Ikram, A. S., & Pillay, S. (2022, April 29). *Admission vital signs as predictors of covid-19 mortality: A retrospective cross-sectional study - BMC emergency medicine*. BioMed Central. Retrieved November 4, 2022, from <https://bmccemergmed.biomedcentral.com/articles/10.1186/s12873-022-00631-7>
- [10] Rizan, C., Reed, M., & Bhutta, M. F. (2021, May 16). *Environmental impact of personal protective equipment distributed for use by Health and Social Care Services in England in the first six months of the COVID-19 pandemic*. Journal of the Royal Society of Medicine. Retrieved November 4, 2022, from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8150566/>
- [11] Castaneda, D., Esparza, A., Ghamari, M., Soltanpur, C., & Nazeran, H. (2018, August 6). *A review on wearable photoplethysmography sensors and their potential future applications in health care*. International journal of biosensors & bioelectronics. Retrieved November 4, 2022, from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6426305/>
- [12] Collins , T., & Woolley , S. (2022, September 13). *Some heart-rate monitors give less reliable readings for people of colour*. The Conversation. Retrieved November 5, 2022, from <https://theconversation.com/some-heart-rate-monitors-give-less-reliable-readings-for-people-of-colour-121007>

[13] Das, D. (2022, May 4). *How max30102 pulse oximeter and Heart Rate Sensor Works and how to interface it with Arduino?* How Does the MAX30102 Pulse Oximeter and Heart Rate Sensor Work and how to Interface it with Arduino? Retrieved November 4, 2022, from [https://circuitdigest.com/microcontroller-projects/how-max30102-pulse-oximeter-and-heart-rate-sensor-works-and-how-to-interface-with-arduino#:~:text=How%20accurate%20is%20MAX30102%3F,saturation%20\(SpO2\)%2C%20respectively.](https://circuitdigest.com/microcontroller-projects/how-max30102-pulse-oximeter-and-heart-rate-sensor-works-and-how-to-interface-with-arduino#:~:text=How%20accurate%20is%20MAX30102%3F,saturation%20(SpO2)%2C%20respectively.)