Monitoring the COVID-19 Diffusion by Combining Wearable Biosensors and Smartphones

Mohammedhusen Manekiya* and Massimo Donelli

Abstract—The management of the current pandemic COVID-19 has been challenging and complex. The main and only successes have been achieved with non-pharmacological interventions (NPI). When tracking, monitoring, and early intervention at home have been delivered to citizens, the contagion can be controlled. In the current pandemic, various methods have been applied to track the COVID-19 virus, such as Korea's mobile phone tracking system. We propose a method based on a wearable bracelet prototype able to detect biomedical parameters, which can be very useful to monitor the virus infection when the patient develops symptoms, such as a high temperature or low blood oxygenation. In particular, the prototype bracelet can measure the blood oxygenation using an infrared optical sensor and measure the temperature of the patient. The bracelet can record the identification number of other bracelet devices that came in proximity. The bracelet is equipped with a built-in low power Bluetooth, aimed to send the recorded data to a smartphone or another device in order to connect them with proper geo-localization and to the web. The identification number of the patient device can be used to trace the number of people and whom he has been in contact with, immediately by the sanitary authorities. Moreover, the bracelet can be used for monitoring the patient's health at home, avoiding hospital's overcrowding. The proposed system not only can effectively localize the trace path of patients positive to the COVID-19 virus or to other respiratory diseases, but also can provide an evolution of the patient symptoms and monitor people in-home quarantine. The system is simple and could be an efficient tool to track any other future pandemics.

1. INTRODUCTION

The novel coronavirus (COVID-19) outbreak started when Wuhan City of Hubei Province in South China reported 27 cases of atypical pneumonia on December 31, 2019 [1]. Later, the Chinese Government and the World Health Organization (WHO) recognized a novel coronavirus (COVID-19) belongs to the same virus family of the Severe Acute Respiratory Syndrome (SARS) that outbroke in 2002–2003 [2]. After a rapid spread and exceeding the total number of cases across the world compared to SARS cases, the SARS-COV-19 (COVID-19) was declared a pandemic by the World Health Organization (WHO) on March 11, 2020 [3]. The COVID-19 is a respiratory disease which means that it primarily injures the vascular endothelium. Globally, the confirmed cases of the COVID-19 have surpassed 15 million, and death has exceeded 636,000. Even when the victims are not at vulnerable age or do not have preexisting comorbidity, the doctors are discerning that a COVID-19 effect can also extend to many vital organs, including the heart, blood arteries, kidneys, abdomen, and brain [4]. Respiratory distress includes a critical vascular insult that mandates intensive care units raise. The approach to ventilator management and contribution is vital. The study in [5] of the Lombardi region has found that most patients were admitted to the ICU with acute hypoxemic respiratory failure that required urgent respiratory support. Moreover, a large proportion of patients who required urgent support were older

* Corresponding author: Mohammedhusen Manekiya (m.manekiya@unitn.it).
The authors are with the Department of Information Engineering and Computer Science, University of Trento, 38100, Italy.

men and had high levels of positive end-expiratory pressure (PEEP). Among the confirmed patients, 88% of them needed Endotracheal intubation and invasive mechanical ventilation, whereas 11% could manage with noninvasive ventilation. The provision and availability of intensive care unit (ICU) beds differ among the countries. Many countries have taken strong lockdown measures to prohibit the virus's transmission, such as imposing the fine, warning citizens from going outdoors, suspending the public gathering, and adjourning transport between cities. These extraordinary measures were presumed to effectively stop virus transmission and gain the necessary time to extend medical resources to highly affected areas. Report [6] suggest that the asymptomatic person with unusually low blood-oxygen levels, or hypoxia is unaware and reacts very normally while talking on their phones or chatting with doctors [7–9]. They define themselves as a healthy person. It is known as a happy hypoxia. Moreover, the knowledge of the asymptomatic persons and critically ill patients are essential for the health and government officials to engage in planning efforts to address community transmission. One reason is the lack of information transparency at the initial stage of the outbreak. Publishing the epidemic information timely and correctly is very crucial for the anti-epidemic response [13–15]. The accurate and transparent report could prevent the spread of the COVID-19 at the beginning. Predicting the pandemic's spread and tracking becomes extremely important for decision-making against the public health crisis. Some governments have developed and adapted the use of Digital Contact Tracing to reduce the disease's spread by accessing the user and the patients' location trails by creating a surveillance state. The Singapore government had demonstrated a new contact-tracing smartphone app called Trace Together as a preventive step toward the COVID-19.

The report [1, 2] shows that the early symptoms of this epidemic are fever (atypical pneumonia), dry-cough, and oxygen deficiency, which leads to the difficulty of breathing. In this study, we present an early-stage system for predicting and monitoring respiratory diseases such as the COVID-19. The system is based on a wearable bracelet prototype, able to measure real-time biomedical parameters useful to create the medical report of a patient remotely. The prototype bracelet is equipped with a low power Bluetooth, temperature sensor, and an infrared optical sensor to identify blood oxygenation. Also, the prototype bracelet is equipped with a built-in unique identification number (ID), which can record the identification number of other bracelet devices when the other devices come into its proximity. These recorded data can be sent to a smartphone application to connect them with proper geo-localization and forward them on the web. This identification record number could help trace the number of people he has been in contact with if any person showing symptoms or tested positive. Our results are promising and vital to managing the novel coronavirus emergency since it can effectively localize the virus's trace path. Besides, it can record the progress of patient symptoms and monitor them at home while in quarantine. The proposed system is only a preliminary prototype, and its performance can be strongly improved by using innovative two-dimensional semiconductors with higher charge carrier mobility as reported in the related literature [16–25].

2. SYSTEM DESCRIPTION

In this section, the real-time life signals monitoring is given in detail; it consists of a wearable bracelet and a suitable android application to customize the bracelet functions to keep track of patient contacts. The wearable bracelet is equipped with an oximeter and a thermometer connected with a microprocessor. The device chosen is the SmartBond DA14681 produced by Dialog Semiconductor, a small-sized board typically used for IoT application, which can provide good computing power despite low power consumption, shown in Fig. 1 [10]. It also supports Bluetooth version 4.2, which requires little energy to operate, ensuring a good transmission speed (theoretically 221.7 kbps kb/s [11]). As a result of the ability for the Smartbond card to use Bluetooth, it was chosen to develop an application that would test its communication and operation.

The elaboration unit is equipped with a GPIO interface, a set of seven I/O channels, an I2C port, and an LBE Bluetooth card aimed to exchange data with a smartphone or another device equipped with Bluetooth. The power supply is provided by the means of a rechargeable battery (CR2032) that guarantees an autonomy about four days of continuous operation. The sample time and data transmission protocol can be set adequately through a suitable mobile phone app. The oximeter (model MAX30101 pulse oximeter and heart rate monitor) is used to measure the blood oxygenation and
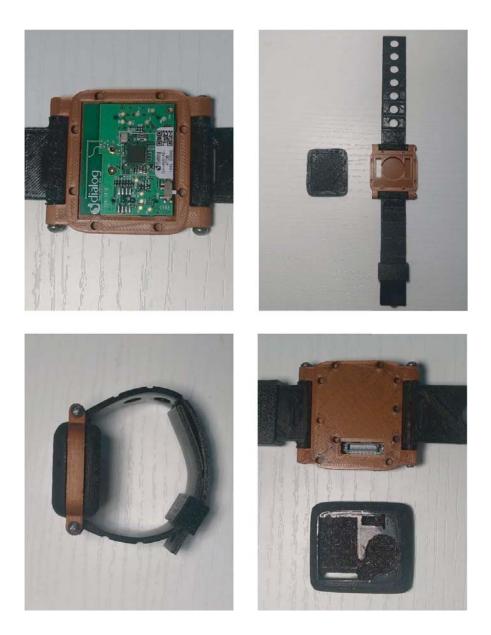
Figure 1. Photo of wearable sensor prototype.

heartbeat rate, and it can be easily connected to the I2C bus. The thermometer is an MLX906114ESF-BAA model, an infrared thermometer designed for non-contact temperature sensing, and it is provided with an internal 17-bit A/D and an I2C port. The sensors are turned on only when the measure is performed in the GPIO interface to save energy. To provide an accurate time stamp to the data, a GY-SI531 clock module has been used. The oxygen sensor makes use of the same infrared sensor commonly used in biomedical devices, and in hospitals, our device makes the measurement on the patient wrist standard devices on the finger or ear. We performed a set of calibration in order to be sure that the provided measure was accurate. All the components, sensors, clock reference, and elaboration unit have been assembled inside a rubber case designed with a 3D printer. Photos of the bracelet prototype are displayed in Fig. 1. As can be noticed, it looks like a standard watch, and it is quite comfortable to wear. At the beginning of the measurement campaign, the system operates as follows: a smartphone app of the bracelet is programmed using Bluetooth. In particular, the reference and sample time are provided to the bracelet. After the initialization, the bracelet starts to acquire the data. It transmits the data
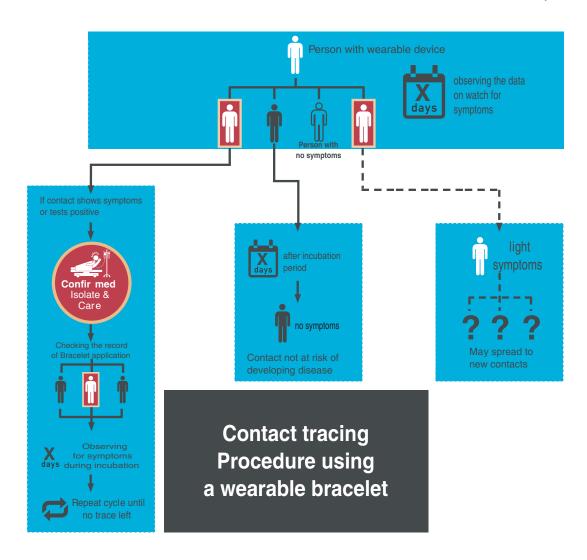
Figure 2. Contract tracing method wearable bracelet to monitor the symptoms of a person. If the symptoms develop, then tracing the Identification number of all the device which came in proximity and monitored their data.

to the smartphone or another device to store or process them. The Android/IOS based application is aimed not only to control the data transmission and initialize the bracelet, but also to track people. It is worth noticing that many available wearable devices can detect the wearers' vital parameters in the market, generally used in medicine and sports, but they have various problems. In the medical field, the devices have great accuracy, but they have very high costs, low availability on the general market, and often require specific software to work. In contrast, in sports, these devices are abundantly present, with a wide variety of cost, accuracy, and battery life, varieties that often require having to compromise, favoring one feature rather than another, like increasing the cost to get a more precise device. Our wearable device is suitable for various uses. It has low cost, good accuracy, and provides raw data so that each user can manage them. Concerning the Android/IOS based application, it has been made to handle the sensors data and track data of the person, which is explained in detail in this section, while the sensors management and data transmission will be discussed in the next section. In Fig. 2, a contact tracing method using a wearable bracelet is demonstrated graphically.

The contact tracing procedure using our wearable bracelet obeys the following rules:

- A wearable device continuously measures the persons vital health parameters data for blood oxygenation and body temperature changes. The information of these sensors has been stored

and sent on the cloud via smartphone in a particular period.

- Simultaneously, the bracelet stores the information of any proximity bracelet, which comes within its Bluetooth range. Each nearby bracelet device's unique identification number can be reserved on the bracelet itself or sent to the web or a cloud.

- Suppose that the sensor data show some unusual changes in temperature or oxygenation level. In that case, the bracelet is programmed to send an alert requiring urgent medical help connecting with the smartphone.

- Once the person is notified, he/she can consult nearby health officials or specialized medical operators, and send them his/her medical record data collected using the bracelet device.

- Medical staff can quickly inform the person to home quarantine and stop the further spread. Moreover, the medical staff will now observe his symptoms for the next few days.

- Meanwhile, the health official can trace the person's movement by using the bracelet track record, which was stored using a unique identification number of each bracelet. In this incubation period, the person has been prohibited from meeting anyone else.

- After learning about the person's movement, the official can contact the following person and tell him/her to have a home quarantine, as explained in the previous point.

- Depending on the bracelet's track record, the previous 3 steps are repeated until it leaves no trace.

- Once all the contacts are identified, public health officials can monitor them to offer counseling, medication, screening, and/or treatment.

By this method, the public health care system can become more organized in an emergency. Moreover, a massive surge in the ICU network and high fatalities can be avoided, as shown in [5, 7–9]. Fig. 3 shows smartphone applications' main screens before and after the search of Bluetooth devices. The application was developed on Android OS, chosen as the most popular SO OS on smartphones, 100% of which supports Bluetooth and of which most support BLE [12]. Concerning the data transmission: characteristic, descriptor, and services are identified by a Universally unique identifier (UUID), a 128-bit identifier, but GATT protocol can be represented with 32-bit or 16-bit codes. The protocol for transmitting detected data needed to exceed the number of requirements, such as:

 (i) Sending sensor values in constant time intervals.
 (ii) Identification, for each value, of the sensor from which it was detected.
(iii) Identification, for each value, of the moment of time in which it was detected.
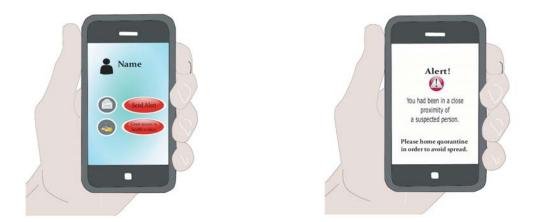(iv) The ability to start a new data submission session and be able to stop it at will.

Figure 3. Graphical Interface of Smartphone using a Contract tracing method using wearable bracelets to monitor a persons symptoms record the location data. If the symptoms develop, then tracing the Identification number of all the devices that came in proximity and monitoring their data.

It was necessary to do so in a structured way to always give the correct meaning to every data received without errors. That is why a data transmission protocol has been created based on the order of the data.

It is worth noticing that the collected data are encrypted, and they can only be visible to the user and medical operators. Only if the user wants, it is possible to share the contact trace, and in any case they do not show any identification data such as name, address, or fiscal code, but only a identification code. The identification code can be translated into a patient's information only by medical qualified personal. In this way, the data privacy is guaranteed. An example of how data related to the detected nearby Bluetooth devices are presented is shown in Fig. 4.

Figure 4. The main window of smartphone application before and after searching for the nearby Bluetooth devices.

3. RESULTS AND DISCUSSION

An experimental measurement campaign has been carried out to assess the capabilities of the proposed wearable bracelet prototype. The temperature, blood oxygenation level, and the heartbeat rate of a healthy subject have been measured continuously every half hour for three days. The goal is monitoring these parameters to detect possible variations such as a temperature above 37.5 degrees and blood oxygenation below 90%, which for significant cases could represent a possible COVID-19 infection or another respiratory disease that requires urgent hospitalization of the patient. The results of the measurement campaign are shown in Fig. 5. As can be noticed, the body temperature is always below 37 degrees. A slight temperature increase can be observed at 17, 41, and 65 hours which correspond
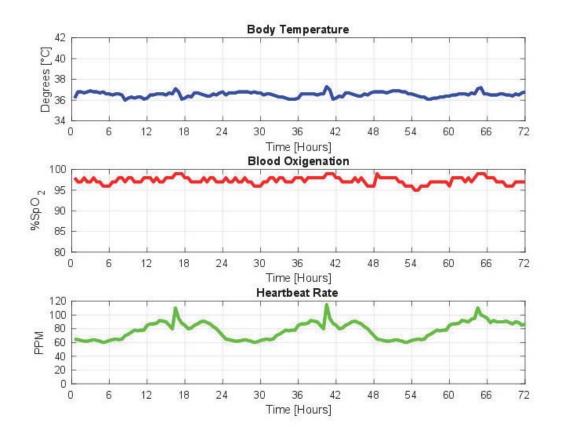
Figure 5. Three days measurement campaign of a healthy subject. The data have been collected every 30 minutes.

to heavy physical activity. The same peaks are present in the heartbeat-rate. When the subject is in the rest state, the heartbeat rate goes down to about 60 BPM. Concerning the blood oxygenation, as can be noticed from the data of Fig. 5, it is always between 95% and 98%, confirming that the patients lungs are healthy.

However, the critical nature of lockdown in Italy limited the experimental study to be performed on a limited number of people. The system has been assessed in our laboratory and not in a crowded area due to the COVID-19 restrictions. Due to these restrictions, in the laboratory, only three persons were allowed, so the tracking system was tested only on two/three persons demonstrating as expected its efficiency. Our future research will focus on the validation of the proposed method on many people and heterogeneity to provide a validated prototype that can be adopted in clinical practice.

4. CONCLUSION

In this work, a system aimed at monitoring real-time vital signs distressed by respiratory diseases such as COVID-19 has been presented and experimentally assessed. The system is based on a wearable bracelet and suitable for iOS-android mobile phone applications. A three days measurement campaign has been carried out, and the data collection has proved the efficiency of the proposed system, which can be used in the future not only to monitor patient health at home but also to track the diffusion of pandemic viruses. The obtained preliminary results demonstrated that the proposed system could be a solid starting point for future development of monitoring and tracking systems. In the next months, the system will be experimentally assessed on patients with lung diseases, thank to a collaboration with a pulmonary department of an hospital in Trento.

REFERENCES

1. "Wuhan municipal health commission infection data," [Online] Available: http://wjw.wuhan.gov .cn/front/web/list2nd/no/710, 2020.

2. Kwok, K. O., A. Tang, V. W. Wei, W. H. Park, E. K. Yeoh, and S. Riley, "Epidemic models of contact tracing: Systematic review of transmission studies of severe acute respiratory syndrome and middle east respiratory syndrome," *Comput. Struct. Biotechnol. J.*, Vol. 17, 186194, Jan. 2019.

3. The World Health Organization, [Online] "WHO Director-Generals opening remarks at the media briefing on COVID-19, March 11 2020," WHO, Mar. 11, 2020.

4. Wadman, M., J. Couzin-Frankel, J. Kaiser, and C. Matacic, "How does coronavirus kill? Clinicians trace a ferocious rampage through the body, from brain to toes," Apr. 17, 2020.

5. Grasselli, G., A. Zangrillo, A. Zanella, et al., "Baseline characteristics and outcomes of 1591 patients infected with SARS-CoV-2 admitted to ICUs of the Lombardy Region, Italy," *JAMA*, Vol. 323, No. 16, 15741581, 2020.

6. Couzin-Frankel, J., "Why don't some coronavirus patients sense their alarmingly low oxygen levels?," Apr. 28, 2020.

7. Grasselli, G., A. Pesenti, and M. Cecconi, "Critical care utilization for the COVID-19 outbreak in Lombardy, Italy: Early experience and forecast during an emergency response," *JAMA*, Vol. 323, No. 16, 15451546, 2020.

8. Onder, G., G. Rezza, and S. Brusaferro, "Case-fatality rate and characteristics of patients dying in relation to COVID-19 in Italy," *JAMA*, Published online Mar. 23, 2020.

9. Richardson, S., J. S. Hirsch, M. Narasimhan, et al., "Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with COVID-19 in the New York City Area," *JAMA*, published online Apr. 22, 2020.

10. Datasheet [Online]: https://www.dialog-semiconductor.com/products/ connectivity/bluetooth-lowenergy/smartbond-da14680-and-da14681.

11. Dian, F. J., A. Yousefi, and S. Lim, "A practical study on Bluetooth Low Energy (BLE) throughput," *2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*, 768–771, Vancouver, BC, 2018.

12. Datasheet [Online]: https://www.bluetooth.com/bluetooth-resources/2019-bluetooth-market- update/.

13. Marini, J. J. and L. Gattinoni, "Management of COVID-19 respiratory distress," *JAMA*, published online Apr. 24, 2020.

14. Caputo, N. D., R. J. Strayer, and R. Levitan, "Early self proning in awake, nonintubated patients in the emergency department: A single EDs experience during the COVID19 Pandemic," *Acad. Emerg. Med.*, accepted Author Manuscript, 2020.

15. Rhodes, A., P. Ferdinande, H. Flaatten, et al., "The variability of critical care bed numbers in Europe," *Intensive Care Med.*, Vol. 38, 16471653, 2012.

16. Viti, L., et al., "Efficient terahertz detection in black-phosphorus nano-transistors with selective and controllable plasma-wave, bolometric and thermoelectric response," *Scientific Reports*, Vol. 6, No. 1, Apr. 2016, 20474.

17. Guo, C., et al., "Anisotropic ultrasensitive PdTe 2-based phototransistor for room-temperature long-wavelength detection," *Science Advances*, Vol. 6, No. 36, Sept. 2020.

18. Guo, C., et al., "Ultrasensitive ambient-stable SnSe 2-based broadband photodetectors for room-temperature IR/THz energy conversion and imaging," *2D Materials*, Vol. 7, No. 3, 035026, Jun. 2020.

19. Paolucci, V., et al., "Self-assembled $SnO_2 = SnSe_2$ heterostructures: A suitable platform for ultrasensitive NO_2 and H_2 sensing," *ACS Applied Materials & Interfaces*, Vol. 12, No. 30, 3436269, Jul. 2020.

20. Agarwal, A., et al., "Plasmonics with two-dimensional semiconductors: From basic research to technological applications," *Nanoscale*, Vol. 10, No. 19, 893846, 2018.

21. Viti, L., et al., "Black phosphorus nanodevices at terahertz frequencies: Photodetectors and future challenges," *APL Materials*, Vol. 5, No. 3, 035602, Mar. 2017.

22. Liu, P., et al., "An optofluidics biosensor consisted of high-finesse Fabry-Prot resonator and microfluidic channel," *Applied Physics Letters*, Vol. 100, No. 23, 233705, Jun. 2012.

23. Liu, P., et al., "An ultra-low detection-limit optofluidic biosensor with integrated dual-channel Fabry-Prot cavity," *Applied Physics Letters*, Vol. 102, No. 16, 163701, Apr. 2013.

24. Chen, X.-M., et al., "A capillary-evaporation micropump for real-time sweat rate monitoring with an electrochemical sensor," *Micromachines*, Vol. 10, No. 7, 457, Jul. 2019.

25. Li, Y.-J., et al., "Transmission of dynamic biochemical signals in the shallow micro uidic channel: Nonlinear modulation of the pulsatile flow," *Microfluidics and Nanofluidics*, Vol. 22, No. 8, 81, Aug. 2018.