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Smart face shield for the monitoring of COVID-19 physiological parameters: Personal protective equipment (PPE) for health-care workers (HCW's) and COVID-19 patients

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Abstract

The COVID-19 pandemic has triggered instabilities in various aspects of daily life. This includes economic, social, financial, and health crisis. In addition, the COVID-19 pandemic with the evolution of different virus strains such as delta and omicron has led to frequent global lockdowns. These lockdowns have caused disruption of trade activities that in turn have led to the shortage of medical supplies, especially personal protective equipment's (PPE's). Health-care workers (HCW's) have been at the forefront of the fight against this pandemic and are responsible for saving millions of lives worldwide. However, the PPE's available to HCW's in the form of face shields and face masks only provide face and eye protection without encapsulating the ability to continuously monitor vital COVID-19 parameters including body temperature, heart rate, and SpO2. Hence, in this study, we propose the design and utilization of a PPE in the form of smart face shield. The device has been integrated with the MAX30102 sensor for measuring the heart rate and oxygen saturation (SpO2) and the DS18B20 body temperature measuring sensor. The readings of these sensors are analyzed by a NodeMCU ESP8266 and measurements are displayed on a laptop screen. Also, the Wi-Fi module of NodeMCU ESP8266 enables compatibility with the ThingSpeak mobile application and permits HCW's and patients recovering from COVID-19 to keep a track of their physiological parameters. Overall, this PPE has been observed to provide reliable readings and the results indicate that the designed prototype can be used for monitoring COVID-19 essential parameters.

Keywords

COVID-19, PPE, face shield, face mask, body temperature, heart rate, SpO2

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Introduction

Ever since the first coronavirus case was identified in December 2019, the COVID-19 pandemic has put the entire world in danger affecting people of all age groups and causing disruption in daily activities.[1,2] The COVID-19 pandemic has been described as one of the most prominent health devastations of the modern era.[3] Apart from exerting impacts on the health field, the COVID-19 pandemic has led to far-reaching social and economic crisis that experts are still trying to measure and cope with.[4–6] According to the latest global statistics, the pandemic caused by the COVID-19 has been the cause of 288,598,994 cases, 5,454,996 deaths as of 1st January 2022.[7,8] The COVID-19 disease primarily affects the respiratory system of an individual with the mouth and nose serving as the primary modes of transmission.[9] Once inside the human body, the it travels through the nasal passages and oral cavity and starts to multiply and spread to other regions of the body.[10] The

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disease primarily effects the respiratory systems including the lungs and in some patients, it also causes severe inflammatory syndrome with symptoms of fever, coughing, fatigue, and loss of taste or smell.[11,12]

The COVID-19 disease has spread to all the continents during infection waves affecting several countries in different ways.[6,13] Furthermore, the COVID-19 virus has been subject to mutations with the latest variants of delta and omicron causing a surge in the reported cases.[14–16] Along with mutations, lack of knowledge and experience pertaining to the virus and limited resources of the health systems in majority of the countries have also been major factors for hospitals getting saturated with patients with bulk burden on the intensive care units.[17] Hence, due to the rapid increase in the number of individuals being infected with the virus, there has been a deficiency of personal protective equipment (PPE) for healthcare workers (HCW's) assigned for treating patients suffering from COVID-19.[18–20] Along with a surge in the COVID-19 cases, frequent lockdowns in different parts of the world have decreased trade activities leading to further delays of PPE's to reach their destinations.[21]

Previous studies have proposed and introduced different kinds of PPE's in relation to the HCW's ensuring protection against the coronavirus. In a study, three-dimensional (3D) printed face shields were designed in order to cope with the shortage of the N95 mask. The face shields were manufactured to be used in the anesthesiology department and were tested for a decontamination protocol for reuse. Bacterial suspensions of E. coli and S. aureus were used for the decontamination protocol and its success was tested via the average log10 reduction colony counts.[22] The results of the study presented an effective decontamination protocol, however, this PPE providing eye and face protection did not involve any physiological parameter measurement in relation to COVID-19.[22] In a similar study, Duke University medical center introduced the design of 3D printed face shields being manufactured by incorporating helmets used by surgeons during arthroplasty procedures.[23] Even though, these face shields provide face and eye protection, they are not capable of measuring physiological parameters associated with COVID-19.[23] Another study demonstrated the design of a disposable face shield manufactured using A4 generic acetate sheet for use during endoscopic procedures.[24] A similar face shield was introduced utilizing materials such as Polylactic acid filaments, Velcro strips, 3D printer, adhesive foam, and transparency films.[25] The face shields in Skamnelos et al.[24] and Amin et al.[25] were able to provide face and eye protection, however, they were not able to measure physiological parameters and monitor symptoms of COVID-19 along with being used only once.

Chaturvedi et al.[26] proposed the design and usage of a 3D printed face shield made of ploy-vinyl-chloride (PVC) film visors that could be used by orthopedic and other front line HCWs. The results of the study exhibited that the designed face shields were suitable for use in operative procedures during COVID-19 pandemic.[26] Pan et al.[27] introduced the design of a smart mask for HCW's so that essential respiratory parameters can be monitored including blood oxygen saturation, body temperature and heart rate. The results of the study revealed reliable working of the designed mask providing protection against the COVID-19 virus. Although, the designed mask in Pan et al.[27] exhibits the capacity to measure significant parameters, it only provides mouth and nose protection and does not provide eye defense. Moreover, the designed mask is not integrated with a mobile application that can enable information to be sent wirelessly.

The literature review exhibits lack of work pertaining to the design of a PPE in the form of a face shield that possesses the ability of monitoring physiological parameters vital during the COVID-19 pandemic. Although, we have mentioned studies as part of the literature review that present a solution in the form of a PPE in providing eye and face protection against COVID-19, they are not capable of continuously measuring COVID-19 symptoms. However, our smart face shield is capable of exhibiting both the above mentioned features as well as telemedicine and according to the best of our knowledge, no such smart face shield has been developed up till now.

Although, a healthcare worker can be tested before and after work, it would be more beneficial for the healthcare worker to keep a continuous track of COVID-19 related symptoms during engagement with patients as it would help the HCW to work safely and confidently, knowing that his/her health is optimized in order to serve the needs of the patients efficiently. It would also help to decrease the spread of the COVID-19 pandemic. Furthermore, our smart face shield apart from healthcare workers, can be used by patients who are recovering or who have recovered from COVID-19 in order to keep a continuous track of symptoms. This can help such patients with adequate feedback and indicate when to seek immediate medical attention. Moreover, this also presents ease of use, as for example, one doesn't have to wear a pulse oximeter every time in order to check his/her SpO2. Hence, we propose the design and use of an innovative smart face shield capable of measuring essential physiological parameters of heart rate, blood oxygen saturation (SpO2), and body temperature. Furthermore, our proposed face shield is based on telemedicine and is integrated with a mobile application so that information relating to the measured physiological variables can be transmitted easily. Our proposed PPE in the form a face shield can be used by HCW's for continuously monitoring COVID-19 related parameters and adhere to protection while treating patients. Also, the face shield can be utilized for post COVID-19 monitoring in individuals so that they can keep a track of their recovery from the virus and ensure that their heart rate, SpO2, and body temperature are at optimal values. A

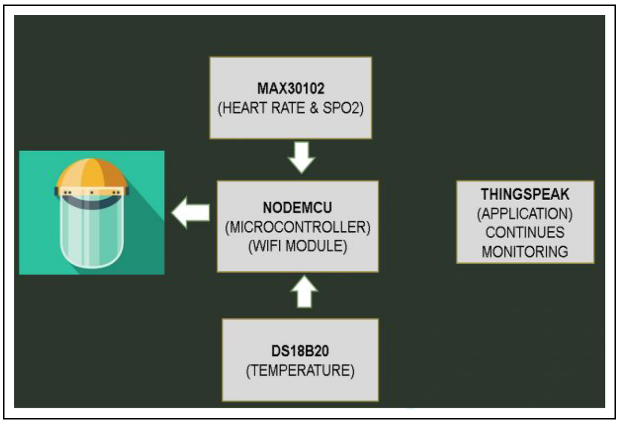

Figure 1. Block diagram of the proposed smart face shield representing the assembly of the components.

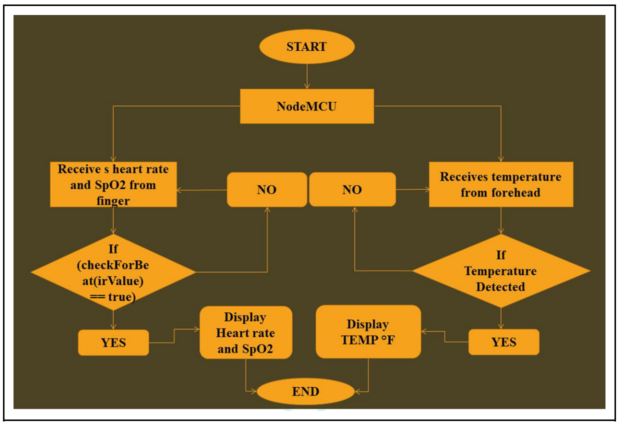

Figure 2. Application of the proposed PPE in the form of a smart face shield showing the flow process between the components.

limitation of our smart face shield is that during the early stages of the COVID-19 disease when an individual does not exhibit any overt physical signs, the smart face shield may not indicate COVID-19 symptoms. However, this is also the case with tests that do give false positive and false negative results. Hence, there is always some chance of error.

The article includes sections including section 2 elaborating the methodology and section 3 describing the results and the findings of the study. Conclusions and future work are described in section 4.

Methodology

Figure 1 demonstrates the working of the proposed face shield in the form of a block diagram and is a representation of the assembly of the components which include a NodeMCU ESP8266, MAX30102 sensor for monitoring heart rate and blood oxygen saturation (SpO2), and DS18B20 temperature monitoring sensor. With the aid of the Wi-Fi component of NodeMCU microcontroller, readings acquired via the MAX30102 and DS18B20 sensors are received, visualized and are wirelessly transmitted to a mobile application known as ThingSpeak. These applications are compatible with the NodeMCU ESP8266. Hence, the readings of heart rate, SpO2, and body temperature are continuously monitored.

The onset of COVID-19 represents symptoms such as fever with serious indications such as difficulty in breathing and shortness of breath.[28,29] Hence, this was the primary reason for monitoring parameters including body temperature, heart rate, and SpO2.

The application of the proposed PPE comprising of a face shield is represented in Figure 2. The NodeMCU ESP8266 functions as the microcontroller unit for receiving and transmitting the values of heart rate, SpO2, and body temperature to the mobile applications enabling continuous monitoring of COVID-19 vital symptoms. The flow process in Figure 2 is initiated once the microcontroller unit is powered on and the detection process begins. The MAX30102 sensor is responsible for detecting the heart rate and SpO2 via the fingertip while the DS18B20 obtains the body temperature from the forehead. The reason of choosing the location of forehead for body temperature measurement as it was an easier placement region considering the design of the face shield. Furthermore, temperature acquired via the forehead has been identified to be a reliable indicator of the body temperature.[30]

A threshold infrared (IR) value of 50,000 has been set for the MAX30102 sensor and detects the heart rate and SpO2 reading in case the IR value is $>$50,000. If the IR value is below the set point of 50,000, no reading of heart rate and SpO2 is going to be measured and the detection process would continue. Moreover, the DS18B20 sensor identifies the true condition and measures the temperature. In case, the true condition is not detected, no temperature is measured and the detection process continues.

The MAX30102 sensor utilized in our designed face shield is manufactured by Mouser Electronics and is an integrated module for the measurement of heart rate and SpO2. It is embedded with internal light emitting diodes (LED's) and photo-detectors that employ the principle of photoplethysmography and operates by shining light onto the skin via the placed fingertip and the heart rate and SpO2 is measured as a function of the reflected light. The DS18B20 body temperature sensor utilized in our proposed PPE in the form of a face shield is manufactured by Maxim Integrated and is integrated with components such as ramp accumulator, temperature coefficient oscillator, counters, and temperature registers.

A total of 25 participants were recruited for testing of the proposed face shield. Ethical review committee of Ziauddin University granted ethical consent to carry out this study. The recruiting and participation of individuals for testing of the face shield was executed only after acquiring consent through a consent form. An individual was allowed as a participant only by consent.

Figure 3. Placement of MAX30102 sensor within the finger clipper that aids in measuring the SpO2.

Figure 4. Box casing for the placement of NodeMCU ESP8266.

An exclusion and inclusion criteria was also formulated. Any individual that exhibited a medical condition affecting the body temperature, heart rate, and SpO2 did not participate. Hence, testing of the face shield comprised of only healthy participants. The 25 participants belonged to an age group of 20–40 years and included 15 males and 10 females.

Our proposed face shield comprises of elements such as NodeMCU ESP8266, MAX30102, and DS18B20 sensors. In order to design the face shield, the individual components were embedded in casings including a finger clipper designed for the placement of the MAX30102 sensor as exhibited by Figure 3 and a box case for the location of the NodeMCU ESP8266 as represented by Figure 4. Figure 5 illustrates the placement of the DS18B20 being fixed in the part of the face shield that is in close proximity with the forehead region of the individual. Following the placements of the components, the face shield was assembled with the aid of a glue gun utilizing glue gum and is shown in Figure 6.

NodeMCU ESP8266 has been used in our designed face shield for receiving and interpreting the values of heart rate, body temperature, and SpO2 as well as transmitting the detected values to ThingSpeak mobile application. The built-in Wi-Fi module of NodeMCU ESP8266 enables wireless transmission of data and continuous monitoring of COVID-19 parameters. Furthermore, it has a small size and is portable and easily incorporated within our designed face shield. Also, it can be programed using C language which is commonly used for programing functions.

A feature that we have integrated with our designed face shield for ease of data transmission and COVID-19 symptoms monitoring is the use of open-source software of ThingSpeak mobile application. ThingSpeak open-source software allows the connection of internet connected devices and the user, thereby putting their communication at ease. ThingSpeak allows visualization, collection, and analysis of live data streams. For the interfacing of ThingSpeak, we created a channel on its webpage and then an ID and the application programing interface (API) key of this channel was added in the programing.

Figure 5. Placement of DS18B20 inside the face shield for the measurement of body temperature.

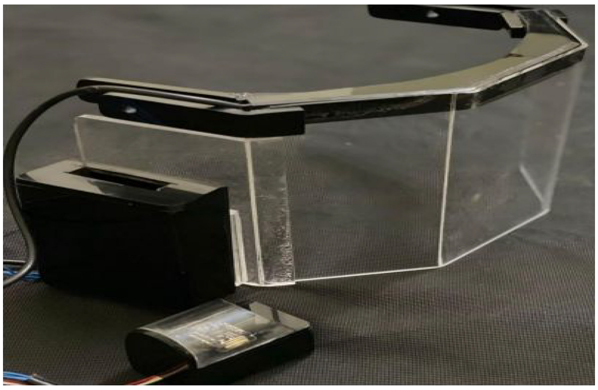

Figure 6. Front view of the designed face shield.

Results and discussion

Measurements of body temperature, heart rate, and SpO2 of the 25 individuals that participated were recorded and the operation of the designed PPE in the form of a face shield was analyzed. Table 1 exhibits the

Table 1. Body temperature, heart rate, and SpO2 measurements of male participants.

Serial number	Body temperature (°C)	Heart rate (BPM)	SpO2 (%)
1	36.4	83.0	97.4
2	36.6	75.0	98.7
3	36.9	77.0	97.9
4	36.8	98.0	99.4
5	36.5	67.0	99.2
6	36.4	78.0	98.9
7	36.8	78.0	97.7
8	36.7	96.0	96.2
9	37.0	64.0	98.6
10	36.4	85.0	96.9
11	36.4	90.0	97.6
12	36.3	66.0	98.6
13	36.7	89.0	98.2
14	36.9	97.0	98.5
15	36.2	65.0	99.0

Table 2. Body temperature, heart rate, and SpO2 measurements of female participants.

Serial number	Body temperature (°C)	Heart rate (BPM)	SpO2 (%)
1	36.3	79.0	98.4
2	36.7	80.0	96.7
3	36.7	96.0	96.9
4	36.6	88.0	98.4
5	36.5	69.0	99.1
6	36.4	87.0	97.9
7	36.9	92.0	97.5
8	36.7	84.0	98.5
9	36.4	74.0	97.8
10	36.3	89.0	96.3

readings obtained from the 15 male participants whereas Table 2 demonstrates the measurements acquired from the 10 female participants. The readings obtained in Tables 1 and 2 signifies the reliable working of our designed face shield and the monitoring of COVID-19 vital parameters.

Figures 7 and 8 illustrate the readings transmitted to the ThingSpeak mobile application which have been interpreted graphically. Figure 7 demonstrates the body temperature, heart rate, and SpO2 obtained for three male participants. Similarly, Figure 8 shows the body temperature, heart rate, and SpO2 for three female participants.

The objective of our study was to design and present the use of a PPE that can be used for monitoring vital physiological parameters during the current COVID-19 pandemic including body temperature, heart rate, and SpO2. Furthermore, the proposed face shield is integrated with ThingSpeak mobile application so that information relating to the measured physiological variables can be communicated and monitored continuously and easily. Even though, PPE's in the form of face shields and face masks have been manufactured in several studies including Armijo et al.,[22] Erickson et al.,[23] Skamnelos et al.,[24] Amin et al.,[25] Chaturvedi et al.,[26] and Pan et al.,[27] providing eye and face protection, they do not cater to the need of monitoring physiological parameters including body temperature, heart rate, and SpO2. Furthermore, they are also not capable of transmitting data wirelessly to a mobile phone.

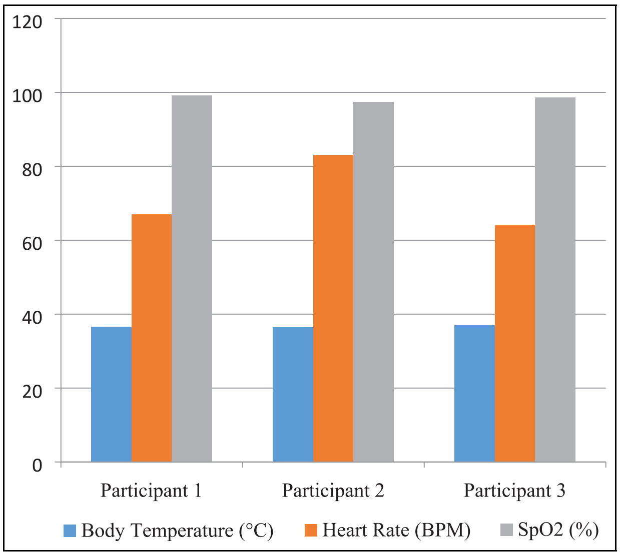

Figure 7. Graphical representation of measurements on ThingSpeak for three male participants.

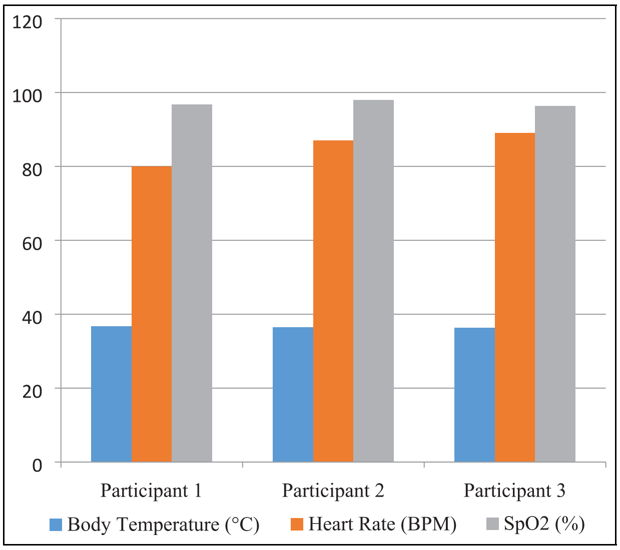

Figure 8. Graphical representation of measurements on ThingSpeak for three female participants.

Conclusions

The proposed study introduces the design and utilization of a face shield that can be used by HCW's in order to ensure protection against COVID-19 as well as the continuous monitoring of their physiological parameters including body temperature, heart rate, and SpO2. Moreover, our designed face shield can also be used by individuals for monitoring post-COVID symptoms and to keep a regular check on their health. Two sensors including MAX30102 for measuring SpO2 and heart rate and the DS18B20 for detection of body temperature have been used so that the manufactured face shield has the ability to monitor important physiological parameters. The NodeMCU ESP8266 serves as the controller unit for receiving the values from the sensors, comparing them with the set thresholds and displaying the results on a laptop. In addition, the NodeMCU ESP8266 allows data to be wirelessly transmitted to the ThingSpeak mobile application which makes it convenient for individuals to monitor COVID-19 parameters on their mobile phones and seek medical assistance in case their parameters deviate from the normal ranges. Work that can be integrated with the existing face shield in the future includes a nasal oxygen mask that be worn by patient in case the blood oxygen saturation level drops below 95%.

Declaration of conflicting interests

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