IMPACT OF FACE MASK USE ON PHYSIOLOGICAL PARAMETERS RELATED TO RESPIRATION DURING DAILY PHYSICAL ACTIVITIES

by

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Kerim Bedri Saçan

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ABSTRACT

IMPACT OF FACE MASK USE ON PHYSIOLOGICAL PARAMETERS RELATED TO RESPIRATION DURING DAILY PHYSICAL ACTIVITIES

Coronavirus outbreak causes every individual to wear a face mask to prevent the spread of the epidemic. Face masks filtrate air from organic or inorganic particles both in inhale and in exhale operations during the normal respiration cycle. There exists a variety of different face masks with different fabrication materials and their use may lead to obstructions in breathing under some circumstances. This thesis work aims to figure out the impact of face mask use on physiological parameters related to respiration during sitting and walking activities. A total of 15 volunteers are directed to perform two different tests; sitting indoors, and walking outdoor in ten-minute durations while their blood oxygen saturation (SPO_2 percent), heart rate (bpm), carbon dioxide level (CO_2), temperature (°C), and humidity (percent) parameters are being monitored. Two different wearable signal acquisition setups are developed for the acquisition and storage of the parameters. Tests are performed for no mask, surgical face mask, and FFP2 respirator. In no mask test, ambient carbon dioxide, humidity, and temperature parameters are recorded while in mask tests, these parameters are recorded at the inner dead space of the mask. For the sitting activity, very similar overall SPO_2 and heart rate measurements are of concern regardless of the mask use (P= 0.58-0.36, and P= 0.82-0.85). Very similar overall SPO_2 and heart rate measurements are also detected for the walking activity (P= 0.98-0.10, and P= 0.65-0.69), however, the heart rates are larger as expected for that activity. Overall CO_2, temperature and humidity measurements are significantly smaller with no mask use but larger with mask use regardless of the activity (P< 0.05). Among the measurements, strong positive correlations exist for SPO_2 and heart rate (r> 0.80). The rest of the measurements are with moderate or poor correlations (r= -0.39-0.96).

ÖZET

GÜNLÜK FİZİKSEL AKTİVİTELERDE YÜZ MASKESİ KULLANIMININ SOLUNUMLA İLGİLİ FİZYOLOJİK PARAMETRELERE ETKİSİ

Koronavirüs salgını, salgının yayılmasını önlemek için toplumda bireylerin yüz maskesi kullanmasına sebep olmaktadır. Yüz maskeleri, solunum sırasında hem nefes alma hem de nefes verme işlemlerinde havayı organik veya inorganik partiküllerden süzmektedir. Kullanılabilecek farklı üretim malzemelerine sahip birçok çeşitli yüz maskeleri vardır ve bunların kullanımı esnasında bazı durumlarda nefes almada tıkanıklığa neden olabilir. Bu tez çalışması, oturma ve yürüme aktiviteleri esnasında yüz maskesi kullanımının solunumla ilgili fizyolojik parametreler üzerindeki etkisini belirlemeyi amaçlamaktadır. Toplamda 15 gönüllü, on dakikalık testler ile kapalı alanda oturma ve dışarda yürüme aktiviteleri olmak üzere on dakikalık süreler ile iki farklı teste tabi tutulmuştur ve testler esnasında kandaki oksijen satürasyonu (yüzde SPO_2), nabız (bpm), karbondioksit seviyesi (CO_2), sıcaklık (°C) ve nem (yüzde) parametreleri gözlemlenmiştir. Parametrelerin alınması ve saklanması için iki farklı giyilebilir sinyal edinim düzeneği geliştirilmiştir. Testler, maskesiz, cerrahi maske ve FFP2 maske ile yapılmıştır. Maskesiz testte ortam karbondioksit oranı, nem ve sıcaklık parametreleri kaydedilirken maske testlerinde bu parametreler maskenin iç boşluk tarafından kaydedilmiştir. Oturma aktivitesi için, maske kullanımından bağımsız olarak genel SPO_2 ve nabız ölçümlerinin benzerliği endişe vericidir (P= 0.58-0.36 ve P= 0.82-0.85). Yürüme aktivitesi için çok benzer genel SPO_2 ve kalp hızı ölçümleri de tespit edimiştir. (P= 0.98-0.10 ve P= 0.65-0.69), ancak nabız oranları bu aktivite için beklendiği gibi daha yüksektir. Genel CO_2, sıcaklık ve nem ölçümleri, maske kullanılmadığında önemli ölçüde daha küçük anlamlılığa sahiptir, ancak aktiviteden bağımsız olarak maske kullanımıyla daha büyük anlamlılığa sahiptir (P< 0.05). Ölçümler arasında, SPO2 ve kalp hızı (r> 0.80) için güçlü pozitif korelasyonlar mevcuttur. Geri kalan ölçümler orta veya zayıf korelasyonlara sahiptir (r= -0.39-0.96).

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LIST OF SYMBOLS/ABBREVIATIONS

ADC	Analog to digital converter
BPM	Heartbeat per minute
HR	Humidity rate
IC	Integrated circuit
IR	Infrared
LED	Light emitting diode
NDIR	Non-dispersive infrared
PPG	Photoplethysmography
ppm	Parts per million
SPO_2	Blood oxygen saturation (percent)

1. INTRODUCTION

1.1. AIM OF THE STUDY

The Coronavirus (COVID-19) disease was first detected in Wuhan, China in December 2019. Since then, the outbreak has enormously spread throughout the world. There are currently 188.655.968 cases and 4.067.517 deaths as reported by World Health Organization (WHO)[1]. COVID-19 is transmitted when people inhale air that is contaminated with droplets from the mouth and tiny airborne particles. The infection spreads by inhaling the particles when people are close together [2]. The spread of the virus may also occur when contaminated fluids contact the eyes, nose, or mouth. On rare occasions, the spread occurs when touching contaminated surfaces [3]. The contamination period lasts up to 20 days on people and can spread the virus even if they don't show any symptoms [4]. The vaccination started in December 2020, 44.1 percent of the world population has received at least one dose of a COVID-19 vaccine and is still in progress [5]. Unfortunately, the emergence of variants of the COVID-19 virus, such as alpha, beta, and theta, means that face masks, which are one of the biggest inhibitors of the spread of the virus, will continue to be used [6].

Face masks are known to be quite functional to prevent the spread of numerous pandemic diseases and recently, increased attention has been drawn for their daily use for coronavirus pandemics. Face masks filtrate the organic and inorganic particles from the air inhaled or exhaled during respiration. However, the use of a face mask may obstruct the breathing process to a certain degree leading to undesirable changes in the physiological parameters related to respiration. The use of a face mask may also lead accumulation of CO_2, humidity, and temperature in-mask zone. In this thesis work, two separate signal acquisition setups are developed to capture physiological parameters related to respiration. One setup is to record blood oxygen saturation rate and heart rate, the other setup is to record CO_2, humidity, and temperature to introduce quantitative metrics and models in determining the changes in the parameters during daily physical activities. The activities are composed of walking an 800 meters distance through 10 minutes outside and 10 minutes sitting in a closed area. Tests are consecutively applied on volunteers with no mask, using a surgical mask and using FFP2 respirator by giving 5-minute breaks with each test. Each test parameter according to the measurement test taken with no mask is assessed.

1.2. FACEMASKS AND RESPIRATORS

There are many types of facemasks and respirators however, in a pandemic, commonly used ones are non-medical masks, surgical masks, FFP1 masks, FFP2 respirators, and FFP3 respirators. Each type of mask and respirator does have its standard.

- Non-medical and cloth masks are made of different kinds of materials. According to WHO, Non-medical masks can be made of numerous kinds of fabric combinations, layer formations, and designs. These combinations of fabric and designs result in a variety of filtration and breathability. The only standardization for non-medical masks comes from the French Standardization Association that defines the minimum performance of filtration and breathability. Bacterial filtration must be at least 70 percent particles and droplets. For breathability, the required maximum inhalation resistance must be 2.4 mbar and maximum exhalation resistance must be 3.0 mbar [7].
- Surgical masks should have European EN 14683 standard and for the following standard similar to the “American Testing and Materials Organization (ASTM)”. The main standards are:
  - BFE (Bacterial Filtration Efficiency): Minimum of 95 percent filtrations from 3-micron droplets.
  - PFE (Particulate Filtration Efficiency): PFE determines the quality of the surgical mask by measuring the particle filtration. The aim is to specify the mask that whether it can filtrate the virus-sized particles. The expectation is to filtrate up to 0.1 micron sizes. The expected particle filtration must be at least 0.5 microns [8].

Figure 1.1. A non-medical mask (left) and a surgical mask (right) [9,10].

- FFP1 mask is mainly used as a dust mask and used for aerosol filtration. At least 80 percent protection of aerosols and leakage to the inside of maximum 22 percent [11]. For particle filtration for medical purposes, the FFP1 mask is the least protective among other FFP mask types. All FFP masks are regulated on EN 149:2001 standard [12].
- FFP2 respirator is similar to N95, KN95, P2, DS2, and KMOEL respirator types. Those varieties of naming are from different regions of the World. BFE is a minimum of 95 percent for the standards, 8 percent internal leakage, and PFE is 11,5 to 15,9 times greater than surgical masks [13].
- FFP3 respirator provides the highest level of protection among other mask and respirator types. It has a minimum filtration percentage of 99 percent and a maximum of 2 percent internal leakage, protecting against very fine particles [13]. Since there is an exhalation valve on the FFP3 respirator, it is easier to exhale, but the droplets and air from exhalation are not filtered and do not prevent the spread of the virus [14,15].

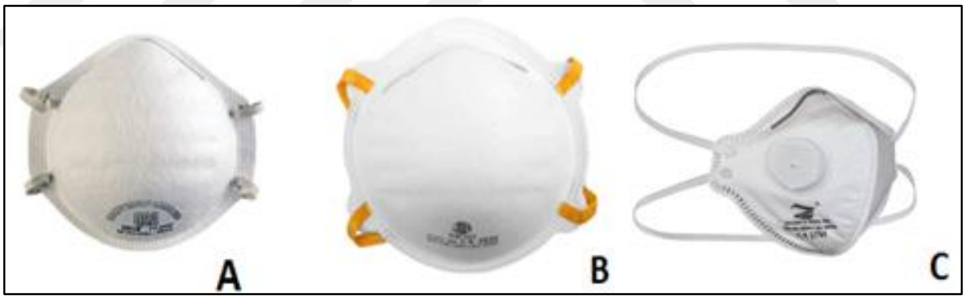


Figure 1.2. a) FFP1 mask, b) FFP2 respirator and c) FFP3 respirator [16–18].

1.3. CARBON DIOXIDE, TEMPERATURE AND HUMIDITY

With each breath, humans convert oxygen into carbon dioxide (CO_2). The concentration of CO_2 in natural ambient air is approximately 417 ppm [19]. The concentration in the indoor air ambient changes between 350 ppm to 2500 ppm [20,21]. The effects of carbon dioxide on health have revealed other symptoms in respiratory disease, respiratory symptoms such as shortness of breath, and other symptoms such as tiredness feeling and headache [22]. Some possible hazards of exposure to CO_2 are listed in Table 1.1 [23,24].

Table 1.1. Hazards of CO_2 exposure.

CO_2 Concentration (ppm)	Potential Symptoms	Exposure Limit
5000	No acute health symptoms	8 Hours
10000	Typically no effects, tiredness feeling.	<8 Hours
15000	Mild respiratory irritation	15 Minutes
30000	Moderate respiratory irritation increased HR and blood pressure.	10 Minutes
40000	Respiratory irritation, increased heart rate and blood pressure.	Immediately dangerous
50000	Strong respiratory irritation, dizziness, headache, and shortness of breath.	Immediately dangerous
80000	Blurred vision, heavy sweating, shivering, unconsciousness, and possible death.	Immediately dangerous

To evaluate the CO_2 concentration in ambient, there are four different sensing methods;

- **Electrochemical method**: A typical model of the electrochemical sensor includes three electrodes as the core for ionic transport. These electrodes are separated by hydrophobic membranes. The membranes are hydrophobic so that they can move the electrolyte between adjacent electrodes, allowing ions to flow out of them. As with any system with three electrodes, it has a working electrode, a reference, and a counter table to operate according to the principle of reduction-oxidation [25].

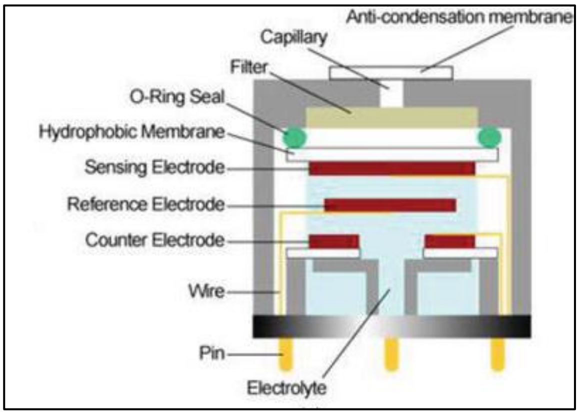


Figure 1.3. An electrochemical type gas sensor [26].

- **Semiconductor method**: The absorbed oxygen on the heated metal oxide material reacts with the detected gas. This reaction changes the resistance value of the circuit. This type of sensor detects gas and its concentration with these resistance differences. The accuracy of this kind of sensor has a good accuracy above 2000 ppm but has low accuracy below 2000 ppm [27,28].

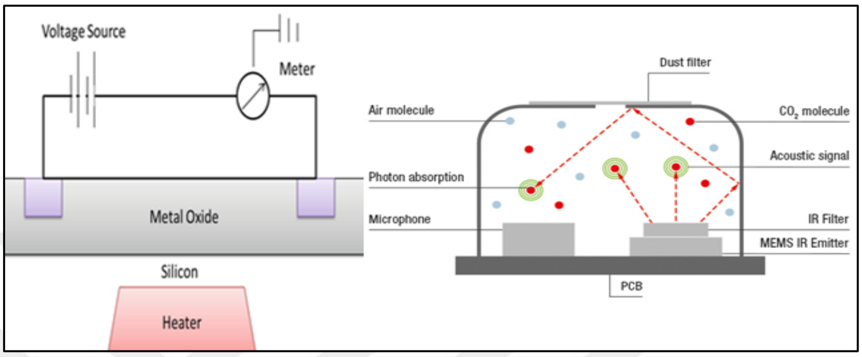


Figure 1.4. Semiconductor gas sensor (left), and photoacoustic gas sensor (right) [29,30].

- **Photoacoustic spectroscopy method:** Mid-infrared light, coordinating with the assimilation groups of the CO_2 particles, is discharged into a for the most part shut estimating cell. The CO_2 atoms in the estimating cell assimilate a portion of the illuminated light, while different particles cannot add to the ingestion because of the range of the transmitted light. The more particles are available in the estimating cell, the more prominent the ingested energy. The consumed energy of CO_2 particles - mostly energizes atomic vibrations, which build the translational energy of the particles and, gratitude to the shut estimating cell expands the pressing factor in the cell. The adjustment of the light source causes an occasional pressing factor change in the estimating cell that can be estimated utilizing a receiver. The mouthpiece signal fills in as a proportion of the quantity of CO_2 particles present in the estimating cell and can be utilized to compute the CO_2 concentration [30]. These types of sensors have the smallest size, cheap value, and have high accuracy [31–33].

- **The non-dispersive infrared (NDIR) method**: uses the characteristics of a single gas to absorb the infrared (IR) light of a specific frequency exposed by the sample gas. The sensor measures the composition and concentration by analyzing the frequency and range of the absorbed light. Since all infrared light of all frequencies emitted by the light source is used, it is called "non-dispersive". Among the IR periodically emitted by the light source, the IR detector only absorbs an amount proportional to the CO_2 concentration of 4.26 µm wavelength in the gas sample. The detector with a built-in filter is configured to be sensitive only to a narrow band with a center of 4.26 µm and emits an electrical signal (proportional to the infrared light it absorbs) to indicate the actual CO_2 concentration [34]. Figure 1.5 shows the spectrum of some gases. To measure total CO_2 concentration, the difference between the light intensity of an IR lamp is measured and the amount of IR light emitted by the sensor. The difference is related to the absorption of light by the CO_2 particles in the air inside the chamber, it is directly proportional to the number of CO_2 particles in the air sampling chamber. In NDIR sensors, the infrared light intensity will be absorbed by gas molecules relation expressed in Lambert-Beer Law.

$$I = I0\ e^{(-\alpha\ell)} \tag{1.1}$$

Where I is the light beam that is transferred to the sample chamber, I0 is the light on the sample chamber, α is the sample absorption factor of the sample and ℓ is the chamber's optical path length. The absorption factor α is the product of the gas concentration and the specific absorptivity of the gas ε which is 4.26 µm for CO2 [35,36]. NDIR sensors have high accuracy, less sensitive to pressure variations, vibrations, and acoustic interference than acoustic sensors [37].

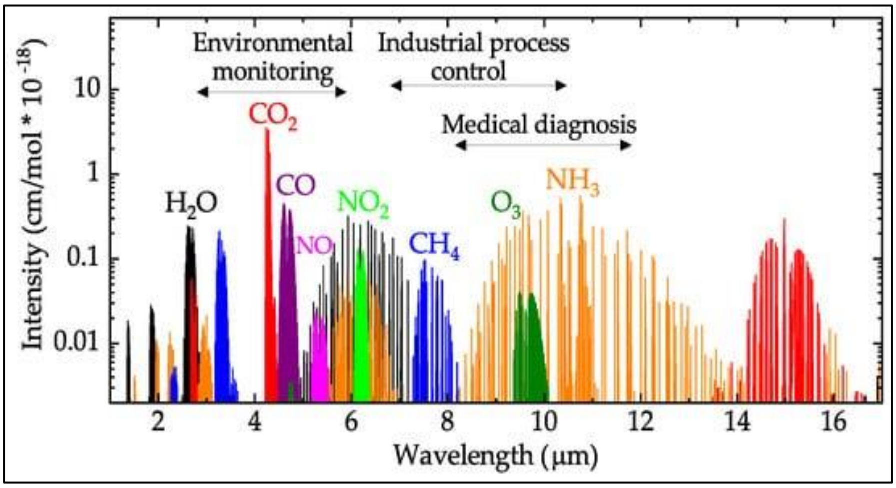


Figure 1.5. Mid-infrared spectrum absorption of gases [34].

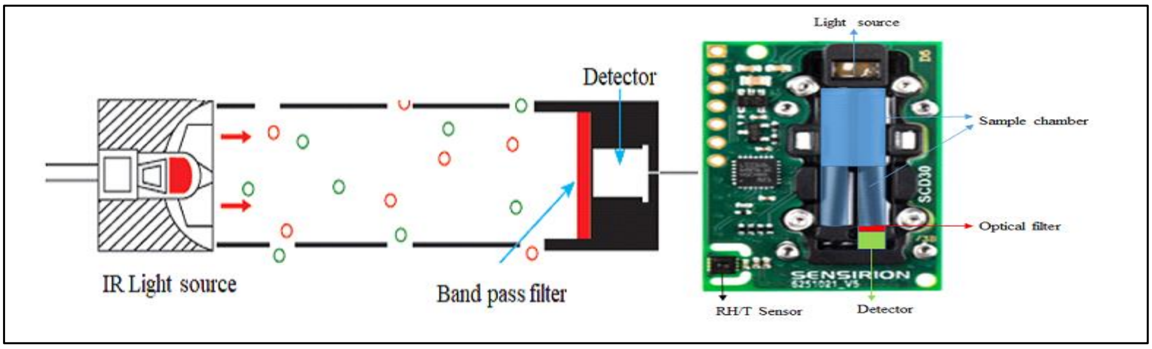


Figure 1.6. The simple design of NDIR sensor (left) and SCD30 sensor (right) [31].

- **Humidity** is a measure of the amount of water vapor in the air. There are different expressions about humidity with different evaluation techniques like saturation humidity, absolute humanity, and relative humidity [38]. RH measures the amount of water in the air related to the maximum amount of water vapor (humidity). There is a relation between temperature and humidity. As the temperature rises, the water vapor rate can be increased in ambient [39]. The RH measurement is stated as a percentage and determined by:

$$\%RH = \left(\frac{Pv}{Ps}\right) \times 100 \quad (1.2)$$

Pv is the actual partial pressure of moisture content in air and Ps is the saturated pressure of moist air at the same given temperature. There are three types of humidity sensors; capacitive, resistive, and thermal conductivity sensors. In this work, a capacitive type humidity sensor is used.

The capacitive humidity sensor, as from the name, uses a capacitor, which is composed of two layers of electrodes with a dielectric material between the electrodes. For capacitive humidity sensors, the dielectric material is hygroscopic, which means it can absorb water molecules in the covered air. Polymer film which dielectric constant of about 3-18 is regularly used in capacitive type humidity sensors [40]. Without the existence of the water molecules, the capacitance is calculated by the geometry and dielectric constant of the capacitor. The dielectric constant k of water vapor at room temperature is about 80, which is much higher than that of dielectric materials. As the dielectric material absorbs water vapor from the surrounding air, the dielectric constant increases, thereby increasing the capacitance of the sensor.

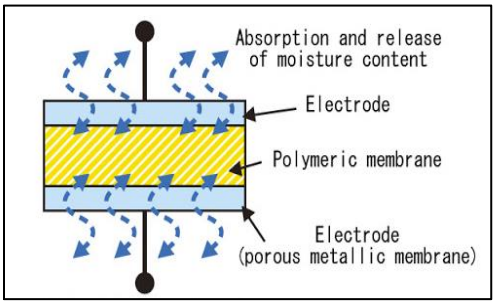


Figure 1.7. Structure of a capacitive humidity sensor [41].

In the change of the capacitor, the relative humidity level can be determined. The capacitive humidity sensor provides stable readings over time. These types of sensors provide near-linear signal amplitudes in the humidity range. The accuracy is proportional to the signal circuit and sensor distance. The nearest distance gives better accuracy [37].

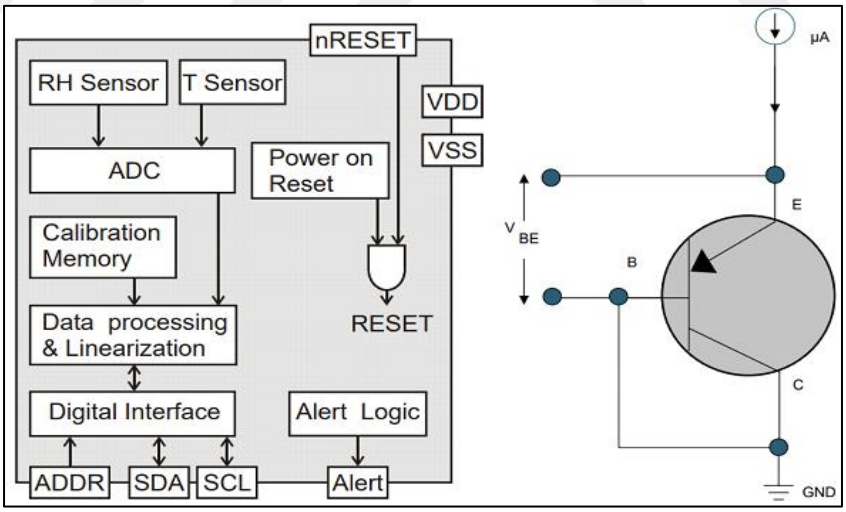


Figure 1.8. Block diagram of SHT31 (left) and its working principle (right) [42].

- **The basic working principle of the temperature sensor** is the voltage across the diode terminals. If the voltage rises, the temperature also rises, followed by a voltage drop between the base of the transistor and the emitter of the diode shown in Figure 1.8. There exists a high variety of temperature sensor types. In this work, an IC temperature sensor is used [43]. The IC temperature sensor is based on silicone material with the precision of temperature relation. As shown in Figure 1.8, the current causes the P-N junction to have an internal forward bias, and the resulting base-to-emitter voltage change (ΔVbe) corresponds to the device temperature.

$$\nabla \mathrm{Vbe} = \left(\frac{kT}{q}\right) \times \ln\left(\frac{Ic}{Is}\right) \tag{1.3}$$

V_{BE} is base-emitter voltage, (kT/q) is the thermal voltage (at room temperature in general 26 mV), I_C is collector bias current, I_S is collector saturation current and q is the electron charge. Given the predictable properties of silicon, integrated circuits provide high linearity and accuracy over a broad heat range [44].

1.4. PULSE OXIMETRY

Pulse oximetry is a non-invasive method used to monitor arterial hemoglobin oxygen saturation (SAO_2 percent). The basic mathematics of pulse oximetry can be derived from the Beer-Lambert law. This fundamental aspect of spectroscopy describes how the intensity of light decays when passing through a non-dispersive substance that absorbs light and is composed of one or more components. This is also called photo-plethysmography (PPG) [45].

$$A \equiv \log\left(\frac{I0}{I1}\right) = E \cdot C \cdot D \tag{1.4}$$

From Beer Lambert's law, the light absorption A where I0 is the incident light intensity, I_1 is the transmitted light intensity, E is an extinction coefficient (dL/g/cm), C is the concentration (g/dL), and D is the thickness (cm).

There are two common types of pulse oximetry sensor configurations: transmissive and reflective. The transmissive type sensor is structured with an optical transmitter and a sensor located on the opposite surface, like the earlobe or toe where the sensor is applied to. For a reflective type sensor, the transmitter and sensor are adjacent to each other, and the sensor can be positioned to a single surface, such as finger and forehead. Figure 1.9. demonstrates the transmissive and reflectance type pulse oximeters. In both pulse oximeter type sensors, the transmitter illuminates the skin with red and IR, and the sensor measures the scattered light transmitted through the blood perfused tissue. Specifically, red light is in 660nm and IR light is 940 nm wavelength [46]. According to FDA (US. Food and Drug Administration), the acceptable accuracy of the pulse oximeter is ±3 percent [47]. Normal ranges of SPO_2 in a healthy person are between 95 and 100 percent [48].

For detecting the SPO_2 value, the quantity of light received by the detector determined the oxygen levels of the hemoglobin. High rate oxygenated hemoglobin (oxyhemoglobin or HbO_2) absorbs higher wavelength light. That means absorbs more IR. Low rate oxygenated hemoglobin absorbs lower wavelength light that is more red light. By the differences in the amounts of IR and red light absorbed from the detector, the SPO_2 rate is calculated by the algorithm. The current values of infrared and red LEDs are inversely proportional (when one is a high current, the other is a low current) to get a better quality signal to the sensor [49].

For the heart rate (HR) measurement, two methods are used in common. The first method uses the peak detection algorithm (PDA) and the second uses the autocorrelation function (ACF). PDA uses a combination of threshold detection and zero crossing. First, a pulse is detected when the threshold is reached, and then the microcontroller measures the PPG signal and obtains its maximum value during the entire AC cycle. When a zero crossing occurs, the algorithm calculates a new threshold. Finally, between two pulses, the counter will get your menstrual period and thus heart rate. For ACF, the microcontroller stores the 1.4-second window of the PPG signal, then calculates the autocorrelation function and determines the position of the first harmonic, the lag from the center to the first peak, or the number of samples, and determines the signal period and therefore the heart rate [50]. Figure 1.10 demonstrates the light absorption diagrams for the oxygenated and deoxygenated hemoglobin for specific wavelengths.

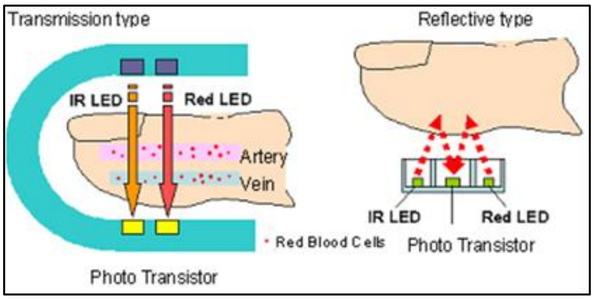


Figure 1.9. Transmissive (left) and reflectance (right) type pulse oximeter [51].

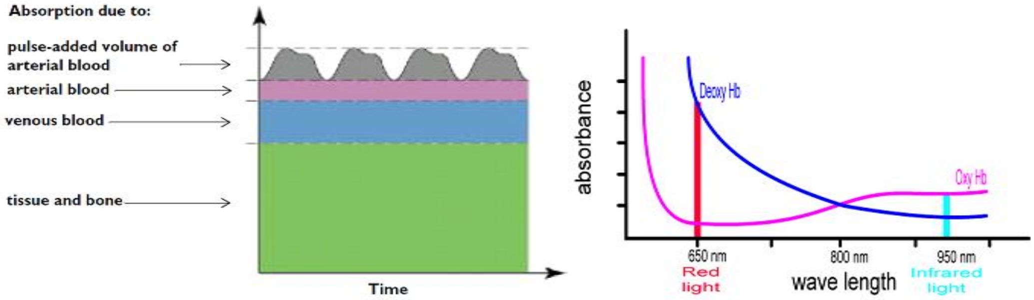


Figure 1.10. Light absorption diagrams [52,53].

1.5. RELEVANT STUDIES

There have been several studies conducted for examination of face mask usage. One study assesses the physiological effects of face masks during workouts with the ergometry cycle. 16 volunteers were tested with no mask, surgical mask, and FFP2 respirator separately. Volunteers have performed their maximum personal physical performances. The measured physical parameters are HR, SPO_2, blood pressure, respiratory rate, and end-tidal CO_2 values with a patient monitor. The results of the mask worn tests are minor differences with no mask in the general and a mild increase of end-tidal CO_2 [54]. Two studies have been conducted with surgical masks worn over FFP2 respirators by healthcare workers and doctors. In one study, a pulse oximeter with a finger probe is used to measure HR and SPO_2. Parameters are recorded while doctors are in operation. 20 volunteered doctors were separated into four groups and each group has different study durations. The test durations are 20, 20-40, 40-120, and 120-240 minutes. The observations are increasing heart frequency, the sensation of shortness of breath, and light-headedness/headache [55]. Another study is applied with 10 volunteers and 1 hour of duration. The measured and recorded parameters are HR, respiratory rate, tidal volume, minute volume, SPO_2, transcutaneous carbon dioxide levels, and respirator dead space gases are monitored and compared with only N95 respirator, without a surgical mask. No significant difference is observed [56]. The other study for effects of the face mask usage is performed with 44 volunteers with and without surgical masks in six minutes walking separately. The recorded parameters are the walked- distance, HR, dyspnea, and SPO_2. The results show that dyspnea is higher with a surgical mask. The other parameter results observed no significant differences [57].

2. MATERIALS AND METHODS

In this thesis work, the aim is to assess the physiological parameters related to respiratory during mask use in daily activities. The daily activities considered are sitting in a closed public and walking outdoor. Two different signal acquisition setups are developed for the purpose as illustrated in Figure 2.1. One setup acquires and records the heart rate and SPO_2 signals, the other setup acquires and records the CO_2, humidity, and temperature signals.

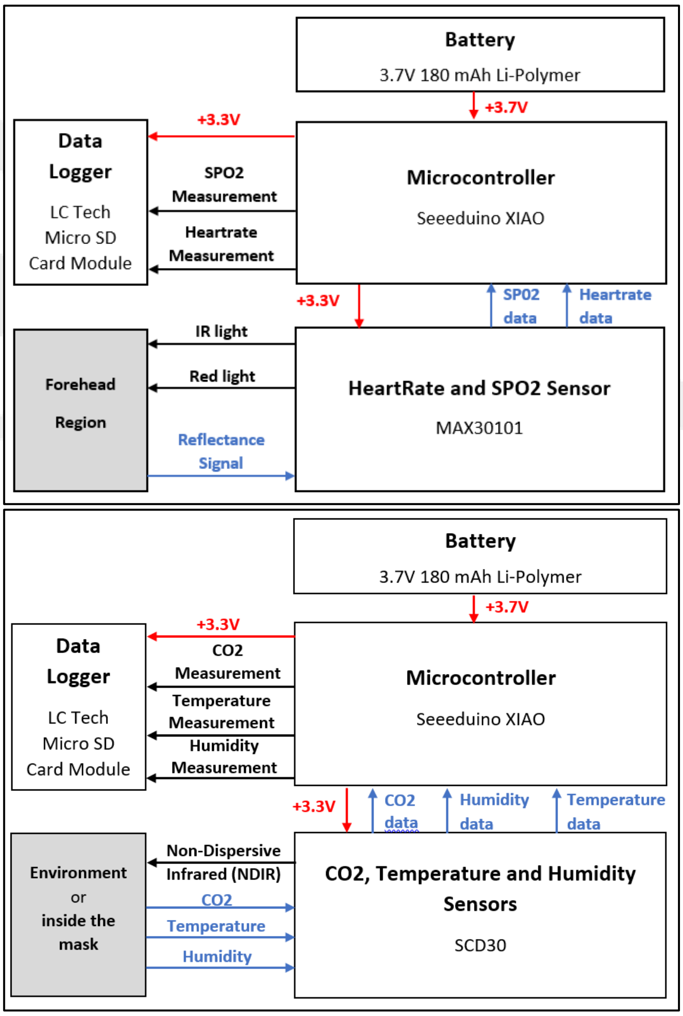


Figure 2.1. Block diagrams of the signal acquisition setups developed.

2.1. HEART RATE AND SPO2 SENSORS

MAX30101 (Maxim Integrated Products Inc., USA) is a reflectance pulse oximeter sensor that makes the detection with the infrared and red light-emitting diodes to reflect light from the conduits and arterioles in the skin. Detection is achieved on how much light is absorbed by photodetectors considering the PPG technique. SpO_2 results are calculated as the percentage of hemoglobin that is saturated with oxygen [58]. Figures 2.2 and 2.3 respectively demonstrate the MAX30101 breakout board with pull-up resistors and the schematics of the MAX30101 breakout board.

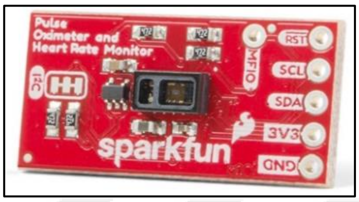


Figure 2.2. MAX30101 breakout board [58].

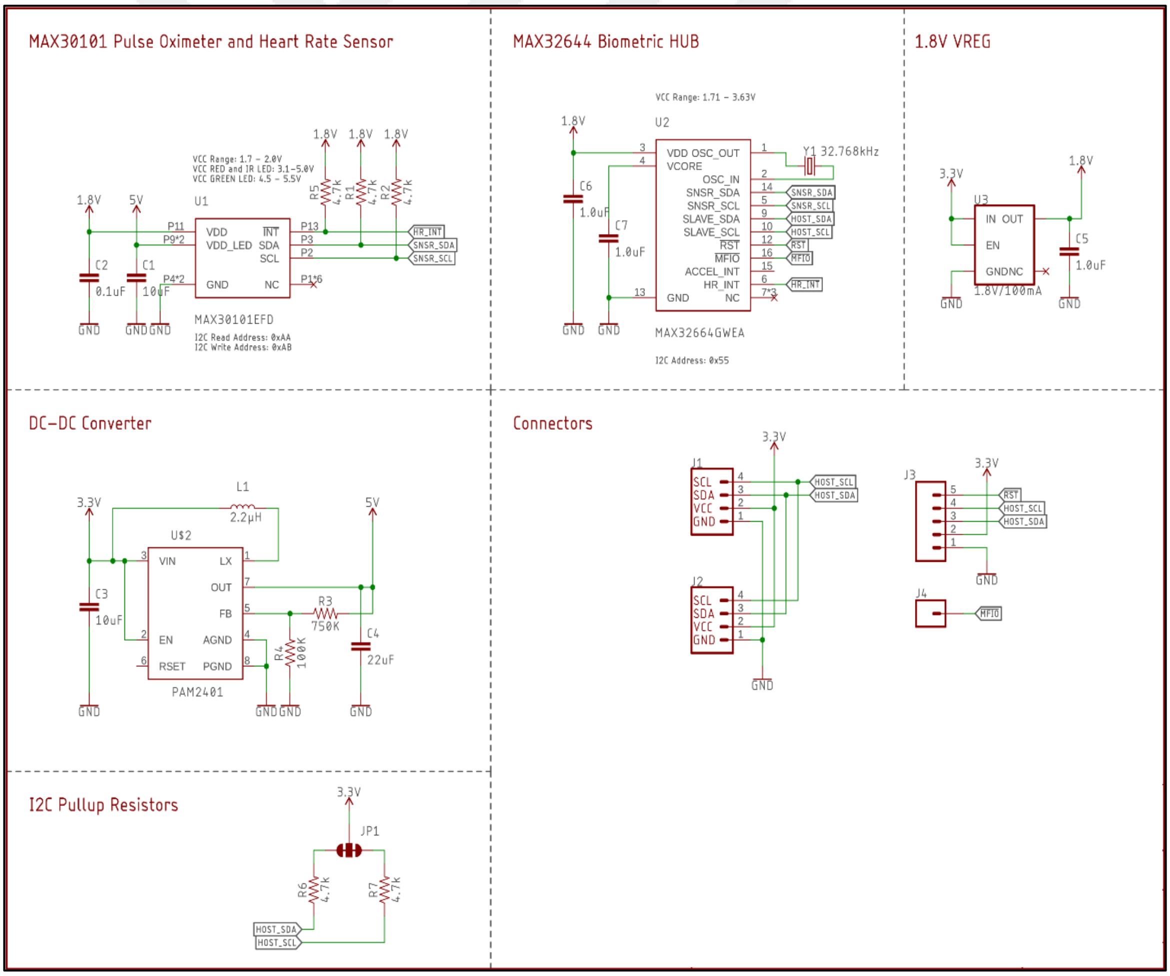


Figure 2.3. Schematics of MAX30101 breakout board [58].

2.2. CARBON DIOXIDE, HUMIDITY AND TEMPERATURE SENSORS

SCD30 (Sensirion AG, Switzerland) is for the accurate determination of CO_2 in the air has been used in many research for air quality analyses [59–61]. The measurement range of the sensor for CO_2 is from 0 to 40000 ppm with an accuracy of ±30 ppm. The sensor can take measurements every two seconds. The breakout board of SCD30 comes with Sensirion SHT31 relative humidity and temperature sensors. The temperature measurement range is -40°C to 70°C with the accuracy of ± (0.4°C + 0.023 x (T [°C] - 25°C)) where T is the temperature value that sensor reads. The relative humidity range is 0 -100 percent with an accuracy of ±3 percent. The operating voltage ranges from 3.3V to 5.5V with overall current consumption of 19 mA [31]. SCD30 breakout board (see Figure 2.4) is capable of communicating with microcontrollers through the I2C interface and is factory calibrated.

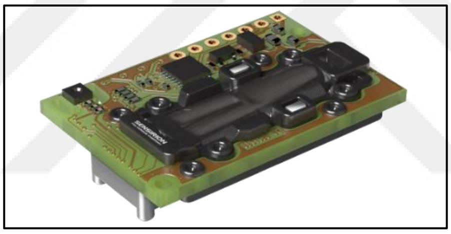


Figure 2.4. SCD30 breakout board [31].

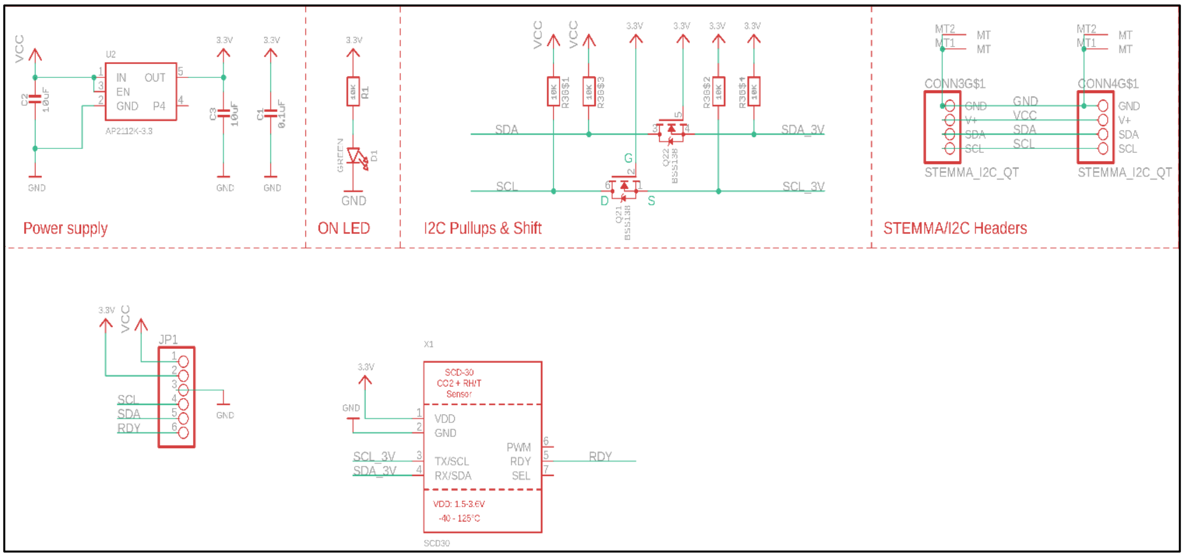


Figure 2.5. Schematics of the SCD30 breakout board [31].

2.3. MICROCONTROLLER

The Seeeduino Xiao (Seeed Technology Co. Ltd., PRC) is a very small and low-power microcontroller with fourteen general-purpose input/output terminals (see Figure 2.6). It is equipped with a USB Type-C interface for supplying power and uploading microcontroller code and is capable of working both 5V and 3.3V. There are power pads at the back of the Xiao that can be soldered via wire to battery useful to make it for a wearable device [62].

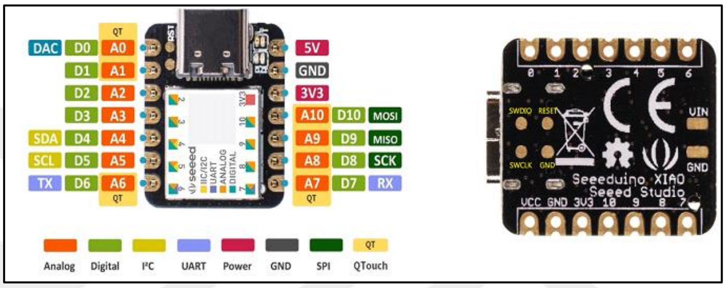


Figure 2.6. Front and back sides of Seeeduino Xiao [62].

2.4. DATA LOGGER

LC Technology micro SD card module (LC Technology International, Inc. USA) is to write or read data to/from a micro SD card and is designed for use with microcontrollers working with both 3.3V and 5V [63]. A 16 gigabyte SanDisk brand micro SD card is used with the module. The file on the SD card closes when the power is off. A new different name labeled file opened when the power is on to avoid any overwriting for the data recorded. The programming consists of opening a new file when power on, has a time recorder in milliseconds with each sample period. Figure 2.7 demonstrates the SD card module.

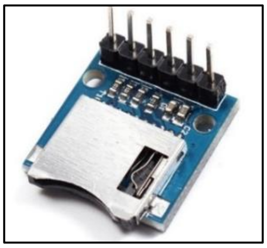


Figure 2.7. LC Tech micro SD card module [64].

Figure 2.8 shows the schematics of the signal acquisition setups developed.

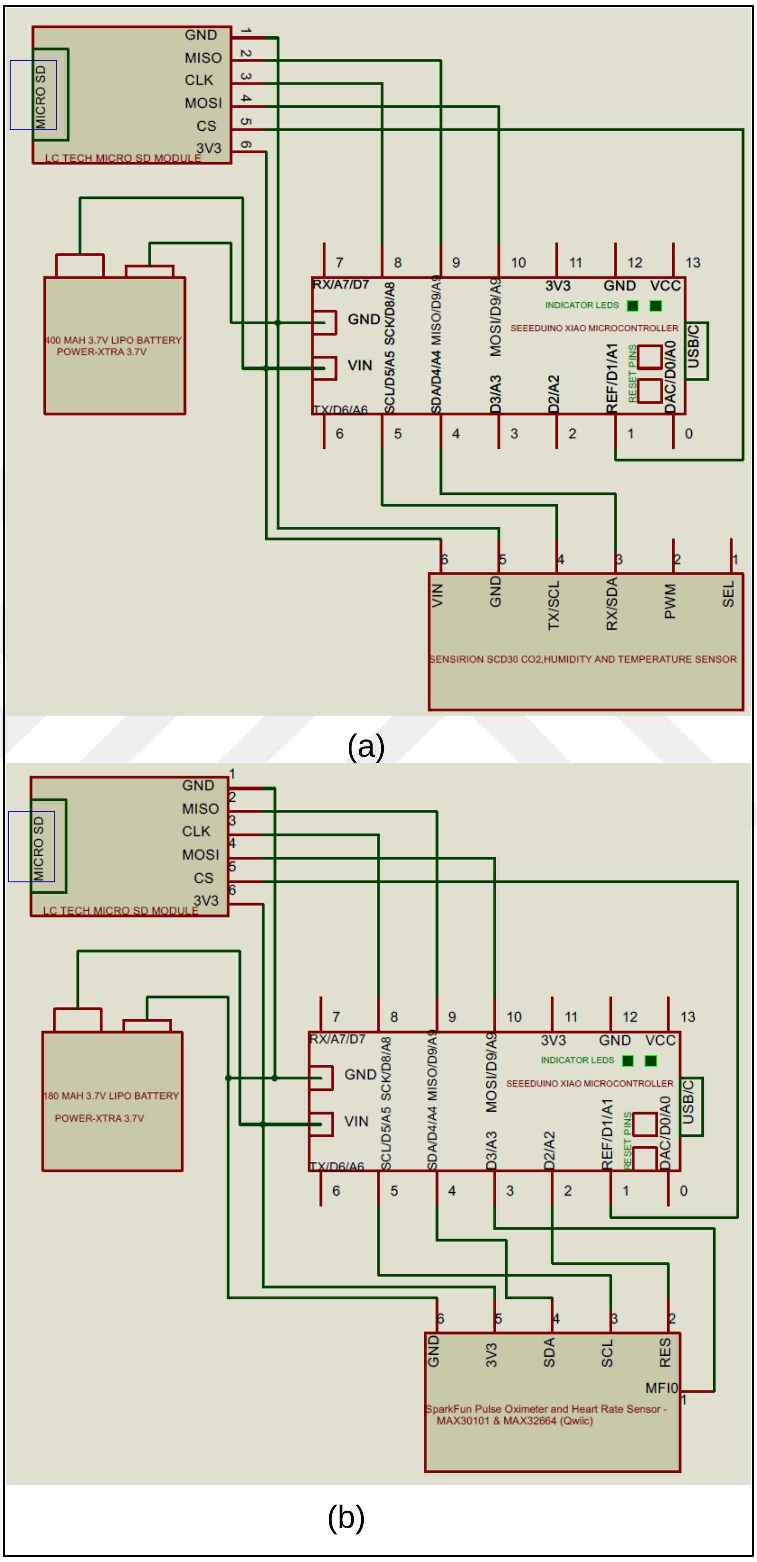
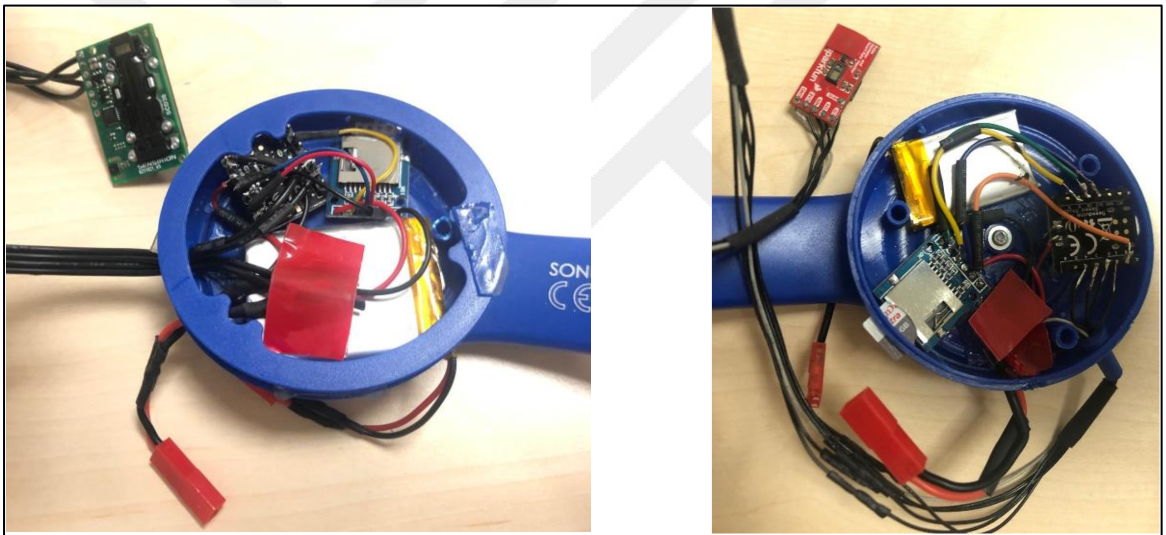


Figure 2.8. Schematics of (a) the CO2, temperature, and humidity signal acquisition setup and (b) the SPO2 and heart rate signal acquisition setup.

2.5. PHYSICAL PLACEMENTS OF THE COMPONENTS AND THE SENSORS

For making a housing for the components, an on-ear headphone is obtained and the speaker parts are removed for spacing and some trimming is made to the headphone to fit the electronic components of the signal acquisition setups developed. The acquisition setup equipped with the MAX30101 breakout board, microcontroller, SD card module, battery, and relevant electronic components are placed on the left ear side. The acquisition setup equipped with the SDC30 breakout board, microcontroller, SD card module, battery, and relevant electronic components are placed on the right ear side. Holes are cut from both sides of the headphone for connections to the outside (see Figure 2.9).



(a) (b)

Figure 2.9. Placements of the components on the ear sides (a) left and (b) right.

During all exercises, heart rate and SPO2 measurements are taken by the MAX30101 sensor placed on the forehead region of a volunteer with a gel-removed ECG electrode. On the other hand, CO_2, temperature, and humidity measurements are taken from the environment by the SCD30 sensor placed on the top side of the on-ear headphone for no mask use case. For mask/respirator use cases, measurements are taken in mask dead space. To do that, the sensor is placed from cheeks through the mask dead space and fitted to the mask from inside with a Velcro band (see Figure 2.10).

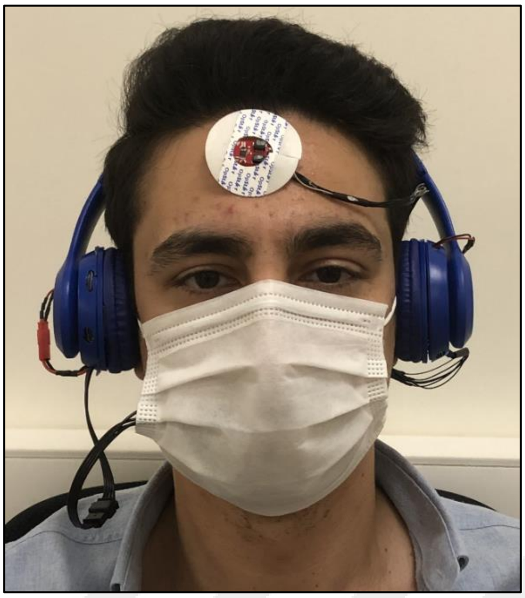


Figure 2.10. Sensor placements for the exercises with mask.

2.6. STUDY POPULATION AND EXERCISE PROTOCOL

A total of 17 volunteer candidates are briefed about the study and their informed consent is secured. Demographic compliance is taken and analyzed considering the exclusion criteria (i.e. physiological disabilities that prevent the candidate from walking, acute or chronic lung and cardiac diseases). Fifteen volunteers (6 female and 9 male; age range: 20-35 years; body mass index range: 18-30) are entered to the study.

For the exercise protocol, two exercises are considered: sitting and walking. Sitting exercises are performed at the biomedical engineering laboratory of Yeditepe University to mimic indoor conditions. Walking exercises are carried out at the fitness center of Yeditepe University. The fitness center is well ventilated to mimic outdoor conditions and the exercise is performed using a walking treadmill (Panatta Bora/1BO403; Panatta Srl, Italy) operated with 4.7 km/h speed for a distance of 800 meters. Each exercise is performed for ten minutes' duration followed by a 5-minutes break, with no mask, with surgical face mask, and with FFP2 respirator.

Selection criteria for the face mask and the FFP2 respirator are high protection, and acknowledged compliances with the standards and registered by the public authorities [65]. The face mask is equipped with three layers: spun-bond inner layer, melt-blown middle layer, and spun-bond outer layer and complies with EN14683:2019 standards. The FFP2 respirator has three layers: spun-bond inner layer, melt-blown middle layer, and spun-bond outer layer and with a nose wire for improved fitting on the face. The respirator has EN:2001+A1:2009 standards. Two surgical face masks and one FFP2 respirator are given to each volunteer. The masks are changed, however, the same FFP2 respirator is used in each exercise. Single-use ECG electrode with conductor gel removed for fitting MAX30101 is changed in each exercise. The on-ear headphone is sterilized with Star Brand 99.9 percent pure isopropyl alcohol and ventilated after use by each volunteer.

2.7. STATISTICAL ANALYSIS

The power analysis is used to determine the minimum number of volunteers needed to be enrolled in the study. Type error probability, α is set to 0.05 while the power, 1- β is set to 95 percent. Within the scope of the research, two different two-sided hypotheses are formed:

- H0: The use of a face mask while sitting or walking does not affect physiological parameters related to respiration such as blood oxygen saturation and pulse.
- H1: The use of a face mask while sitting or walking has an effect on physiological parameters related to respiration, such as oxygen saturation in the blood and heart rate, while the use of a face mask decreases oxygen saturation and increases heart rate.
- H0: While individuals are sitting or walking, the carbon dioxide, temperature and humidity data in the area of the mask do not differ according to the external environment during the use of the face mask.
- H1: During the use of a face mask while individuals are sitting or walking, the carbon dioxide, heat, and humidity measurements in the inside of the mask vary according to the external environment. The heat, humidity, and carbon dioxide ratios inside the mask are significantly higher than in the outside environment.

Kolmogorov-Smirnov test is used to determine the parametric or non-parametric distribution of measured variables. Paired t-test is used to determine statistical significance for variables measured for no mask use and mask use. Pearson correlation analysis is used to determine correlations in the measured variables for no mask use and mask use. A P value of <0.05 is considered to be statistically significant. All statistical analyses are conducted using IBM SPSS for Windows (version 25.0; IBM Corp., Armonk, NY).

3. RESULTS

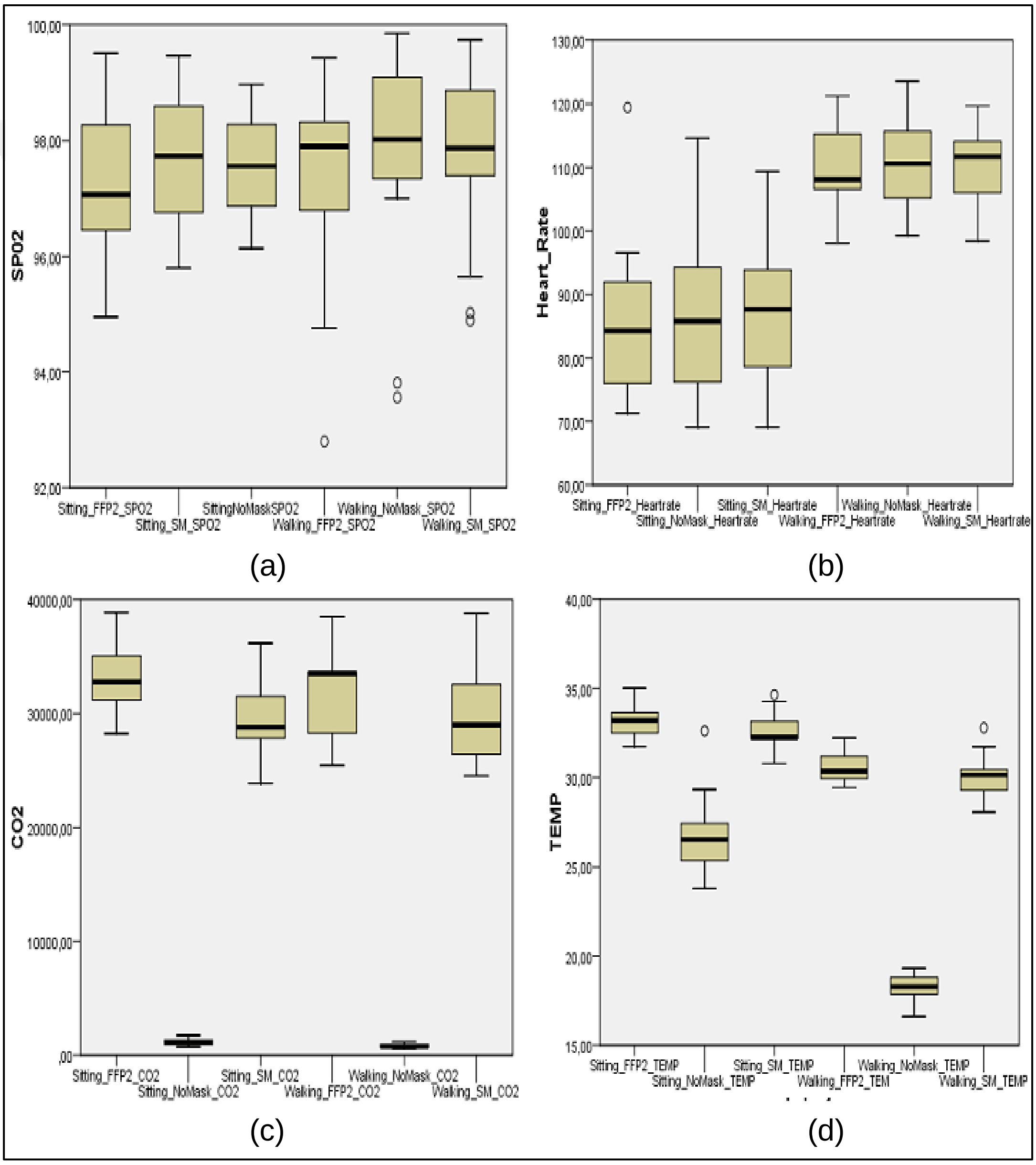
Power analysis figures out a minimum number of 13 volunteers, however, a total of 15 volunteers has been enrolled in the current study. The SPO_2, heart rate, CO_2, temperature, and humidity measurements recorded during the sitting and walking activities with no mask, surgical mask, and FFP_2 respirator are listed in Table 3.1. Corresponding box plots are seen in Figure 3.1. For the sitting activity, very similar overall SPO_2 and heart rate measurements are of concern regardless of the mask use (P= 0.58-0.36, and P= 0.82-0.85). Very similar overall SPO_2 and heart rate measurements are also detected for the walking activity (P= 0.98-0.10, and P= 0.65-0.69), however, the heart rates are larger as expected for that activity. Overall CO_2, temperature and humidity measurements are significantly smaller with no mask use but larger with mask use regardless of the activity (P< 0.05).

Table 3.1. Descriptive statistics of the measurements

		Sitting Activity	**Walking Activity**
SPO_2 (%)	No mask	97.51 ± 0.88 [a] 96.14 - 97.56 - 98.18 [b]	97.74 ± 1.87 93.56 - 98.02 - 99.86
	Surgical Mask	97.62 ± 1.15 95.80 - 97.73 - 99.47	97.74 ± 1.55 94.89 - 98.02 - 99.74
	FFP2 Respirator	97.34 ± 1.23 94.95 - 97.07 - 99.51	97.27 ± 1.68 92.80 - 97.90 - 99.43
Heart rate (bpm)	No mask	85.82 ± 12.78 69.13 - 85.82 - 114.63	110.70 ± 7.00 99.34 - 110.62 - 123.57
	Surgical Mask	87.67 ± 10.71 69.13 - 87.67 - 109.38	110.28 ± 6.20 98.46 - 111.68 - 119.69
	FFP2 Respirator	84.30 ± 12.60 71.33 - 84.30 - 119.42	110.27 ± 6.90 98.04 - 108.11 - 121.24
CO_2 (x10^3 ppm)	No mask	1.18 ± 0.28 0.73 - 1.17 - 1.76	0.83 ± 0.17 0.63 - 0.78 - 1.20
	Surgical Mask	29.58 ± 3.18 23.88 - 28.80 - 36.19	29.17 ± 4.02 24.54 - 28.99 - 38.80
	FFP2 Respirator	33.21 ± 3.11 28.26 - 32.78 - 38.86	32.00 ± 3.76 24.55 - 33.53 - 38.52
Temperature (°C)	No mask	26.64 ± 2.23 23.79 - 26.53 - 32.62	18.29 ± 0.68 16.53 – 18.29 – 19.32
	Surgical Mask	32.57 ± 1.10 30.80 - 32.26 - 34.64	30.02 ± 0.32 28.07 – 30.16 – 32.79
	FFP2 Respirator	33.12 ± 0.91 31.74 - 33.20 - 35.02	30.62 ± 0.22 32.24 – 30.37 – 29.46

Humidity (%)	No mask	33.35 ± 2.09 29.37 - 34.32 - 35.45	39.06 ± 2.07 36.36 - 38.77 - 43.87
	Surgical Mask	74.08 ± 12.19 48.20 - 75.14 - 90.71	88.98 ± 5.01 79.54 - 89.86 - 94.72
	FFP2 Respirator	76.57 ± 8.51 60.89 - 77.94 - 94.56	88.83 ± 5.69 78.14 - 90.37 - 96.01

[a] Mean ± SD. [b] Minimum - Median – Maximum



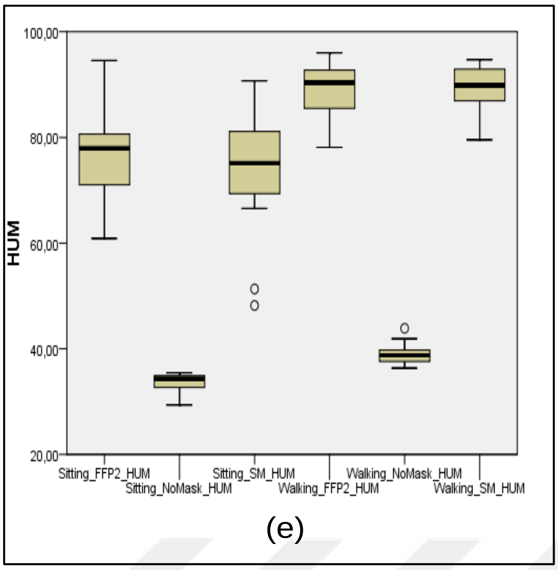


Figure 3.1. Boxplots for (a) SPO2, (b) heart rate, (c) CO2, (d) temperature, and (e) humidity during sitting and walking activities.

Table 3.2 shows the correlations between the measurements for sitting and walking activities with no mask, surgical mask, and FFP2 respirator. Among the measurements, strong positive correlations exist for SPO_2 and heart rate with significance (r> 0.80, and P< 0.05). The rest of the measurements are with strong, moderate or poor correlations (r= -0.39 - 0.96) with no significance (P= 0.96-0.06).

Table 3.2. Correlations between the measurements.

		Sitting Activity		Walking Activity	
		r	***P***	**r**	***P***
SPO_2	No mask - surgical mask	0.80	*	0.84	*
	No mask - FFP2 respirator	0.81	*	0.83	*
Heartrate	No mask vs surgical mask	0.86	*	0.86	*
	No mask vs FFP2 respirator	0.95	*	0.82	*
CO_2	No mask vs surgical mask	-0.39	0.89	-0.35	0.20
	No mask vs FFP2 respirator	0.50	0.06	0.49	0.06
Temperature	No mask vs surgical mask	0.28	0.30	0.90	0.74
	No mask vs FFP2 respirator	-0.34	0.20	0.38	0.17
Humidity	No mask vs surgical mask	-0.13	0.96	0.38	0.22
	No mask vs FFP2 respirator	0.29	0.29	0.20	0.29

* P < 0.05

4. DISCUSSION

This thesis work aims to reveal the respiratory-related impacts of face mask use on healthy people in daily life. To do this, the need for designing a wearable physiological signal acquisition setup is essential. The design has to gather the raw signals from the body, process them and then record the results for analysis. First of all, the decision of which signals should be gathered from the body are determined. The respiratory system directly affects the SPO_2 and heart rate. MAX30101 sensor is decided to gather these signals. The exhaled breath is needed to be analyzed which some of it is inhaled back. To do this, the SCD30 sensor is decided for use. Since these signals are gathered from the head region, the circuit components which are a microcontroller to control the operation of the circuit, an SD card module to record the data captured by the sensor, and a battery for running all of the components are fitted into one ear side of a headphone. For MAX3101 placement, the temporal bone site may be chosen at first glance but there exists our previous study it can be also placed on the temporal bone site [66]. A hearing aid device is obtained for placing MAX30101. All of the components inside the hearing aid device are removed and the outer shell of the device is trimmed for MAX30101. Finally, MAX30101 is fitted to it and tested. Signal readings gave insufficient data. We figure out that the headset makes pressure on the sensor and skin and affects the sensor readings. This design is canceled and MAX30101 is placed on the forehead region. After that, data are gathered successfully. MAX30101 offers SPO_2 and heart rate measurements while SCD30 allows CO_2, temperature, and humidity measurements. For sitting activity, very similar overall SPO_2 and heart rate measurements are of concern regardless of the mask use while very similar overall SPO_2 and heart rate measurements are also detected for walking activity. However, the heart rates are larger as expected for that activity. Besides, overall CO_2, temperature, and humidity measurements are significantly smaller with no mask use but larger with mask use regardless of the activity. In the use of both surgical face masks and FFP2 respirators, a huge accumulation of measured parameters is anticipated in the dead space of the mask/respirator that leads to poor air quality for breathing. Breathing high CO_2 concentrations may lead to serious health issues meanwhile exhaled CO_2 concentrations may be hazardous to inhale.

5. CONCLUSION

This thesis work aims to test the impact of the mask usage-related respiratory pattern effects during sitting and walking activities with a developed signal acquisition system for the purpose. The developed design is well fitted to each volunteer and benefits from comfort while acquiring SPO_2, heart rate, CO_2, temperature, and humidity signals inside the mask of the volunteer. The signals are converted into information very successfully and are transferred easily to a computer. For the sitting activity, very similar overall SPO_2 and heart rate measurements are of concern regardless of the mask use while very similar overall SPO_2 and heart rate measurements are also detected for the walking. However, the heart rates are larger as expected for that activity. Besides, overall CO_2, temperature, and humidity measurements are significantly smaller with no mask use but larger with mask use regardless of the activity. In future studies, we are planning to integrate SPO_2 and heart rate sensor on a wireless earbud and to provide mobile phone connectivity. In this manner, the user can easily read and record his results or show the results to a medical consultant. Moreover, the results of high-rated CO_2 and temperature may figure out any conducive environment for the growth of bacteria, fungus, mold, or yeast. The mask samples will be analyzed to clarify this issue and average mask usage durations will be measured to observe the impact of the skincare enclosed in the mask's dead space area.

REFERENCES

1. WHO Coronavirus (COVID-19) Dashboard | WHO Coronavirus (COVID-19) Dashboard With Vaccination Data [Internet]. [cited 2021 Jul 18]. Available from: https://covid19.who.int/

2. Jayaweera M, Perera H, Gunawardana B, Manatunge J. Transmission of COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy. Environ Res. 2020 Sep;188.

3. Scientific Brief: SARS-CoV-2 Transmission | CDC [Internet]. [cited 2021 Jul 22]. Available from: https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/sars-cov-2-transmission.html

4. Xiao AT, Tong YX, Gao C, Zhu L, Zhang YJ, Zhang S. Dynamic profile of RT-PCR findings from 301 COVID-19 patients in Wuhan, China: A descriptive study. J Clin Virol. 2020 Jun;127.

5. Coronavirus (COVID-19) Vaccinations - Statistics and Research - Our World in Data [Internet]. [cited 2021 Sep 24]. Available from: https://ourworldindata.org/covid-vaccinations

6. SARS-CoV-2 Variant Classifications and Definitions [Internet]. [cited 2021 Jul 22]. Available from: https://www.cdc.gov/coronavirus/2019-ncov/variants/variant-info.html

7. Santarsiero A, Giustini M, Quadrini F, D'alessandro D, Fara GM. Effectiveness of face masks for the population. Ann Ig [Internet]. 2021 [cited 2021 Jul 22];33(4):347–59. Available from: https://www.annali-igiene.it

8. PFE Particulate Filtration Efficiency Test - EUROLAB [Internet]. [cited 2021 Aug 12]. Available from: https://www.eurolab.com.tr/en/testler/tekstil-analizleri/pfe-testi

9. Is Cloth Face Mask Effective Against Viruses? | International News Agency [Internet]. [cited 2021 Oct 5]. Available from: https://internationalnewsagency.org/is-cloth-face-mask-effective-against-viruses/

10. Why are Cloth Masks rated "Extremely Poor" for COVID? Why is a 3 Ply Procedural

Face Mask More Effective? [Internet]. [cited 2021 Oct 5]. Available from: https://blog.gotopac.com/2020/06/26/do-cloth-face-masks-work-why-is-a-3-ply-procedural-mask-more-effective/

11. Protective Masks: Faced with Coronavirus, Standard Development Bodies Follow Multiple Leads - AFNOR Group [Internet]. [cited 2021 Jul 23]. Available from: https://www.afnor.org/en/news/protective-masks-faced-with-coronavirus-standard-development-bodies-follow-multiple-leads/

12. CEN - Technical Bodies - [Internet]. [cited 2021 Jul 23]. Available from: https://standards.cen.eu/dyn/www/f?p=204:110:0::::FSP_PROJECT,FSP_ORG_ID:32928,6062&cs=1FC98AD34A5EE26A0CB5A6155ED4D6E5E

13. Lee S-A, Hwang D-C, Li H-Y, Tsai C-F, Chen C-W, Chen J-K. Particle Size-Selective Assessment of Protection of European Standard FFP Respirators and Surgical Masks against Particles-Tested with Human Subjects. J Healthc Eng. 2016;2016.

14. Staymates M. Flow visualization of an N95 respirator with and without an exhalation valve using schlieren imaging and light scattering. Phys Fluids. 2020 Nov 1;32(11).

15. Filtering Facepiece Respirators with an Exhalation Valve: Measurements of Filtration Efficiency to Evaluate Their Potential for Source Control. 2021 Dec 1 [cited 2021 Jul 23]; Available from: https://www.cdc.gov/niosh/docs/2021-107/

16. Jonsson Workwear | FFP1 Disposable Masks [Internet]. [cited 2021 Oct 5]. Available from: https://www.jonssonworkwear.com/ffp1-dust-mask-disposable-20pcs

17. N95 Respirator Mask [Internet]. [cited 2021 Oct 5]. Available from: https://www.noinsurancemedicalsupplies.com/n95-respirator-mask/

18. FFP3 Face Mask with valve | Alpidex [Internet]. [cited 2021 Oct 5]. Available from: https://www.alpidex.com/en/respiratory-masks/a-16241

19. Carbon Dioxide | Vital Signs – Climate Change: Vital Signs of the Planet [Internet]. [cited 2021 Jul 23]. Available from: https://climate.nasa.gov/vital-signs/carbon-dioxide/

20. Lawrence EO, Apte MG, Fisk W], Daisey JM. ·· Preprint Associations Between Indoor C02 Concentrations and Sick Building Syndrome Symptoms in US Office Buildings: An Analysis of the 1994~1996 BASE Study Data.

21. Wargocki P, Wyon D, Sundell J, … GC-I, 2000 undefined. The effects of outdoor air supply rate in an office on perceived air quality, sick building syndrome (SBS) symptoms and productivity. innenraumanalytik.at [Internet]. [cited 2021 Jul 23]; Available from: http://www.innenraumanalytik.at/Newsletter/wargocki.pdf

22. Tietjen GE, Khubchandani J, Ghosh S, Bhattacharjee S, Kleinfelder J. Headache symptoms and indoor environmental parameters: Results from the EPA BASE study. Ann Indian Acad Neurol [Internet]. 2012 Aug [cited 2021 Jul 23];15(Suppl 1):S95. Available from: /pmc/articles/PMC3444215/

23. FLAVORINGS-RELATED LUNG DISEASE [Internet]. [cited 2021 Jul 23]. Available from: https://www.cdc.gov/niosh/topics/flavorings/limits.html

24. Zhang X, Wargocki P, Lian Z. Human responses to carbon dioxide, a follow-up study at recommended exposure limits in non-industrial environments. Build Environ. 2016 May 1;100:162–71.

25. Electrochemical Sensor - an overview | ScienceDirect Topics [Internet]. [cited 2021 Jul 23]. Available from: https://www.sciencedirect.com/topics/materials-science/electrochemical-sensor

26. Electrochemical Gas Sensors – Membrapor [Internet]. [cited 2021 Oct 5]. Available from: https://www.membrapor.ch/electrochemical-gas-sensors/

27. Fine GF, Cavanagh LM, Afonja A, Binions R. Metal Oxide Semi-Conductor Gas Sensors in Environmental Monitoring. Sensors 2010, Vol 10, Pages 5469-5502 [Internet]. 2010 Jun 1 [cited 2021 Jul 24];10(6):5469–502. Available from: https://www.mdpi.com/1424-8220/10/6/5469/htm

28. Gas Sensors types and mechanism | CO2 Sensors | PRODUCTS | Asahi Kasei Microdevices (AKM) [Internet]. [cited 2021 Jul 24]. Available from: https://www.akm.com/global/en/products/co2-sensor/tutorial/types-mechanism/

29. Hassan HS, Elkady MF. Semiconductor Nanomaterials for Gas Sensor Applications.

2020 [cited 2021 Oct 5];305–55. Available from: https://link.springer.com/chapter/10.1007/978-3-030-26672-1_10

30. PASens® Technology | Sensirion [Internet]. [cited 2021 Jul 24]. Available from: https://www.sensirion.com/en/about-us/company/pasensr-technology/

31. CO2 Sensor SCD4x | Sensirion [Internet]. [cited 2021 Jul 24]. Available from: https://www.sensirion.com/en/environmental-sensors/carbon-dioxide-sensors/carbon-dioxide-sensor-scd4x/

32. Scholz L, Ortiz Perez A, Bierer B, Eaksen P, Wöllenstein J, Palzer S. Miniature low-cost carbon dioxide sensor for mobile devices. IEEE Sens J. 2017 May 1;17(9):2889–95.

33. Palzer S. Photoacoustic-Based Gas Sensing: A Review. Sensors 2020, Vol 20, Page 2745 [Internet]. 2020 May 11 [cited 2021 Jul 24];20(9):2745. Available from: https://www.mdpi.com/1424-8220/20/9/2745/htm

34. Popa D, Udrea F. Towards Integrated Mid-Infrared Gas Sensors. Sensors 2019, Vol 19, Page 2076 [Internet]. 2019 May 4 [cited 2021 Jul 24];19(9):2076. Available from: https://www.mdpi.com/1424-8220/19/9/2076/htm

35. Hodgkinson J, Smith R, Ho WO, Saffell JR, Tatam RP. Non-dispersive infra-red (NDIR) measurement of carbon dioxide at 4.2μm in a compact and optically efficient sensor. Sensors Actuators B Chem. 2013;186:580–8.

36. Wei P-S, Hsieh Y-C, Chiu H-H, Yen D-L, Lee C, Tsai Y-C, et al. Absorption coefficient of carbon dioxide across atmospheric troposphere layer. Heliyon [Internet]. 2018 Oct 1 [cited 2021 Jul 24];4(10):785. Available from: /pmc/articles/PMC6174548/

37. CO2 - Measurement Theory - Basics | JLC International | jlcinternational.com [Internet]. [cited 2021 Jul 24]. Available from: https://jlcinternational.com/co2-measurement-theory-basics/

38. Farahani H, Wagiran R, Hamidon MN. Humidity Sensors Principle, Mechanism, and Fabrication Technologies: A Comprehensive Review. Sensors (Basel) [Internet]. 2014 Apr 30 [cited 2021 Jul 24];14(5):7881. Available from:

/pmc/articles/PMC4063076/

39. Lawrence MG. The Relationship between Relative Humidity and the Dewpoint Temperature in Moist Air: A Simple Conversion and Applications. Bull Am Meteorol Soc [Internet]. 2005 Feb 1 [cited 2021 Jul 24];86(2):225–34. Available from: https://journals.ametsoc.org/view/journals/bams/86/2/bams-86-2-225.xml

40. Matsuguchi M, Umeda S, Sadaoka Y, Sakai Y. Characterization of polymers for a capacitive-type humidity sensor based on water sorption behavior. Sensors Actuators B Chem. 1998 Jul 1;49(3):179–85.

41. capacitance - How exactly does a (capacitive) humidity sensor work? - Physics Stack Exchange [Internet]. [cited 2021 Oct 5]. Available from: https://physics.stackexchange.com/questions/575105/how-exactly-does-a-capacitive-humidity-sensor-work

42. Datasheet SHT3x-DIS. 2019 [cited 2021 Jul 25]; Available from: www.sensirion.com

43. Types of Temperature Sensors and Their working Principles | Features [Internet]. [cited 2021 Jul 25]. Available from: https://www.elprocus.com/temperature-sensors-types-working-operation/

44. Texas Instruments. The Engineer's Guide to Temperature Sensing. Specialist. 2020.

45. M E. On the analysis of fingertip photoplethysmogram signals. Curr Cardiol Rev [Internet]. 2012 Jun 26 [cited 2021 Jul 31];8(1):14–25. Available from: https://pubmed.ncbi.nlm.nih.gov/22845812/

46. Wukitsch MW, Petterson MT, Tobler DR, Pologe JA. Knowing Your Monitoring Equipment PULSE OXIMETRY: ANALYSIS OF THEORY, TECHNOLO6Y, AND PRACTICE. Vol. 4, J Clin Monit. 1988.

47. Pulse Oximeter Accuracy and Limitations: FDA Safety Communication | FDA [Internet]. [cited 2021 Jul 26]. Available from: https://www.fda.gov/medical-devices/safety-communications/pulse-oximeter-accuracy-and-limitations-fda-safety-communication

48. Hypoxemia (low blood oxygen) - Mayo Clinic [Internet]. [cited 2021 Jul 26].

Available from: https://www.mayoclinic.org/symptoms/hypoxemia/basics/definition/sym-20050930

49. Mendelson Y, Cheung PW, Neuman MR, Fleming DG, Cahn SD. Spectrophotometric Investigation of Pulsatile Blood Flow for Transcutaneous Reflectance Oximetry. Adv Exp Med Biol [Internet]. 1983 [cited 2021 Jul 26];159:93–102. Available from: https://link.springer.com/chapter/10.1007/978-1-4684-7790-0_9

50. Ayance AT, Santiago Ramírez H, Miguel J, Pérez R, Gerardo C, Palacios T. Wireless heart rate and oxygen saturation monitor ARTICLES YOU MAY BE INTERESTED IN. 2019 [cited 2021 Jul 26];2090:40010. Available from: https://doi.org/10.1063/1.5095913

51. Applications of pulse oximetry method - online presentation [Internet]. [cited 2021 Oct 5]. Available from: https://en.ppt-online.org/366859

52. Light absorption by different tissue, at the top we see the... | Download Scientific Diagram [Internet]. [cited 2021 Oct 5]. Available from: https://www.researchgate.net/figure/Light-absorption-by-different-tissue-at-the-top-we-see-the-plethysmogram-generated-by_fig4_221913041

53. How pulse oximeters work explained simply. [Internet]. [cited 2021 Oct 5]. Available from: https://www.howequipmentworks.com/pulse_oximeter/

54. D E, A K, Y I, E M, R Z, B B, et al. Return to training in the COVID-19 era: The physiological effects of face masks during exercise. Scand J Med Sci Sports [Internet]. 2021 [cited 2021 Aug 13];31(1). Available from: https://pubmed.ncbi.nlm.nih.gov/32969531/

55. E P, C L, A R, G R. [Effect of a surgical mask on six minute walking distance]. Rev Mal Respir [Internet]. 2018 Mar 1 [cited 2021 Aug 13];35(3):264–8. Available from: https://pubmed.ncbi.nlm.nih.gov/29395560/

56. RJ R, A C, WJ W, AJ P, JB P. Surgical mask placement over N95 filtering facepiece respirators: physiological effects on healthcare workers. Respirology [Internet]. 2010 Apr [cited 2021 Aug 13];15(3):516–21. Available from: https://pubmed.ncbi.nlm.nih.gov/20337987/

57. Scarano A, Inchingolo F, Rapone B, Festa F, Tari SR, Lorusso F. Protective Face Masks: Effect on the Oxygenation and Heart Rate Status of Oral Surgeons during Surgery. Int J Environ Res Public Health [Internet]. 2021 Mar 1 [cited 2021 Aug 13];18(5):1–11. Available from: /pmc/articles/PMC7967725/

58. MAX30101 High-Sensitivity Pulse Oximeter and Heart-Rate Sensor for Wearable Health | Maxim Integrated [Internet]. [cited 2021 Jul 30]. Available from: https://www.maximintegrated.com/en/products/interface/sensor-interface/MAX30101.html

59. Salman N, Kemp AH, Khan A, Noakes CJ. Real Time Wireless Sensor Network (WSN) based Indoor Air Quality Monitoring System. IFAC-PapersOnLine. 2019 Jan 1;52(24):324–7.

60. Hanfstaengl L, Parzinger M, Spindler U, Wellisch U, Wirnsberger M. Identifying occupant presence in a room based on machine learning techniques by measuring indoor air conditions. E3S Web Conf [Internet]. 2020 Jun 30 [cited 2021 Jul 30];172:22005. Available from: https://www.e3s-conferences.org/articles/e3sconf/abs/2020/32/e3sconf_nsb2020_22005/e3sconf_nsb2020_22005.html

61. Molnár J, Lorinc T, Slavko O. Design and Implementation of an Intelligent Air Quality Sensor. Proc Int Conf Mod Electr Energy Syst MEES 2019. 2019 Sep 1;74–7.

62. Seeeduino XIAO - Seeed Wiki [Internet]. [cited 2021 Aug 12]. Available from: https://wiki.seeedstudio.com/Seeeduino-XIAO/

63. SD Card interface board made by LC Studio/lcsof... | element14 | Arduino [Internet]. [cited 2021 Aug 8]. Available from: https://www.element14.com/community/thread/15572/l/sd-card-interface-board-made-by-lc-studiolcsoftnet

64. For Arduino SD Card Module Shield Micro SD Storage Board Mini Miniture Micro Memory Module With Pins AVR ARM|sd card module|module sd cardarduino sd card module - AliExpress [Internet]. [cited 2021 Oct 5]. Available from: https://www.aliexpress.com/item/32674728363.html

65. Rahimi Z, Shirali GA, Araban M, Mohammadi M javad, Cheraghian B. Mask use among pedestrians during the Covid-19 pandemic in Southwest Iran: an observational study on 10,440 people. BMC Public Heal 2021 211 [Internet]. 2021 Jan 14 [cited 2021 Jul 25];21(1):1–9. Available from: https://link.springer.com/articles/10.1186/s12889-020-10152-2

66. Sacan Ve Gokhan Ertas KB. Performance assessment of MAX30100 SpO2/heartrate sensor. 2017 Med Technol Natl Conf TIPTEKNO 2017. 2017 Dec 22;2017-January:1–4.

APPENDIX A: ETHICS COMMITTEE APPROVAL

T.C. YEDİTEPE ÜNİVERSİTESİ
GİRİŞİMSEL OLMAYAN KLİNİK ARAŞTIRMALAR
ETİK KURULU

Versiyon No 1.0

Sayfa 1 / 2

KARAR FORMU

2.09.2021

ETİK KURUL BİLGİLERİ	Etik Kurulun Adı	Yeditepe Üniversitesi Girişimsel Olmayan Klinik Araştırmalar Etik Kurulu
	Açık Adres	Yeditepe Üniversitesi Diş Hekimliği Fakültesi, Bağdat Cad. No. 238 Göztepe 34728 Kadıköy, İstanbul
	İnternet Sayfası	http://goetik.yeditepe.edu.tr/
	Telefon	0216 363 60 44
	E-posta	goetik@yeditepe.edu.tr

DEĞERLENDİRİLEN BELGELER	Islak imzalı başvuru dosyası, CD'si ve elektronik başvuru	☒
	Araştırma başlığı ve araştırmacıların isimleri	☒
	Başvuru dilekçesi	☒
	Araştırmanın;	☒
	• Niteliği	☒
	• Önemi ve özgün değeri	☒
	• Amaç ve hedefleri	☒
	• Yöntemi	☒
	• Yönetimi	☒
	• Yaygın etkisi	☒
	• Araştırma bütçesi (Mevcutsa)	☒
	• Süresi ve uygunluğu (Zaman cetveli)	☒
	• Kaynakları	☒
	Araştırma izin belgesi / belgeleri	☒
	Bilgilendirilmiş Gönüllü Olur Formu (yapılan araştırmaya özel olarak hazırlanmış)	☒
	Taahhütname-1 Dünya Tıp Birliği Helsinki Bildirgesinin son versiyonunun ve Sağlık Bakanlığı'nın ilgili tüm kılavuzlarının okunmasına dair taahhüt	☒
	Taahhütname-2 Daha önce yapılmış etik kurul başvuruları mevcut olup olmadığına dair taahhüt	☒
	Taahhütname-3 Araştırma sırasında araştırma bütçesinde yer almayan ve gönüllünün kendisine veya Sosyal Güvenlik Kurumuna ek yük getirecek hiçbir işlem uygulanmayacağına dair taahhüt	☒
	Taahhütname-4 COVID-19 hastalarında tedavi yaklaşımları ve bilimsel araştırmalar genelgesi okunmasına dair taahhüt	☒
	Araştırmacıların her birisine ait özgeçmiş formu	☒
	Ek belgeler (Varsa kullanılan ölçek izinleri vb.)	☒

KARAR BİLGİLERİ	Başvuru Numarası	202104016
	Toplantı Tarihi	21.06.2021
	Toplantı Yeri	Çevirim içi (Google Meet)
	Karar No	8

Araştırmanın Başlığı **Günlük Fiziksel Aktivitelerde Yüz Maskesi Kullanımının Solunumla İlgili Fizyolojik Parametrelere Etkisi**

Araştırmacılar **Doç. Dr. Gökhan Ertaş, Kerim Bedri Saçan**

T.C. YEDİTEPE ÜNİVERSİTESİ
GİRİŞİMSEL OLMAYAN KLİNİK ARAŞTIRMALAR
ETİK KURULU

Versiyon No
1.0
Sayfa 2 / 2

BAŞVURU NUMARASI: 202104016

KARAR 2.09.2021

☒ KABUL	☐ RET ☐ *KAPSAM DIŞI (GİRİŞİMSEL)* ☐ *BİLİMSEL VE/VEYA ETİK KURALLARA AYKIRI* ☐ *BİR SORUMLU ARAŞTIRMACININ (TEZ İSE TEZ DANIŞMANI), BİR TOPLANTIYA **İKİ (2) ADETTEN FAZLA ÇALIŞMA BAŞVURUSUNDA** BULUNMASI* ☐ *KURUM İÇİ BAŞVURULARINDA **YEDİTEPE UZANTILI E-POSTA HESABI** İLE GİRİŞ YAPILMAMIŞ OLMASI* ☐ *ŞARTLI KABULDE BELİRTİLEN REVİZYONLARIN ZAMANINDA VE/VEYA İSTENİLDİĞİ ŞEKİLDE YAPILMAMIŞ OLMASI*

Araştırmanın Başlığı **Günlük Fiziksel Aktivitelerde Yüz Maskesi Kullanımının Solunumla İlgili Fizyolojik Parametrelere Etkisi**

Araştırmacılar **Doç. Dr. Gökhan Ertaş, Kerim Bedri Saçan**

APPENDIX B: MICROCONTROLLER CODE

```
// Code for SCD30 sensor:
// This code is originally taken from
// https://github.com/sparkfun/SparkFun_SCD30_Arduino_Library
// But modified regarding to current requirements
// of the current thesis work

#include <Wire.h>
#include <Wire.h>
#include <SPI.h>
#include <SD.h>
#include "SparkFun_SCD30_Arduino_Library.h"

int sensor;
File main_folder;               // initialize folder for saving
File dataFile;                  // initialize sd file
const int chipSelect = 1;       // CS pin on sd card module
int prev_file_indx = 0;         // used for file naming
String fileName = "000";
SCD30 airSensor;

void setup()
{
  Serial.begin(115200);
  Wire.begin();

  if (airSensor.begin() == false)
  {
    Serial.println("Air sensor not detected. Please check wiring !");
    while (1);
  }
  airSensor.setMeasurementInterval(2);        //Set 1 measurement/2s

  // verify SD card is working
  if (!SD.begin(chipSelect)) {
      return;
  }
  main_folder = SD.open("/");
  fileName = sd_saver(main_folder);
  dataFile = SD.open("DATA"+fileName+".csv",FILE_WRITE);
  dataFile.println("TIME, CO2(ppm), TEMPERATURE, HUMIDITY");
  dataFile.close();
  delay(1000);
}

void loop()
{
  // SD save section
  String data_array = "";
  sensor=airSensor.dataAvailable();
    Serial.print("co2(ppm):"); Serial.print(airSensor.getCO2());

    Serial.print(" temp(C):"); Serial.print(airSensor.getTemperature());

    Serial.print(" humidity(%):"); Serial.print(airSensor.getHumidity());

    Serial.println();
```

```
    data_array += String(millis());                  data_array += ",";
    data_array += String(airSensor.getCO2());        data_array += ",";
    data_array += String(airSensor.getTemperature()); data_array += ",";
    data_array += String(airSensor.getHumidity());   data_array += ",";

    dataFile = SD.open("DATA"+fileName+".csv",FILE_WRITE);
    // if the file is valid, write to it:
    if(dataFile){
    dataFile.println(data_array); dataFile.close();
    }
    delay(2000);
}
String sd_saver(File dir){
  while(true){
    // iterate all files to ensure no overwrites
    File entry = dir.openNextFile();
    if (!entry){break;}
    String entry_name = entry.name();
    if ((entry_name.substring(4,7)).toInt()>=prev_file_indx){
      prev_file_indx = (entry_name.substring(4,7)).toInt()+1;
      if (prev_file_indx>=100){
        fileName = String(prev_file_indx);
      } else if (prev_file_indx>=10){
        fileName = "0"+String(prev_file_indx);
      } else{
        fileName = "00"+String(prev_file_indx);
      }
    }
    entry.close();
  }
  return fileName;
}
```

```
// Code for MAX30101 sensor:
// This code is originally taken from
// https://github.com/sparkfun/SparkFun_Bio_Sensor_Hub_Library
// But modified regarding to current requirements
// of the current thesis work

#include <SparkFun_Bio_Sensor_Hub_Library.h>
#include <Wire.h>
#include <SPI.h>
#include <SD.h>

File main_folder;               // initialize folder for saving
File dataFile;                  // initialize sd file
const int chipSelect = 1;       // CS pin on sd card module
int prev_file_indx = 0;         // used for file naming
String fileName = "000";

int resPin = 2;
int mfioPin = 3;
int algoRange = 80;     // ADC Range (0-100%)
int algoStepSize = 50; // Step Size (0-100%)
int algoSens = 50;      // Sensitivity (0-100%)
int algoSamp = 150;     // Number of samples to average (0-255)

SparkFun_Bio_Sensor_Hub bioHub(resPin, mfioPin);
bioData body;

void setup(){
  Serial.begin(115200);
  Wire.begin();

  int result = bioHub.begin();

  if (result == 0)
    Serial.println("Sensor started!");

  // Adjusting the Automatic Gain Control (AGC) Algorithm
  int error = bioHub.setAlgoRange(algoRange);
  if (error > 0){
    Serial.println("Could not set algorithm's Range.");
  }
  error = bioHub.setAlgoStepSize(algoStepSize);
  if (error > 0){
    Serial.println("Could not set the step size.");
  }
  error = bioHub.setAlgoSensitivity(algoSens);
  if (error > 0){
    Serial.println("Could not set the sensitivity.");
  }
  error = bioHub.setAlgoSamples(algoSamp);
  if (error > 0){
    Serial.println("Could not set the sample size.");
  }

  int algoVal = bioHub.readAlgoRange();
  Serial.print("Algorithm set to: "); Serial.println(algoVal);

  int stepVal = bioHub.readAlgoStepSize();
  Serial.print("Algorithm set to: "); Serial.println(stepVal);
```

```
  int senVal = bioHub.readAlgoSensitivity();
  Serial.print("Algorithm set to: "); Serial.println(senVal);

  int sampVal = bioHub.readAlgoSamples();
  Serial.print("Algorithm set to: "); Serial.println(sampVal);

  Serial.println("Configuring Sensor.");
  error = bioHub.configBpm(MODE_ONE);
  if (error > 0){
    Serial.println("Could not configure the sensor.");
  }

  Serial.println("Loading up the buffer with data....");
   // verify SD card is working
    if (!SD.begin(chipSelect)) {
      return;
    }
    main_folder = SD.open("/");
    fileName = sd_saver(main_folder);
    dataFile = SD.open("DATA"+fileName+".csv",FILE_WRITE);
    dataFile.println("TIME, Heart rate, Blood Oxygen");
    dataFile.close();
  delay(4000);
}

void loop(){

    body = bioHub.readBpm();
    Serial.print("Heart rate: ");     Serial.println(body.heart rate);
    Serial.print("Confidence: ");     Serial.println(body.confidence);
    Serial.print("Oxygen: ");         Serial.println(body.oxygen);
    Serial.print("Status: ");         Serial.println(body.status);

    String data_array = "";
    data_array += String(millis());           data_array += ",";
    data_array += String(body.heart rate);    data_array += ",";
    data_array += String(body.oxygen);        data_array += ",";

    dataFile = SD.open("DATA"+fileName+".csv",FILE_WRITE);
    if(dataFile){
        dataFile.println(data_array);
        dataFile.close();
    }
  delay(250);
}

String sd_saver(File dir){
  while(true){
    // iterate all files to ensure no overwrites
    File entry = dir.openNextFile();
    if (!entry){
      break;
    }
    String entry_name = entry.name();
    if ((entry_name.substring(4,7)).toInt()>=prev_file_indx){
      prev_file_indx = (entry_name.substring(4,7)).toInt()+1;
      if (prev_file_indx>=100){
        fileName = String(prev_file_indx);
      } else if (prev_file_indx>=10){
```

```
        fileName = "0"+String(prev_file_indx);
      } else{
        fileName = "00"+String(prev_file_indx);
      }
    }
    entry.close();
  }
  return fileName;
}
```