Low-Cost Pulse Oximetry and Infra-Red Temperature Device for COVID-19 Patients

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Abstract

With the beginning of the COVID-19 pandemic in early 2020, there was a pressing need for simple yet effective remote monitoring solutions. In this paper, we describe a low-cost device developed for monitoring COVID-19 patients. The device uses an ESP32 module and integrates two distinct off-the-shelf biomedical sensors: a pulse oximeter by MAXIM, and an infra-red (IR) thermometer by MELEXIS. The device communicates with a smartphone via Bluetooth which then sends the acquired data to a cloud-based platform. An initial evaluation was performed at Coimbra's Polytechnic Institute, and covered reproducibility and agreement with standard clinical devices, revealing a strong correlation for the pulse oximeter and a necessity for further testing the IR thermometer.

1 Introduction

The last two years were marked by the COVID-19 pandemic that struck the world. This disease, caused by the virus SARS-CoV-2, spread worldwide and forced health care systems to quickly adapt to a remote monitoring paradigm. Lacking the tools to do so, the majority of the monitoring was performed through phone calls between the patients and the health care providers, further increasing the overall workload of the latter.

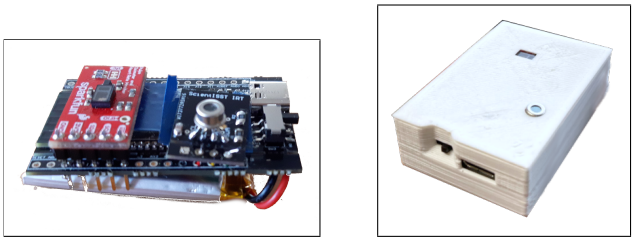
Phone calls were used to query patients regarding their symptoms and vital signs, trying to grasp the evolution of the disease. Patients would be questioned about the most frequent COVID-19 symptoms, namely: tiredness, dry cough, myalgia, dyspnea, loss of smell, gustatory dysfunction, rhinorrhea, asthenia, and sore throat [1, 2, 3]. They would also be asked to evaluate their body temperature for tracking fever, which is a usual predictor for this disease. Knowing the blood oxygen saturation would allow detecting "silent" hypoxemia (*i.e.*, unperceived lack of oxygen) [5], something that can occur in COVID-19 patients.

We developed a novel solution for this remote monitoring paradigm, which we called e-CoVig. Our solution implements at-home support and self-reporting of patients, using the smartphone as the primary data collection interface, coupled with a low-cost specialized device. We focused on the monitoring of heart rate (HR), oxygen saturation (SpO_2), body temperature, and symptomatology questionnaires [4]. Therefore, the same assessment performed through phone calls is still being carried out but, using the tools we developed, it is facilitated, more objective, and automated.

2 e-CoVig Device Implementation

The e-CoVig device, showcased in Figure 1, uses the ESP32 microcontroller as its mainboard and the off-the-shelf sensors connected to it. A pulse oximeter, the MAX30101 (high-sensitivity SpO2 and HR sensor using reflective photoplethysmography), is coupled with the MAX32664 (low-power sensor hub family, which seamlessly communicates with several MAXIM biometric sensors and computes biometric information). An IR thermometer, the MLX90615, which we integrated into our own PCB, is used for body temperature measurement. The temperature measurements are smoothed using a moving average filter (N=3), and the body temperature from the measured surface temperature is estimated using linear regression. The parameters for this regression were obtained by comparing temperature measurements between the MLX90615 sensor and an F102 forehead IR thermometer.

This work was supported by Fundação para a Ciência e Tecnologia (FCT) under the projects' reference: 255_596880547 e-CoVig; UIDP/50009/2020; UID/EEA/50009/2019; DSAIPA/AI/0122/2020 (AIMHealth) through IT - Instituto de Telecomunicações; and through LARSyS - FCT Plurianual funding 2020-2023; which is gratefully acknowledged.



(a) (b)

Figure 1: The developed device with pulse oximeter and IR thermometer (a), and the same device inside a 3D printed case (b).

Type of measurement	1st measurement	2nd measurement	Mean difference	p-value
Heart rate (BPM)	80.10 ± 15.60	81.00 ± 16.00	0.90 ± 4.30	0.257
SpO_2 (%)	97.30 ± 2.60	97.40 ± 2.10	0.10 ± 1.30	0.783
Temporal temperature (°C)	36.68 ± 0.26	36.75 ± 0.25	0.07 ± 0.16	0.020
Tympanic temperature (°C)	35.59 ± 0.24	35.56 ± 0.23	-0.03 ± 0.08	0.045

Table 1: Pairwise comparison of the e-CoVig repeated measurements.

The device measures SpO2, HR, and temperature two times per second and, once a Bluetooth connection is established, the values are sent via Bluetooth Serial in a JSON format to the smartphone, as shown below:

```
{"HR": 72, "Confidence": 100, "SpO2": 99, "Status": 3,
"Object Temperature": 33.0, "Ambient Temperature": 15.1}
```

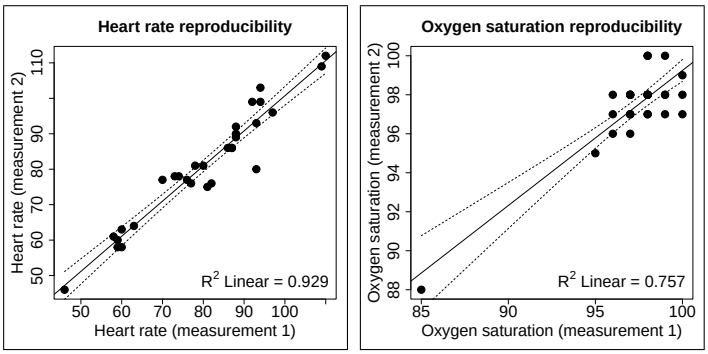
When the smartphone receives the measured data, forwards it to a remote monitoring cloud platform designed for health care professionals. This allows for an easy, scalable, and remote monitoring of a large number of patients.

3 Results

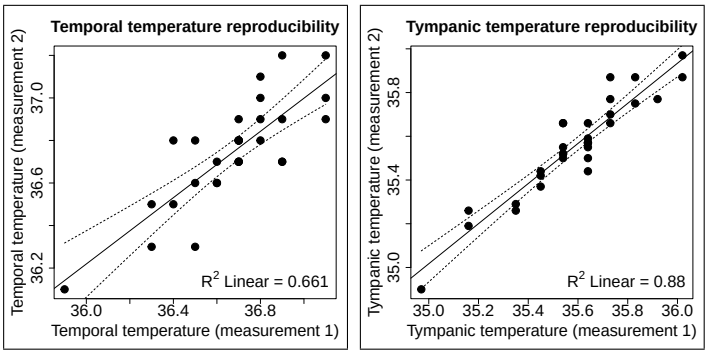
A cross-sectional study was designed to ascertain the reproducibility and accuracy of the measurements of heart rate, SpO_2, and body temperature (temporal and tympanic) with the developed device. A population of 30 volunteers was recruited among the students and staff of Coimbra's Polytechnic Institute, which we greatly acknowledge. The average age of this group was 23.33 ± 9.67 with 22 participants out of the 30 being female. None of the participants presented any COVID-19 symptoms during the study. All the evaluations were performed in the morning, in a laboratory with appropriate and controlled conditions. Every participant was seated comfortably for 10 minutes, to ensure the best measurement conditions. For the reproducibility assessment, repeated-measurements comparisons were performed for each participant. For the agreement assessment, one measurement was performed with the developed device and, right after, another with a standard clinically validated device.

3.1 Reproducibility Results

The e-CoVig device measurements assessing reproducibility are summarized in Table 1 and are showed in Figure 2. As demonstrated, no significant differences were observed for heart rate, oxygen saturation, and tem-

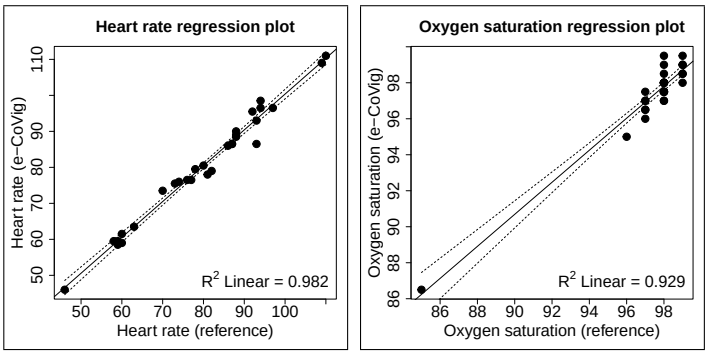


(a) (b)

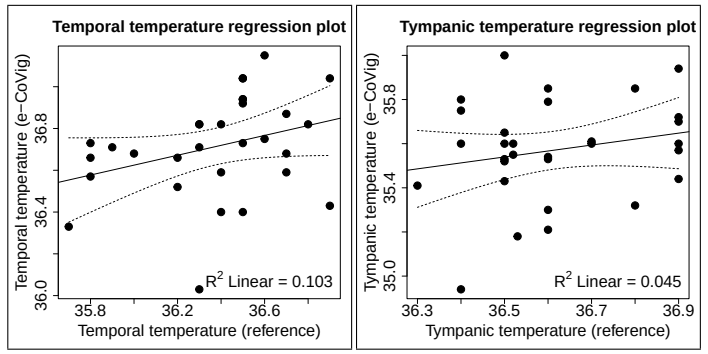


(c) (d)

Figure 2: Regression plots representing the e-CoVig repeated-measurements correlation. (a) heart rate (in BPM); (b) SpO_2 (in %); (c) temporal and (d) tympanic temperatures (in °C). The solid line represents the regression line computed using unweighted least squares, while the dashed lines correspond to 95% confidence bands.



(a) (b)



(c) (d)

Figure 3: Regression plots representing the correlation between the measurements with the e-CoVig device and the standard reference device. (a) heart rate (in BPM); (b) SpO_2 (in %); (c) temporal and (d) tympanic temperatures (in °C). The solid line represents the regression line computed using unweighted least squares, while the dashed lines correspond to 95% confidence bands.

Type of measurement	Standard device	e-CoVig device	Mean difference	p-value
Heart rate (BPM)	80.10 ± 15.60	80.50 ± 15.70	0.40 ± 2.10	0.912
SpO_2 (%)	97.50 ± 2.50	97.40 ± 2.30	-0.10 ± 0.70	0.829
Temporal temperature (°C)	36.37 ± 0.33	36.71 ± 0.24	0.34 ± 0.34	< 0.001
Tympanic temperature (°C)	36.62 ± 0.18	35.57 ± 0.23	-1.04 ± 0.26	< 0.001

Table 2: Pairwise comparison between the e-CoVig and the standard device measurements.

poral and tympanic temperatures. It is important to note that the temporal temperature measurements may appear sparser, but the range of measurements is 1 °C and the IR thermometer used has an accuracy of ±0.5 °C.

3.2 Agreement Results

Regarding the comparison of measurements between the e-CoVig device and clinically-validated devices, the results are summarized in Table 1 and are presented in Figure 3.

The mean difference obtained for the e-CoVig tympanic temperature measurement is greater than the temporal temperature (-1.04 ± 0.26 vs. 0.34 ± 0.34, respectively, $p < 0.001$), which can be explained by the fact that the temporal measurements correspond to an estimation of the core temperature; in reality, the forehead is colder than the tympanic region. Therefore, since a linear transformation is applied by the e-CoVig device to estimate the body temperature, the device will overshoot for tympanic measurements. Nevertheless, the standard deviation was smaller for the tympanic measurements, indicating that this method of acquisition is less susceptible to variability caused by the acquisition procedure.

The temperature measurements presented worse results, which can be explained by the narrow range of temperatures measured, as explained in Section 3.1.

4 Discussion

Preliminary validation results with healthy patients indicate that it accurately and reliably provides measurements of heart rate, blood oxygenation, and body temperature. This device is easy to use and low-cost to produce, facilitating its integration in the remote monitoring paradigm of COVID-19 patients. Besides being a useful tool in households for monitoring people, it can also be used in nursing homes and other health care facilities, since it merges two common devices into one: a pulse oximeter and an IR thermometer.

The temperature measurements presented a narrow range of values in the trial at Coimbra's Polytechnic Institute, reinforcing the necessity of validating the e-CoVig device with a broader range of temperatures, allowing to validate this use-case for the MLX90615 IR temperature sensor. Fortunately, our device is currently being used at Santa Maria's Hospital with COVID-19 patients, which will allow for further validating the developed low-cost specialized device. Evaluating the preliminary results of 20 samples, we report an improvement in the temporal temperature measurements, showing a mean difference of -0.31 ± 0.50 and a p-value of 0.101.

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