Special Section: Consumer Technology-Based Solutions for COVID-19

Can IoMT Help to Prevent the Spreading of New Coronavirus?

Firat Aydemir
Dumlupinar University

***Abstract*—This article presents a potential solution based on the Internet of Medical Things for the COVID-19 epidemic, which determines the symptoms of the disease without required any user action and warns the user. In medical studies on COVID-19 in the literature, the most common symptoms encountered since the onset of COVID-19 disease have been reported as fever, dry cough, fatigue, anorexia, anosmia, and dyspnea. The average incubation period is 5 days; therefore, it is very important to detect the symptoms even before the infected people notice the signs, and warn them. Thus, it can be ensured that they isolate themselves from society against the possible disease condition and prevent the spread of the disease. A wrist-worn device that does not physically disturb the person is proposed to track the health conditions of the person and detect the symptoms of COVID-19 at the early stages.**

In late December 2019, a series of pneumonia cases of unknown origin occurred in Wuhan, China's Hubei province. Many of these patients reported that they were in the Huanan Seafood Wholesale Market, which sold many live animal species before they got sick. On January 7, 2020, the World Health Organization (WHO) declared this new virus as the 2019 coronavirus, namely 2019-nCoV. On February 11, 2020, WHO called the disease caused by the 2019-nCoV virus, as COVID-19. On January 30, 2020, the WHO declared the COVID-19 epidemic as a public health emergency of international concern. Afterward, COVID-19 was identified as pandemic on March 11 due to the spread and severity of the virus in 113 countries, except in China, where the first outbreak started. Nowadays, the number of active cases worldwide has reached 17 million and the number of casualties has reached 675 000 (in August 2020). These numbers reveal the fact that the disease is spreading very quickly, and more measures should be taken to prevent this spread.

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Many cities, and even some countries, were all quarantined to prevent the spread of the virus. While many domestic and international flights were canceled, sports tournaments, international events, concerts, and festivals were postponed to a later date. All these measures were necessary steps to stop the spread of the virus. So, how does the virus spread? Human-to-human transmission occurs through direct contact or by droplets that spread through the infected person's cough or sneeze. Infected droplets can reach up to 2 m distance and remain infectious for days.[1] The contact of the infected person with healthy individuals or the time of being in the same environment increases the probability of the transmission of the disease.[2]

The measures taken to prevent the spread of the virus bring daily life and economic activities to a near-halt. The negative effects of the epidemic on economic and social life are increasing day by day; therefore, countries plan to gradually relax coronavirus restrictions. However, as in the case of many European countries, the second wave, in which new cases increase, may emerge after restrictions were loosened. At this point by using the technology, the spreading of the virus can be stopped by enabling people with signs and symptoms of Covid-19 to take tests and isolate themselves; because it is thought that patients are at the most contagious stage when they are symptomatic.

In this article, we present a wrist-worn device solution that is based on the Internet-of-Medical-Things (IoMT) to detect the symptoms of Covid-19 in the early stages. The most common symptoms of the patients are fever, dry cough, fatigue, anorexia, anosmia, and dyspnea.[3,4] The earlier we can detect such symptoms, the more we can prevent the spread of the virus.

The parts of the article are arranged as follows. Section II presents a detailed literature survey of the existing measurement methods for the mentioned symptoms. The proposed methodology is explained in Section III. The conclusions and further discussions on this article are given in Section IV.

RELATED WORK

The most common symptoms that COVID-19 patients suffer are mentioned above. In this section, the details of these symptoms are explained, and the measurement methods in the literature are mentioned. Since the system we have proposed is a wrist-worn wearable device, studies in which measurements are taken from the wrist are emphasized.

Fever

When a person is healthy, his/her body temperature is around 37 °C under normal conditions. But when the body is faced with a virus or bacteria, body temperature often goes up and this results in fever. It can be said that fever is one of the most important symptoms of illness or infection, which was also mentioned in the COVID-19 outbreak literature.

The traditional medical thermometers which are used in many places to monitor people's health conditions do not seem an efficient method considering that many people need to be measured. Wearable sensors seem a better solution to overcome this handicap, besides that kind of sensors can provide a continuous measurement. Thus, unexpected body temperature increments, especially during sleep periods, can be detected. Because many parameters need to be measured with the body temperature, a simpler structure can be created by using infrared thermopile sensors or high-accuracy digital temperature sensors as used in many commercial products in the market.

Dry Cough

Cough is one of the important protection mechanisms of the human body to clear the airway, and dry cough occurs in association with viral infections of the upper respiratory tract.[5] According to the studies on COVID-19, dry cough is one of the commonest symptoms causing by the 2019-nCoV virus. As already mentioned, the virus spreads through droplets from an infected person's cough. Therefore, it is very critical to inform the patient at the early stages of the illness by detecting the abnormal increases of the cough.

There are many studies in the literature for the detection of cough through audio signals, which can be obtained from microphone.[6, 7] They got high cough detection rates by applying filters, using signal processing methods, and

machine learning algorithms. For future studies, more accurate results can be obtained by using data processing algorithms on real COVID-19 patient's cough data. For now, in our proposed solution, the audio signals which can be recorded via an internal microphone placed into the wrist-worn device can be processed to monitor the number of coughs at certain time intervals.

Fatigue

Fatigue can be described as a lack of energy, and it can be a symptom of many diseases. COVID-19 patients are also suffering from fatigue. Measuring fatigue can be a complex process, and an easy method may not exist.

Instead of measuring fatigue directly, monitoring the physical activity during the daytime may also give an idea about the level of fatigue. Using a three-axis accelerometer to sense the movements is a widely used method in the literature[8, 9] and commercial products. Daily activity durations are regularly recorded in the system. In case of a decrease in motion due to fatigue, this situation might be evaluated as a symptom of an infection by the proposed system and the user can be informed.

Anorexia

Anorexia as a symptom can simply be described as a decreased appetite, which means not feeling hungry or lacking the desire to eat. Sometimes people do not even realize that they have no appetite, so if this happens as a result of a disease, it is important to detect this situation and warn the person as soon as possible. Anorexia cannot be measured directly; however, by following the daily eating habits of the person, when any reduction in food intake occurs, it can be concluded that the person shows anorexia as a symptom.

In one related study, audio analysis of the chewing sound was used to follow eating for dietary monitoring; they used audio signals which were recorded by placing a microphone at the inner ear, besides a limited amount of food was used at analysis.[10] Based on another methodology, the periods of eating are detected by tracking wrist motion.[11] To track the wrist motion of the subjects, custom watch-like devices which include accelerometer and gyroscope were used. In terms of application, it seems more cost-effective to obtain daily nutritional durations by following wrist movements, because the accelerometer could also be used for the fatigue detection.

Anosmia

Anosmia can be defined as the loss of the ability to detect one or more smells. Infection of the upper respiratory tract because of COVID-19 results with olfactory disorders, which were reported in many European countries. To detect anosmia without taking notification from people is very challenging.

In research on fragrance inhalation, it has been shown that diastolic blood pressure (DBP) of subjects is increased when they are exposed to fragrance inhalation of grapefruit essential oil.[12] Thus, if the blood pressure changes can be monitored after the release of grapefruit essential oil to the environment, the existence of the anosmia can be detected. Besides many commercial watch type products on the market for blood pressure measurement, different methods are mentioned in the literature.[13] For our proposed solution, which aims to measure all required data from a single measurement site, cuffless continuous measurement of blood pressure based on the pulse transit time (PTT) method is convenient. PTT can be determined from two pulse signals; such as photoplethysmography (PPG) and impedance plethysmography (IPG) signals.[14]

Dyspnea

Dyspnea, which is also described as shortness of breath, is a feeling of not breathing well. One of the other important symptoms caused by 2019-nCoV is shortness of breath.

Shortness of breath because of 2019-nCoV may not be seen in everyone, yet this situation generally causes respiratory distress and if the condition progresses, the patient should be taken under medical supervision. If the person has underlying ailments, the probability of having respiratory distress is even higher depending on that situation.

The respiratory rate is an important criterion for the evaluation of shortness of breath. The

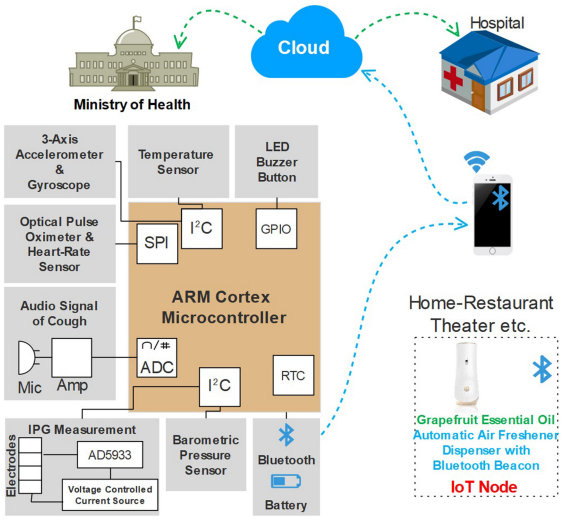

Figure 1. Block diagram of the proposed solution.

normal respiratory rate measured for a healthy person is between 12 and 20 breaths/min. Single respiration occurs in two stages; inhalation and exhalation. When the person breathes in, his/her heart rate increases, and when he/she breathes out, it decreases. This relationship between heart rate and breathing cycle is called respiratory sinus arrhythmia (RSA). The respiratory rate can be calculated by using the RSA component without adding a new hardware component to the wrist device.[15]

DESIGN EXAMPLE

Device Architecture

The block diagram of the wrist-worn IoMT based device and other structures in the proposed system solution is presented in Figure 1.

The wrist-worn device includes several sensors, a battery, a Bluetooth module to establish wireless connectivity with user smartphone and automatic air freshener dispensers, for user interaction with some peripheral components (LED, push-button, etc.), and a 32-bit ARM Cortex microcontroller.

The body temperature is measured via infrared thermopile sensors with standard I^2C serial interface and wide operating voltage range (3 to 5 V). A microphone is placed into the device to keep track of the person's daily cough count. After an amplifier circuit with automatic gain control, the audio signals are converted into digital signals through the ADC in the microcontroller. In order for the device to detect the cough sound; some cough audio data and other environmental noises are needed to create a dataset at first, and then a decision can be made via machine learning. A cloud-based embedded machine learning solution, edge impulse, is used to get quick results. The Mel Frequency Cepstral Coefficient (MFCC) signal processing block is used to extract the spectrogram of each audio data. Then, the neural network is trained to recognize the cough. If enough COVID-19 patients' cough audio data can be collected, the system can be trained to distinguish between a normal cough and a cough caused by coronavirus.

The three-axis accelerometer and gyroscope sensors are used to monitor wrist movements; thus, the time elapsed while eating and drinking something can be detected. Moreover, the person's hand height changes are measured via a barometric pressure sensor, so the wrist movements which are similar to the movements that occur while eating and drinking something are eliminated. According to the recorded data, the reduction rate in eating and drinking can be determined. Besides, by tracking persons' daily activities via these three-axis accelerometer and gyroscope sensors, the reduction in the daily activity rate is reported to the user as fatigue.

High sensitivity pulse oximeter and heart-rate sensor, MAX30102, which is an ultra-low-power system with 1.8-V main supply voltage and a 3.3-V internal LEDs supply voltage is chosen for the proposed solution. Although the person's heart rate is constantly monitored, the only significant data are those recorded at rest. The respiratory rate is calculated from the raw heart rate via the RSA phenomenon. During the resting time, daily changes over respiratory rate require significant attention; the user must isolate himself/herself for at least 3–5 days and track his/her situation. And also, this sensor is used to record the PPG data, which is utilized to get blood pressure with IPG signals received from the IPG measurement circuit that consists of electrodes and a high precision impedance converter system, AD5933. Blood pressure is an essential value for the efficient diagnosis, management, and prevention of diseases as well as detecting the loss of the

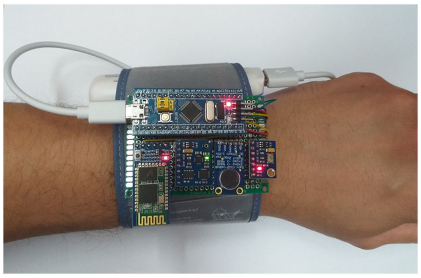

Figure 2. First prototype device.

ability to identify the grapefruit essential oil. The grapefruit essential oil is sprayed to the environment at certain intervals via the IoT-based automatic air freshener dispensers, which should be provided by the government or local authorities. They should be placed to cover the entire area of private spaces such as houses and apartments, and various commercial spaces such as bars, cafés, and restaurants. During each emission, the Bluetooth beacon in the dispenser sends information about spraying to inform wrist-worn devices or mobile phones. Then, an increase in blood pressure is expected in about 10 min after the beacon notification. If not, the user is informed of the possible loss of smell.

Results

The first rapid prototype device is presented in Figure 2. All measurements were taken in the daytime from 9:00 A.M. to 6:00 P.M. for 7 days; it could not be tested during the sleep periods of the subject, since the rapid prototype was not a compact one. The subject is a 36-year-old male healthy individual.

The body temperature was measured at certain time intervals, and the daily average body temperature changes are shown in Figure 3. The average heart rate and the time spent during eating and drinking are also shown on the same graph. The respiration rate of the subject, the total number of coughs detected during the measurement period, and the number of steps are shown in Figure 4. The changes in the blood pressure of the subject within 30 min after the release of grapefruit essential oil to the office via the IoT-based automatic air freshener dispenser are presented in Figure 5.

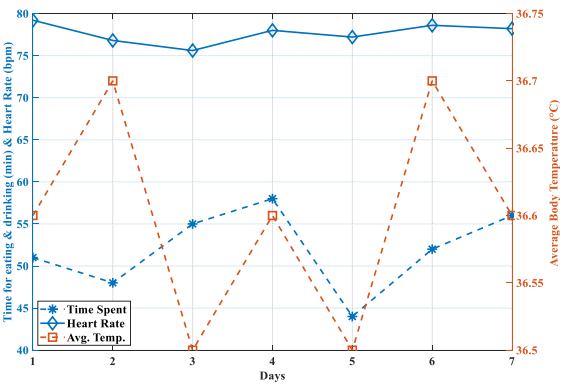

Figure 3. Average body temperature, time spent during eating and drinking, heart rate.

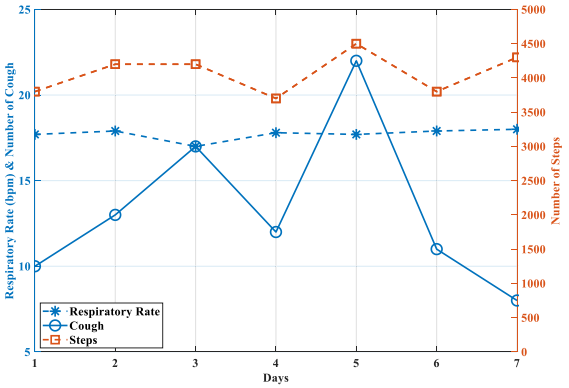

Figure 4. Respiratory rate, number of cough, number of steps.

In order to use the battery more efficiently, the device does not contain any LCD screen. All kinds of notifications are made with a LED on the device. Detailed notifications and data analysis are shown on a mobile application on the user smartphone. Moreover, if some of the possible symptoms are detected, this information is transferred to the hospital database and the ministry of health database via the mobile application.

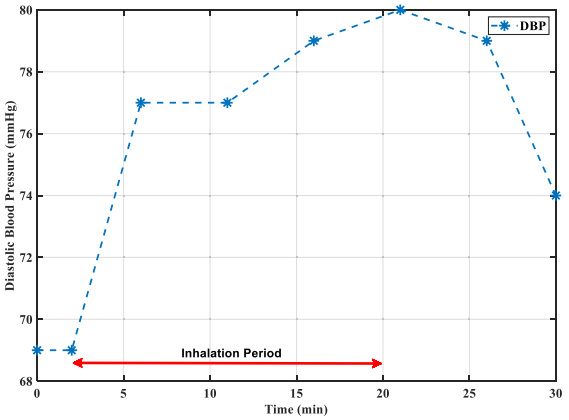

Figure 5. Changes in DBP after releasing of grapefruit essential oil.

CONCLUSION

One of the best ways to prevent the spread of the 2019-nCoV is to isolate anyone who might be carrying the virus. Unfortunately, unless the person is tested for the 2019-nCoV, he/she does not know that he/she is infected before getting sick. Therefore, detecting COVID-19 symptoms in the early stages plays a vital role. The proposed IoMT based wrist-worn device is aimed to detect the most common symptoms of the disease. When any symptom is detected, the person is warned to get self-isolation; moreover, the health conditions of the patient transfer to the cloud database via the mobile application, so the healthcare specialist is informed about the patient's current situation.

In future studies, by making a compact device, the system will be tested with people at high risk of the disease, such as healthcare professionals. Moreover, via the mobile application that will be developed, the user can reach to all data showing the health status.

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Fırat Aydemir is currently an assistant professor of computer engineering with Dumlupınar University. His research interests include embedded systems, sensor systems, and smart IoT systems. Contact him at firat.aydemir@dpu.edu.tr