

# Analysis of facial regions for precise measurement of oxygen saturation and heart rate

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## Abstract

Advancements in information technology fields such as the Internet of Things (IoT) and artificial intelligence are actively being utilized in medicine to develop innovative solutions that address pressing issues. One such issue is the rising incidence of respiratory system diseases in humans. Within the framework of the current project, a respiratory trainer has been developed to enhance the training process through the acquisition of biofeedback, thereby achieving improved outcomes. This project utilizes the Arduino UNO microcontroller and various sensors for acquiring data on patient physiological status. The current study investigates the application of MAX30102 and HW-827 sensors for measuring oxygen saturation (SpO<sub>2</sub>) and heart rate. The aim of this research is to explore the feasibility of obtaining these measurements from the face with the goal of subsequently integrating the sensors into a breathing mask and determine the optimal facial region for data acquisition. This article includes an analysis of existing solutions. Subsequently, the article presents the results of an analysis of measurements obtained from various facial regions. This analysis employed the Pearson correlation coefficient. Further research will focus on optimizing sensor integration based on these findings.

## Keywords

IoMT, breathing trainer, biofeedback, Arduino UNO, sensors, MAX30102, HW-827

## 1. Introduction

One of the most dynamically evolving areas of information technology application is the field of medicine. The progression of research in fields such as the Internet of Things (IoT), specifically the Internet of Medical Things (IoMT), artificial intelligence, or augmented and virtual reality [1] enables the development of more effective solutions to address current healthcare challenges. In recent years, respiratory system diseases have emerged as a prominent concern, exacerbated by the recent COVID-19 pandemic and the deteriorating environmental situation. This study [2] indicates that the overall prevalence of post-COVID dyspnea is 26% or higher. Concurrently, another study [3] discusses the adverse effects of deteriorating environmental conditions on human respiratory health and the exacerbation of comorbid diseases.

Within the framework of the project "Development of a software and hardware complex for monitoring and correcting respiratory functions based on multimodule technologies" a breathing trainer has been developed [4]. This simulator enables real-time monitoring of the patient's physiological parameters and facilitates the wireless transmission of collected data to the physician's device. The developed system utilizes the CCS811 sensor for air quality monitoring, along with the HTU21, BMP280, and BME280 sensors for monitoring temperature, humidity, and pressure. Finally, the MAX30102 sensor is employed for monitoring heart rate and oxygen saturation [5]. Hence, the integration of such a biofeedback system facilitates comprehensive regulation and oversight of the

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training process, thereby contributing to the enhancement of its overall effectiveness. During the implementation of the project, the optimal placement of saturation and heart rate sensors emerged as a critical issue. For precise measurement of oxygen saturation and heart rate, the fingertip regions, or areas just below the wrist are most commonly employed. However, it was proposed to investigate the feasibility of integrating the sensors directly into the mask, which would enhance the mask's usability and comfort for patients.

The scientific literature provides examples of successfully implemented projects involving the integration of selected sensors directly within a mask for physiological monitoring. For example, the study [6] describes a mask equipped with temperature and humidity sensors to detect and process respiration signals, designed to alleviate stress and anxiety. Another project [7] outlines the production of customized masks for healthcare professionals, equipped with two types of sensors: temperature and strain. In this project temperature is monitored to detect fever and irregular breathing patterns (common symptoms of respiratory diseases), while strain monitoring provides alerts to prevent facial irritation from mask use. Another one project [8] presents a prototype mask designed for the detection of infection symptoms. This mask incorporates sensors for measuring temperature, relative humidity, and air pressure in conjunction with the assessment of body temperature, heart rate, and oxygen saturation levels through the auricular method.

Thus, the aim of this study is to identify the most suitable facial regions for optimal data acquisition directly through a breathing mask.

## 2. Materials and methods

This study employs the MAX30102 sensor (Figure 1) and the HW-827 heart rate sensor (Figure 2) to collect physiological data.



**Figure 1:** MAX30102 sensor [9].



**Figure 2:** HW-827 heart rate sensor [10].

The MAX30102 is a non-invasive optical sensor designed for determining blood oxygen levels and measuring heart rate. To achieve this, the sensor employs two light-emitting diodes (LEDs): one emitting red light and the other emitting infrared light. These two LEDs emit light that passes through skin tissues and is partially absorbed by blood. The quantity of light is measured using a photodiode that detects the reflected or transmitted light. During cardiac contraction, the blood volume within the vessels expands, resulting in a corresponding change in the amount of light

absorbed. This change is registered by the photodiode. The oxygen saturation (SpO<sub>2</sub>) measurement necessary for this project is determined by the difference in absorption between the first and second LEDs. The use of the I2C protocol for data transmission simplifies the process of monitoring these data. However, utilizing a single sensor poses risks due to the possibility of malfunctioning LEDs or inaccuracies in data acquisition. For this reason, the HW-827 pulse sensor is additionally employed in the project. The operating principle of this sensor is identical to that of the MAX30102. Furthermore, this project employs an Arduino UNO microcontroller as a central component for managing sensor interactions. The Arduino UNO satisfies the requisite specifications for communication via the I2C protocol and handling analog data.

Optimal sensor performance requires that the skin zone exhibit adequate blood perfusion while having minimal hair and subcutaneous fat. Furthermore, accurate sensor calibration requires comparing the acquired data with measurements from a reference device that provides benchmark values for oxygen saturation and heart rate. Traditionally, during the performance of breathing exercises, these parameters are measured using a pulse oximeter - a medical diagnostic device designed for the non-invasive measurement of blood oxygen saturation level. For this reason, the Medilux Mars XP10 pulse oximeter (Figure 3) was selected as the reference device for the present project. This pulse oximeter operates as follows: the device is placed on a finger, then following an initial calibration phase, it subsequently displays the measured oxygen saturation and heart rate values on its monitor.



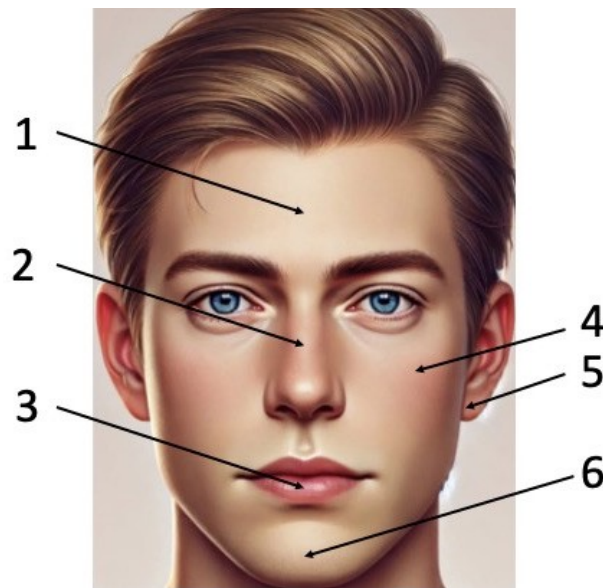
**Figure 3:** The Medilux Mars XP10 pulse oximeter [11].

The study will be conducted according to the following algorithm:

1. Initialization of the Pulse Oximeter. The pulse oximeter is activated to begin data acquisition;
2. Calibration Phase. The device undergoes a calibration process to ensure accurate measurements;
3. Execution of the Program on Arduino UNO. The microcontroller initiates the program to control data acquisition from the sensors;
4. Sensor Data Acquisition. The system collects physiological data from the sensors;
5. Data Comparison. The acquired data is analyzed and compared with reference values to evaluate measurement accuracy. The comparison will be performed based on the Pearson correlation coefficient.

For accurate data collection in the proposed system, it is also necessary to observe how analogous sensors used in existing successful systems, such as similar pulse oximeters or any smartwatches equipped with similar functionality. Firstly, comparable devices are attached to more stable parts of the body than the face, specifically on wrists or fingers. Furthermore, these devices typically operate in conditions where the measurement sites are shielded from direct light. Finally, these devices do not function continuously. Instead, they initially undergo a calibration phase to stabilize the data acquisition process before outputting the measured results.

We will examine the facial regions of the human face, as illustrated in Figure 4.



**Figure 4:** The facial regions of the human face.

1. The frontal region, or forehead, presents a well-suited area for sensor application owing to its uniform blood perfusion.
2. The nasal bridge features thin skin and robust blood perfusion, making it a potentially suitable site for sensor placement. Nevertheless, it is anticipated that the attachment of sensors to this area may present challenges, despite this aspect being critically important for effective implementation.
3. The lips are excessively sensitive, rendering it unsuitable for sensor attachment.
4. The cheeks have good blood circulation; however, the presence of a subcutaneous fat layer may lead to inaccuracies in sensor performance.
5. The earlobes have good blood perfusion; however, similar to the nasal region, it is presumed that difficulties may arise in securing the sensors in this area.
6. The chin is characterized by limited blood circulation and significant mobility, rendering it an unsuitable location for sensor placement.

Additionally, it is also possible to place sensors on the human neck. Nevertheless, a significant challenge lies in designing a sensor attachment method that allows patients to comfortably use the breathing trainer being developed in the project.

The study involved a single male participant, 24 years of age, with relatively tall stature, average body build, and a Fitzpatrick Skin Phototype of III (medium). Optical sensors such as the MAX30102 used in this project operate on the principle of light reflection or absorption by the skin, and melanin content directly affects the absorption of infrared and red light, potentially influencing measurement accuracy. Consequently, in scientific experiments of this nature, particularly those involving biometric measurements, reporting the Fitzpatrick skin phototype enhances the reliability and interpretability of the data. The participant was healthy, and his body temperature at the time of measurement was 36.6 °C. It is important to note that a potential increase in the patient's body temperature may influence measurements obtained from both facial regions and the finger. However, in this instance, the pulse on the face will be more pronounced due to the active vasodilation of the facial skin vessels, leading to a correspondingly more significant increase in the pulse wave. Nevertheless, according to medical indications, respiratory exercises with this system are to be performed only when the patient's body temperature is within the normal range; therefore, at this stage testing was not conducted when this parameter deviated from the norm. All physiological

parameters of the participant were within normal ranges, including resting heart rate, respiratory rate, blood pressure, and oxygen saturation. The participant had no history of chronic respiratory conditions or cardiovascular disorders. The participant reported a moderate level of daily physical activity. The participant wore lightweight clothing that did not restrict breathing. The studies conducted within this project were approved by the local ethics committee and carried out in accordance with established ethical standards for research involving human volunteers.

Measurements were conducted under moderate indoor temperature, humidity, and atmospheric pressure. Illumination was adequate but not excessive, a parameter of particular relevance in this type of experiment given the use of optical sensors.

Measurements were conducted under conditions of relative patient rest, reflecting both the pilot nature of this development stage and the intended application of the system for respiratory exercises performed in a resting state. For each selected facial region, a total of 20 measurements were conducted. Tests were not conducted on the lip and chin areas, as preliminary analysis identified these regions as entirely unsuitable for sensor placement, as described in detail above. To ensure precise analysis of the measurements, a representative sample is crucial. The chosen sample size is adequate for determining data stability and conducting requisite statistical computations. Subsequently, the acquired data were compared against reference values obtained from a supplementary device Medilux Mars XP10 by employing Pearson's correlation coefficient.

### 3. Results and discussion

Table 1 presents the calculated values of Pearson's correlation coefficient [12] for various facial regions. According to the established methodology, a Pearson correlation coefficient of 0 denotes a lack of any linear relationship between the variables and a coefficient close to 1 signifies an unambiguous positive linear relationship between the variables in question. Accordingly, values between 0.7 and 0.9 are generally interpreted as indicating a strong positive correlation, whereas values exceeding 0.9 are considered very strong, reflecting in this experiment a high degree of agreement between the sensor measurements and the reference device. Thus, a high Pearson correlation coefficient in this context indicates that the sensor readings reliably track the reference pulse oximeter measurements across the tested facial regions, thereby validating the feasibility of employing these sensors for non-finger-based monitoring.

**Table 1**  
Results of Pearson correlation coefficient

| № | Facial regions | Pearson's coefficient           |          |
|---|----------------|---------------------------------|----------|
|   |                | MAX30102                        | HW-827   |
| 1 | Forehead       | 0,918976                        | 0,912495 |
| 2 | Nasal bridge   | 0,912851                        | 0,917522 |
| 3 | Lips           | unsuitable for sensor placement |          |
| 4 | Cheeks         | 0,905536                        | 0,880076 |
| 5 | Earlobes       | 0,942941                        | 0,913365 |
| 6 | Chin           | unsuitable for sensor placement |          |

Consequently, the findings of the research indicated that the most precise measurements of oxygen saturation and heart rate were acquired from the earlobes. Nevertheless, the conducted tests confirmed that difficulties associated with sensor attachment in this area may adversely affect patient comfort and ease of use. The sensors positioned on the nasal and frontal regions exhibited favorable results, with accuracy levels that were comparable to each other. Conversely, the measurements obtained from the cheeks were identified as the least precise; however, they remained sufficiently reliable, indicating that this area is still suitable for sensor attachment. The relatively high performance observed in the nasal and frontal regions may be partly attributed to their stable blood

perfusion and comparatively low subcutaneous fat content, whereas the slightly lower accuracy recorded on the cheeks may result from thicker soft tissues and a higher likelihood of motion artifacts induced by facial expressions. It should be noted that all measurements were performed under resting conditions, and future testing during respiratory exercises may reveal additional challenges, such as motion artifacts or alterations in local blood flow.

Interestingly, a related study [13] compared  $\text{SaO}_2$  (the actual arterial oxygen saturation measured by laboratory blood analysis) with  $\text{SpO}_2$  (the noninvasive estimate of blood oxygen saturation) obtained at the forehead, earlobe, finger, and toe in patients admitted to a cardiac surgery intensive care unit. Using Pearson's correlation coefficient among other methods, the results identified the earlobe as the site providing the highest measurement accuracy. Moreover, another study [14] reported a similarly high Pearson correlation coefficient for heart rate detection using in-ear photoplethysmography. In that case, the coefficient of 0.83 demonstrated the adequate performance of an in-ear wearable PPG sensor in obtaining valid and reliable heart rate measurements in patients with epilepsy. It should be noted that although these studies [12, 13] report relatively high Pearson correlation coefficients, the results obtained in the present project surpass them, as shown in Table 1.

However, despite the positive experimental results, it is important to acknowledge the limitations of the present study. First, only a single participant was involved in this experiment, which reflects the pilot nature of the research. The primary objective at this stage was not to obtain statistically significant evidence in support of a specific hypothesis, but rather to assess the technical feasibility of the prototype, specifically, the correct operation of the sensors across different facial regions, the stability of connections, and the quality of the recorded signals. At this phase, the critical task is to evaluate the fundamental viability of the measurements and to identify potential technical issues, rather than to draw conclusions about data variability within a broader population. Nevertheless, to capture potential variability associated with anatomical features, skin pigmentation, tissue thickness, and other individual factors, future experiments will necessarily involve a larger and more diverse cohort. At present, however, the prototype remains under active development, and large-scale measurements would be premature. Such investigations are planned as the next stage of the project. Accordingly, the results obtained at this stage of the study will be used solely to refine the prototype design rather than to draw final conclusions. The project development methodology comprises an initial phase of equipment and algorithm debugging, followed by an expansion of the sample to achieve statistically significant results.

The influence of skin pigmentation, ambient temperature, and humidity represents another limitation of this experiment. These factors act as external variables that may distort sensor readings, for example, by altering light absorption in pulse oximetry or affecting the electrical conductivity of sensors. The present study was conducted with a single participant under moderate temperature and humidity conditions, which were not systematically varied. Consequently, the results cannot be directly generalized to individuals with different skin phototypes or to environments with differing thermal or humidity profiles. Such controlled experimental conditions are consistent with the pilot nature of this project stage, as discussed above. At an early phase, it is prudent to hold most variables constant to minimize extraneous noise and focus on debugging the core functions of the system. Future stages of the project are planned to incorporate a broader range of environmental conditions to enable statistical validation and ensure robustness across diverse scenarios.

Another limitation of the present study is that all experiments were conducted exclusively under resting conditions. This choice reflects the objectives of the current stage, which focused on verifying sensor functionality, measurement accuracy, and the correctness of signal-processing algorithms. At rest, signals are more stable and less affected by noise, allowing for the detection of fundamental calibration errors and the assessment of sensitivity and accuracy without the confounding influence of dynamic artifacts. Physical activity, by contrast, introduces additional factors such as fluctuations in skin temperature and humidity, movement of facial tissues and muscles, and abrupt changes in respiratory and heart rates. Eliminating these variables at an early stage makes it possible to concentrate on the intrinsic performance of the system. Moreover, active movements may cause sensor displacement, damage, or loss of contact, thereby complicating debugging. The project

development methodology therefore includes an initial verification of baseline accuracy and signal stability in a resting state, followed by the controlled introduction of motion artifacts during low-intensity activity and, subsequently, an evaluation of system robustness under realistic conditions. This stepwise approach is consistent with medical device development standards and reduces the risk of data loss.

## 4. Conclusion

The conducted study confirmed the feasibility of measuring oxygen saturation and heart rate through a breathing mask. The accurate collection of data was identified as the most critical factor. The research involved a comprehensive analysis of different facial regions, as well as an assessment of the potential for sensor attachment in these areas. The results indicated that the most accurate measurements are achievable in the earlobe regions. In cases where sensor attachment in this area is not feasible, the forehead and nasal regions may also be selected, as they demonstrated good results as well. Given the goal of integrating sensors into a respiratory mask, the forehead and nasal bridge appear to be the most practical primary sites for sensor placement, offering an optimal balance between measurement accuracy and structural feasibility.

The results of this experiment provide a foundation for the development of intelligent respiratory masks capable of real-time monitoring of heart rate and other physiological parameters, which may enhance the effectiveness of respiratory training and improve patient comfort. Further research will focus on examining the various options for sensor integration within the respiratory trainer system, guided by the results obtained from this study. Moreover, in view of the limitations of this pilot stage, subsequent phases of development will include experiments involving a broader range of participant characteristics, as well as testing the sensors during controlled breathing exercises and under varying environmental conditions such as temperature, humidity, and ambient illumination changes. Optimization of sensor attachment methods and, if necessary, data-processing methods will be undertaken to ensure stable measurements even during movement or respiratory effort such as those including accelerometer-based correction. Moreover, for example, to minimize noise caused by changes in external illumination, adaptive filtering algorithms can be implemented. If necessary, such measures will increase the reliability of the system and the stability of measurements under dynamic conditions.

In the long term, findings of this study represent a preliminary step toward the integration of accessible IoMT-based solutions into rehabilitation programs for patients with chronic respiratory diseases or post-COVID complications.

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## Declaration on Generative AI

During the preparation of this work, the authors used ChatGPT in order to: Grammar and spelling check. Further, the authors used ChatGPT for the Figure 4 in order to generate image of a human face. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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