Monitoring the Health and Movement of Quarantined COVID-19 Patients with Wearable Devices

Muhammad Nazrul Islam, Nafiz Imtiaz Khan, Noor Nafiz Islam, Samuli Laato, and A. K. M. Najmul Islam

Abstract This study explores the requirements and possibilities of wearable devices for ensuring and supporting the home quarantine of suspected COVID-19 patients. We adopted a design science research (DSR) approach and conducted a requirement elicitation study through semi-structured interviews with 36 participants including doctors, home quarantined people and local administrative personnel. Based on the analysis of the interview data, we identified some design considerations for the proposed system. Based on these results we developed a proto- type wearable device and a cloud-server solution which we tested with regards to usability and how well the system meets our design goals. The findings suggest the proposed solution to be able to assist in the remote monitoring of the location and health condition of quarantined people, relieving work load from medical doctors as well as quarantine surveillance officials. The designed wearable device is reusable, meaning that once a patient has recovered from the disease, the same device can be used by other patient.

Keywords Monitoring of COVID-19 patients · Wearable device for remote monitoring · Pandemic control · System usability

---

M. N. Islam (✉) · N. I. Khan · N. N. Islam
Department of Computer Science and Engineering, Military Institute of Science and Technology (MIST), Mirpur Cantonment, Dhaka 1216, Bangladesh
e-mail: nazrul@cse.mist.ac.bd

S. Laato
Department of Future Technologies, University of Turku, Turku, Finland

A. K. M. N. Islam
LUT School of Engineering, LUT University, Lappeenranta, Finland

S. Adibi et al. (eds.), *The Science behind the COVID Pandemic and Healthcare Technology Solutions*, Springer Series on Bio- and Neurosystems 15,
https://doi.org/10.1007/978-3-031-10031-4_10

1 Introduction

The novel coronavirus disease (COVID-19) was first reported in December 2019 and was declared a global pandemic on March 11th 2020 by the World Health Organization [1]. As of 29 September 2021, there have been 232,636,622 confirmed cases of COVID-19, including 4,762,089 deaths, reported to WHO [2]. The most common symptoms of the disease are fever, cough and shortness of breath. Less common symptoms are aches and pains, sore throat, diarrhea, conjunctivitis, headache, loss of taste or smell, rashes on skin, and discoloration of fingers or toes [3, 4]. As the virus is transmitted from human to human through contact as well as the main transmission method is person-to-person [5], quarantine measures are an effective way to prevent it from spreading [6].

As the time from exposure and symptom onset is generally between two and 14 days [3] (average of five days), most countries made it mandatory for all travelers returning from foreign countries to stay in quarantine for two weeks. In addition, individuals were advised to adopt personal health measures such as quarantining themselves to minimize the spreading of the disease [7, 8]. While most people obediently stayed in home quarantine when instructed to do so, a proportion of people ignore the rules. Because of this, some countries resorted into enforcing quarantine laws with the help of the police or even the military. However, several countries have limited resources to ensure people with suspected infections to stay at a designated place with proper facilities [9–11]. Use of technology to monitor patients remotely to ensure quarantine may ease the tasks of law enforcing agencies. One often suggested and used method was remote surveillance through mobile phone data [12, 13]. Other suggested measured included internet of things (IoT) device, data analytic, artificial intelligence, machine learning, and robotic system [14–16].

The use of wearable devices and sensor based systems for pandemic control is natural, for example: Quer et al. [17] investigated if personal sensor data ac- cumulated over time can detect small changes that indicate infection, such as in COVID-19 patients. Shubina et al. [18] provided a brief technical review of existing contact tracing solutions and discussed the possible impact of wearable in combating the spread of a highly infectious illness. In [19], the authors suggested a new intelligent method for contact tracking and COVID-19 cluster prediction. Similarly, in [20], authors proposed a wearable bracelet to track COVID-19 pa- tients in real time. In another study, Tripathy et al. [21] proposed an Internet of Medical Things based wearable system for contact tracing to maintain social distancing to fight with COVID-19, while Tavakoli [22] theoretically discussed how the wearable technology can be used for healthcare during the COVID-19 pandemic; like augmented/virtual reality based wearable systems may facilitate to collaborate with several doctors and patients for remote diagnosis or treatment planning.

Again, it can be found that similar solutions have successfully been used before the COVID-19 pandemic to monitor, for example, the movement of Alzheimer patients and children [23], locating soldiers locations during a military operation [24], and human (women) safety band to send the emergency message with location details to the Police [25]. Again, in many countries distant monitoring with electronic devices are used as a condition of pretrial release, or post-conviction supervision, like probation or parole [26, 27]. Electronic monitoring has also been used to track juveniles [28], immigrants awaiting legal proceedings [29], adults in drug rehabilitation programs [30], and individuals accused or convicted of domestic violence [31]. Remote monitoring is used as a mechanism for reducing jail and prison populations [32]. These solutions can include feedback and alarming systems that respond to sensor input and the individuals' movement.

However, very few studies have been conducted focusing on the wearable or sensor based systems to fight against COVID-19 pandemic though a number of digital initiatives have been taken to fight with COVID-19 pandemic [33–36]. Thus, a sensor-based wearable device could be developed to assist and monitor people in quarantine during the COVID-19 pandemic. One of the established requirements for this kind of a system from the governments' perspective is that it can be used to monitor the quarantined patients. However, it remains unclear what the other major requirements of such a system would be.

Therefore, the objectives of this research are to (1) identify the requirements that need to be considered for developing a wearable device to monitor movement and health of quarantined COVID-19 patients, and (2) propose a solution based on the identified requirements. To address these research objectives, we interviewed 36 individuals including doctors, home-quarantined patients, and administrative personnel and formulated a set of design objectives. A prototype of the wearable system considering the functional requirements was then implemented and evaluated to explore the quality attributes of the proposed system.

2 Research Method

To address the research objective, we adopted a design science research (DSR) approach as guided by Vaishnavi and Kuechler [37]. The overall research method was adopted from prior similar DSR studies [38, 39] and included the following five steps: (1) awareness of problem; (2) suggestion; (3) development; (4) evaluation; and (5) conclusion. These steps are showed in Fig. 1. The process steps (first column) are linked to corresponding methods and activities of the research (second column), and the actual outcomes of the DSR are depicted in the last column. Next, we describe each of these five steps.

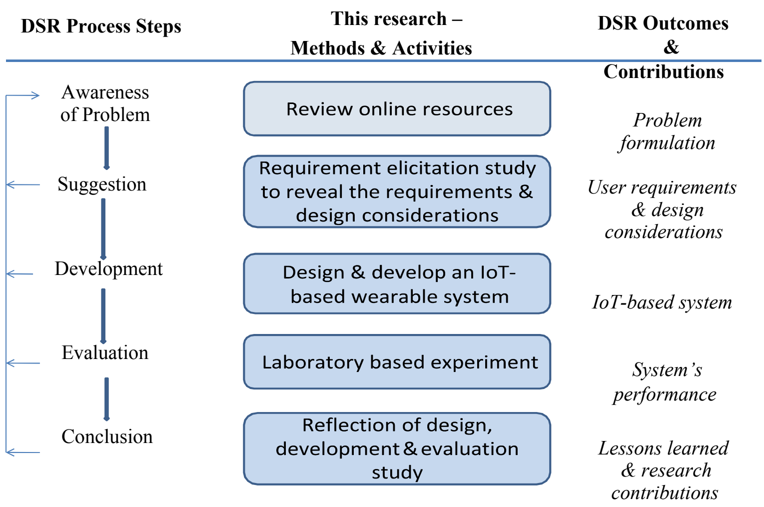


Fig. 1 Overview of the research methodology

The first step, awareness, refers to conceptualizing the situation and the problem at hand. In our case we define it as how to use technology to control, monitor and assist quarantined COVID-19 patients. Due to the novelty of the COVID-19 situation and the nature of our study, we reviewed related published research papers, online news articles, blog posts and website contents to better frame the problem [6, 40–43].

The next step is suggesting a solution to the problem. We propose developing a wearable system that could monitor and assist quarantined patients. In order to identify the requirements for such a solution we created a requirement elicitation study, interviewing 36 participants (doctors, quarantined patients and local administration personnel). The aim of these interviews was twofold: (1) to under- stand the scope of the imposed quarantines and quarantined patients' problems that could be alleviated with technology; and (2) to reveal the functional and design requirements of the law enforcement for monitoring and controlling the imposed quarantine measures.

As a third step in the process is the development of the system. We developed a rapid prototype in our lab based on the findings of step 2, and iterated the development process following agile software development recommendations. In the fourth step, we evaluated the feasibility of our solution in a laboratory environment. This process included testing the usability of the solution as well as how it matched the design goals set for the system. In the fifth and final conclusion step we present the main outcomes, contributions and open issues for further investigation and research on this topic.

3 Requirement Elicitation Study

3.1 Participants Profiles

We conducted semistructured interviews with a total of 36 people, among them five doctors, three professionals from Institute of Epidemiology Disease Control and Research (IEDCR) of Bangladesh, 17 suspected patients and 11 people who were working on local administration and had the responsibility to ensure quarantine of COVID-19 effected people. The IEDCR professionals are responsible for researching epidemiological and communicable disease in Bangladesh as well as disease control. The patients' average age was 36 years. Interviewed doctors worked at a local hospital and community clinics, and among them three were directly in charge of serving COVID-19 patients. Considering the vulnerable situation, the interviews with patients were done through telephone. Local administrative personals and professionals from IEDCR were interviewed physically.

3.2 Study Procedure

The interviews were semi-structured and were carried out in Dhaka, Bangladesh. A separate set of questions were prepared for each group of participants (patients, doctors, local administrator and personnel from IEDCR) keeping in mind the research objectives.

Participants' consent to ensure anonymity and confidentiality were collected through email or in a printed form. The Research and Development wing of authors' institute provided the ethics approval. Also, to record the audio of the interview sessions, permission was asked directly from each participant at the beginning of the interview situation. The audio recordings were later transcribed for analysis and were kept securely on trusted servers on the authors' institute.

3.3 Revealed Requirements

The transcribed interviews were analyzed qualitatively. Two researchers separately read the transcribed interview data and coded the relevant pieces of information. After the coding was completed, both researchers met together to compare the results of their coding. The inter-coder agreement [44], calculated as the sum of all the agreements divided by the sum of all agreements and disagreements was 0.89. The disagreements were resolved by discussions.

The themes revealed through the qualitative data analysis were clustered into four broad categories as showed in Table 3 in Appendix A that represents the example quotes after translation, the revealed codes and their associated categories. In the following, we describe each of these categories in detail.

1. Need for a remote monitoring and assistant system—One of the most important themes that emerged from the preliminary analysis as well as the interview data was the need for a remote monitoring and assistance system for home-quarantined people. The administrative personnel and doctors both stated that there is an inadequate number of administrative personnel to monitor and assist suspected patients, and that there is also a lack of sufficient number of resources to ensure utilities in quarantine centers and hospitals. Because of these reasons it is best for all, if suspected patients stay at home-quarantine rather than at hospitals or quarantine centers.
2. Monitoring disease specific health related data: People affected by the COVID-19 disease suffer respiratory and breathing problems [3]. The interviewed medical doctors and IEDCR personnel stated that the continuous health assessment of hospitalized and home-quarantined patients is mandatory. They stated that it is important to monitor patients' heart rate and body temperature even if they stay at self-quarantine. Thus the ability to remotely and continuously monitor patients' health was deemed as an important requirement for the system.
3. Barriers to adopt the IT-based device: The participants saw several barriers that might limit their adoption of the proposed IT-device. The two main issues were: (1) the lack of experience with technology; and (2) privacy issues. The doctors and IEDCR also raised a concern about the accuracy of health data, while the administrative personnel were afraid of potential misuse of the technology.
4. Design and functionality considerations: The following ten considerations are proposed based on the interviews: (1) accurate location tracking–an accurate time-stamped location signal is important to ensure that the patients are adequately quarantined; (2) unique identification—each quarantined person needs to be uniquely identified via the system (3) data accuracy–health related (e.g. heart rate and body temperature) data needs to be accurate and reliable to afford the making of remote health diagnosis; (4) light-weighted device—the wearable device need to be light-weighted to be comfortable to use and wear at all times; (5) easy-to-use –the device needs to be easy to use to avoid technology stress and to make using it as easy as possible; (6) easy-to-learn—similar to the ease-of-use, the use of the device should not require extensive technical know-how; (7) protect privacy—as the device is collecting sensitive information such as health and time-stamped location data, maintaining data privacy is paramount. The users' should be made fully aware who has the ability to view their data, where it is being sent and will it be deleted at some point; (8) cost-effectiveness—the development costs of the system need to be reasonable; (9) portability—the wearable system needs to be portable so that any person wearing the device may continue normal movement in their home; and

(10) reusability—the wearable system needs to be reusable, so that it can be redistributed onward to the next patients after the quarantine period is over.

The first two themes indicate the importance of staying at home quarantine. They also highlight the necessity of an assistant system for managing quarantine and to monitor health related data. The third theme highlights the barriers of using such systems by the end users. Finally, the fourth theme highlights the design and functionality considerations.

4 Proposed Wearable Device Solution

To address the system requirements identified in the elicitation study, we de- signed and built an internet-based wearable system. As a solution we propose a wearable device with an inbuilt GPS and fingerprint scanner connected to a cloud server that can provide live location to the central monitoring team. The wearable prototype system contains a heart rate monitor, temperature monitor, an internet transceiver, a display, and a feedback system, among other requirements. The system will be inexpensive and implementable for large number of susceptible patients and this will replace the need of physical monitoring.

4.1 System Architecture

Figure 2 displays overall architecture of the developed system whereas, Fig. 3 exhibits a layered architectural view of system components that are used to develop the

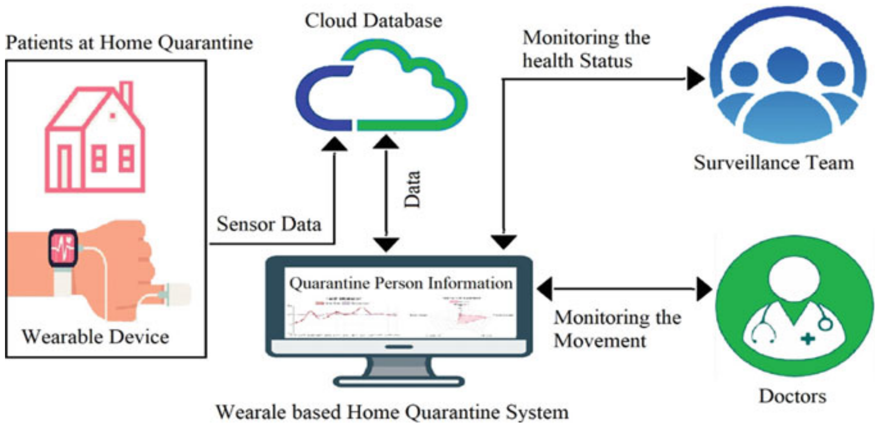


Fig. 2 An overview of system architecture

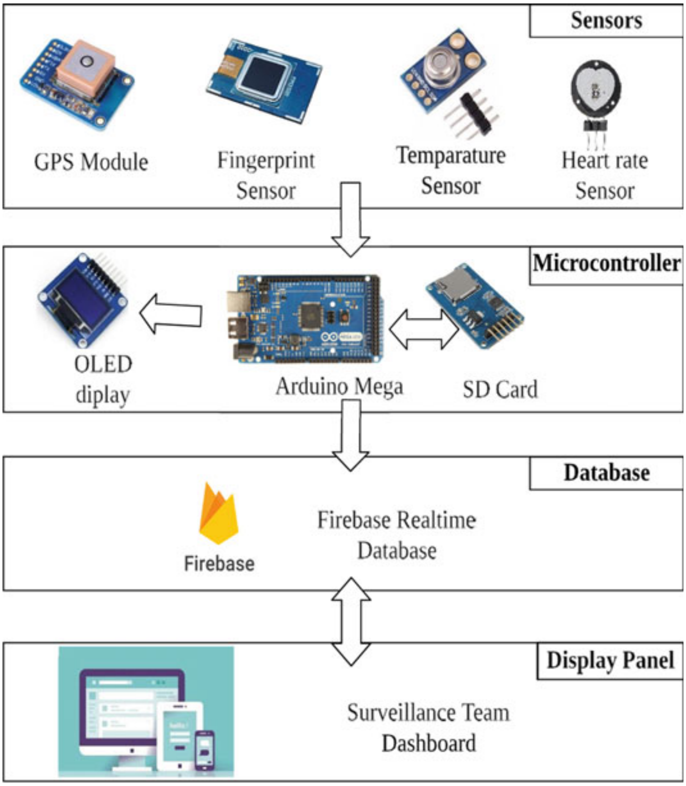


Fig. 3 A layered architectural view of system components

prototype of the system. The system consists of four sensors for measuring the (1) heart rate; and (2) body temperature; of the patient as well as for (3) fingerprint scanning; and (4) getting the user's time-stamped location. The sensors are connected to an Arduino micro-controller that also features an OLED display for visual feedback to the user. The Arduino connects to the cloud database, synchronizing the sensor data there. The medical and surveillance professionals can then access this data to ensure guidelines are met and the patient remains in good health.

4.2 *Workflow of the Proposed System*

Figure 4 represents the work flow of the proposed system. The wearable device is given an identification number so that in case of many devices, the surveillance team will be able to monitor each person individually. For the device to work, at first it needs to be registered with a person's unique ID, home location and fingerprint. Device will continuously capture real time location, heart rate and body temperature

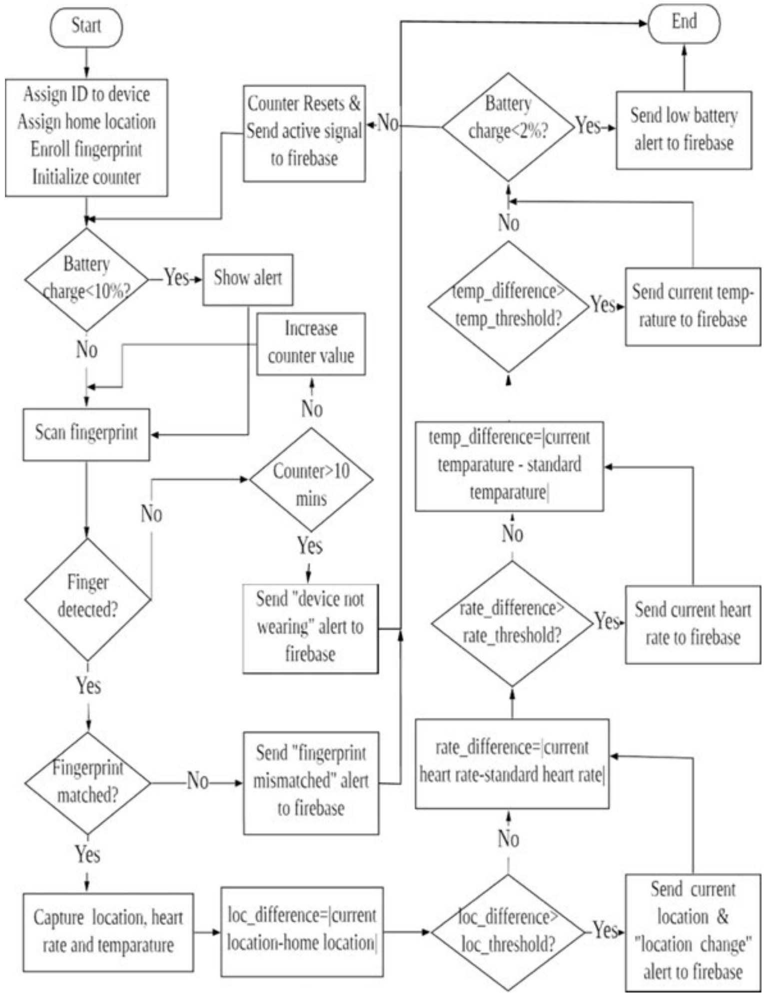


Fig. 4 System workflow diagram

of the quarantined person provided that user's real time fingerprint matched with the registered fingerprint. In case of a failure to detect a valid finger, the device will count up to 10 minutes before sending an alert to Firebase cloud based database. Captured data from the device (location, heart rate and temperature) will be continuously compared to their expected values. If any of those differences exceed their respective permitted threshold values, then the system will send the most recent data along with an alert signal (if any) to the cloud based database. For example, if the difference between quarantined person's current location and home location exceeds a permitted threshold value, a "location change alert" along with current location will be sent to the cloud. Also, in case there are systematic changes in the heart rate or body temperature, the system will send the current heart rate or body temperature to the cloud.

Regardless, the device has any data (location, heart rate, temperature) or alert to send to the cloud or not, the device will send an active signal to the cloud continuously which will ensure that the device is active.

This device will run by DC (direct current) power supply supported by a battery. So after a fixed time, the device needs to be charge. When charge the device has less than 10% battery left, an emergency light associated with the device will turn on, and it will remain on, until the device is plugged in with the charger. When the battery life of the device goes extremely low (2%) the device will send an alert signal to the cloud before turning off so that the surveillance team can be dispatched to look into the situation. As charging the device is an issue, each person will be given two wearable devices, so that while one is in charging, other one can be used. This way, continuous monitoring of quarantined people will be ensured.

4.3 Prototype Development

The prototype development was divided into two parts: (1) the hardware device and related software; and (2) the cloud monitoring system. In this section we present the development of both.

Developing the Hardware Device: The proposed system includes two bio- signal sensors to obtain the health related data that includes: (a) pulse sensor (SEN-00162)—a plug-and-play heart-rate sensor for Arduino to find the pulse rate as heart bit per minute (bpm), and (b) a temperature sensor (GY-906 MLX90614ESF)—to measure and send the body temperature. Similarly, other two surveillance related sensors were used: (a) fingerprint sensor (AS608) having three levels of features like pattern, minutiae points, and pores and ridge shape for recognition purposes; and (b) a GPS sensor (GY-NEO-6M V2) to keep the track of the patients who are in quarantine. For showing notifications to user, an OLED display (DIS-0091) is used. Apart from these; an Arduino Mega (mi-crocontroller board) was used as a processing unit that intelligently controls the other sensors. All the sensors are directly connected with micro controller board in different pins. After recognizing the user through the fingerprint sensor, the microcontroller takes analog data from GPS, temperature and heart rate sensors. These data are then sent to the cloud-based database. A 9V battery (MIS-00004) is used to give power to the device. The key functionalities of the proposed system and associated logics to ensure proper data flow to the cloud based surveillance system is shown in Algorithm 1.

Algorithm 1: FingerCap

```
Initialization of sensors, display, counter;
while true do
    if battery.charge() ≤ 10 percent then
        display("ALERT!! Low battery");
    end
    if fingerprint.detect_valid_finger() then
        if fingerprint.matched_enrolled_finger() then
            capture(location,heart rate,temperature,timestamp); loc
            difference=|location - home location|;
            rate difference=|heart rate-std heart rate|;
            temp difference=|temperature-std temperature|;
            if loc_difference ≥ loc_threshold then
                firebase.send_data(ID, location, timestamp);
                firebase.send_alert(ID,"location change",timestamp);
            end
            if rate_difference ≥ rate_threshold then
                firebase.send_data(ID,heart rate,timestamp);
            end
            if temp_difference ≥ temp_threshold then
                firebase.send_data(ID,temperature,timestamp);
            end
            if battery.charge() ≤ 2 percent then
                firebase.send_alert(ID,"Battery low",timestamp);
                break;
            else
                counter=0;
            end
        else
            firebase.send_alert(ID,"fingerprint mismatched",timestamp);
            break;
        end
    else
        if counter ≥ 10min then
            firebase.send_alert(ID,"Device not wearing", timestamp);
            break;
        else
            counter=counter+1;
        end
    end
end
```

In the Algorithm 1, at first, battery charge of the device will be checked. In case, battery charge is low, the user will get an alert through the Organic Light Emitting Diode (OLED). Next, the fingerprint scanner will try to scan continuously the fingerprint of user. If no fingerprint is detected, then the counter will stay on and the device will count until 10 minutes has passed. After this, the device will send an alert to the surveillance team that the device is inactive. If the fingerprint is detected, the system will check whether it matches with the initially given fingerprint of the user or not. If it does not match with the given fingerprint, the device will send an alert to the surveillance team again. Next, the device will capture the present location, heart rate and temperature of the user and send it to the cloud server. This loop is then repeated.

Dashboard for the surveillance team: A Graphical User Interface based dashboard or system, which is connected with the cloud based database, is capable of presenting all data received from multiple wearable devices. A few prototypical interfaces of the dashboard are displayed in Figs. 5 and 6 in Appendix B. This interface can be used by the surveillance team as well as medical doctors to access the sensitive information of the patients. As such, it requires an authentication via a password and a username. Through the monitoring interface personnel can look up statistics of individual users as well as overall statistics of all who are followed with the wearable sensors. The visual dashboard (Fig. 6) is complementary to the automatic warnings that are sent out by the wearable devices in case they are disconnected or the patients break quarantine.

5 Evaluating the Prototype

A lighted weighted evaluation study was conducted at Software Engineering Laboratory at authors' institute to measure the functional accuracy and the usability of the proposed system. For each primary feature/function of the system, a test case scenario was prepared and then conducted five times. The percent of the success rate and the average delay in seconds are showed in Table 1. With the exception of the fingerprint mismatch and the capturing the current location, all other functionalities cleared the tests.

We then set out to evaluate the system's usability. Five faculty members were invited as a test subjects. During the evaluation study, firstly a brief presentation about the objective of this study was given to the participants. Second, the proposed system was demonstrated to them and they were given the opportunity to use the system for roughly 5 minutes. Finally participants were asked to perform a set of tasks with the system. Finally they were asked to provide their opinion about the usability and effectiveness of the proposed system, and give any recommendations they might have come up with. A brief summary of the recorded data is given in Table 2.

The results showed that each participant was able to perform the designated tasks with comparatively minimum number of attempts (see Table 2). For example, for 40% (4 out of 10 tasks) tasks participants did not ask any questions from the observing researchers. A similar result was found for the number of at- tempts. Except for the task number six, all other tasks took less than or around half a minute to complete. The participants also viewed the graphical results generated by the tool during their testing and generally said that it would be an efficient way for the doctors to remotely monitor quarantined persons. All the participants were satisfied with this system, and expressed that the overall usability of the system was good. According to them, the system would be easy to learn for the surveillance team members as well.

Table 1 Results of the evaluation study (functional accuracy test)

Task name	Test-case description	% of success	Delay (Second) M ± SD
(a) Monitoring heart rate	How the users data are received/visualize in the system's dashboard	100%	10.0 ± 0.632
(b) Monitoring temperature		100%	3.4 ± 0.8
(c) Capturing location		80%	3.2 ± 0.74
(d) Fingerprint mismatch alert	If the real time fingerprint don't match with the quarantine person's fingerprint, it gives alert to the dashboard	80%	3.6 ± 0.48
(e) Not wearing alert	If the quarantine person is not wearing the device, it gives alert to the dashboard	100%	3.8 ± 0.78
(f) Low battery alert	If the device's battery is less than 2%, it gives alert to the dashboard	100%	2.0 ± 0.632
(g) Low battery notification to user	If the device's battery is less than 10%, it gives alert to the user (quarantine person)	100%	1.4 ± 0.4898
(h) Location change alert	If the quarantine person move outside the designated area, it gives alert to the dashboard	100%	5.0 ± 0.632

6 Conclusions

This study presented the empirical design and implementation of a wearable de- vice for monitoring the health and physical location of quarantined COVID-19 patients. Using DSR, we first conducted a qualitative interview study for identifying the design requirements of such a system. Then based on our findings, we iteratively developed a prototype. We evaluated the prototype from two perspectives: (1) how well it takes into account the design goals; and (2) usability. Based on our findings, the developed wearable system coupled with the cloud-server connection is a practical and useful solution for assisting health professionals and government officials in pandemic control and situation monitoring.

Our study has the following limitations. First, the developed prototype was not yet put in the form of an actual wearable device. While the basic system and usability requirements were met, additional testing with the next phase of the prototype is still needed before moving into production. Second, affordability of the device was prioritized. The prototype was cost-effective, meaning that better results may be achieved in case the cost of the system is not an issue. Third, some aspects of the system such as using it while taking a shower or using it while sleeping were not

Table 2 Results of the evaluation study (system usability)

Task	Number of attempts (M ± SD)	Task completion time (second) (M ± SD)	Number of times asking help (M ± SD)
T1: Log in to the system using given credentials	1 ± 0	10.2 ± 1.72	0 ± 0
T2: Find list of all home quarantine people in Mirpur area	1 ± 0	10.8 ± 1.46	0 ± 0
T3: Find statistical information of all home quarantine people in Dhaka region	1 ± 0	10.6 ± 1.85	0 ± 0
T4: Enroll a new home quarantine person in the system	1.2 ± 0.4	28.6 ± 2.57	0.2 ± 0.4
T5: Remove a quarantine person from the system	1 ± 0	5.4 ± 1.01	0 ± 0
T6: Contact a quarantine person in Mirpur area whose location has been changed	1.6 ± 0.8	131.8 ± 7.90	0.6 ± 0.8
T7: Notify doctor for a person in Mirpur area whose heart rate and temperature is high	1.8 ± 0.74	31.2 ± 2.31	0.8 ± 0.74
T8: Notify nearby police for a person in Mirpur area whose location has been changed and who is contacted previously	1.6 ± 0.8	39.6 ± 3.00	0.6 ± 0.8
T9: Find number of persons in a particular area who are not currently wearing the device	1.4 ± 0.48	11 ± 1.41	0.4 ± 0.48
T10: Save health information graph of Mr. X in pdf format and e-mail it to a concerned doctor	1.6 ± 0.8	28.2 ± 2.31	0.6 ± 0.8

tested. The shower problem might be solved by simply asking users to take showers that are shorter than 10 min, or by making the device waterproof. The problem with sleeping with the device is the fingerprint scanning requirement. The device needs to be fitted so that the fingerprints are scanned automatically at all times and does not require any additional work from the user. Fourth, a central cloud based database is used in the system which may get downed by receiving data from a large number of devices. In future, for implementing the system for a large number of areas, separate interconnected databases shall be maintained for each of the areas rather keeping a central database. Finally, constant internet connection is a mandatory requirement for this device to work. This means that continuous monitoring will not be ensured in case of having no internet connection.

We regard our findings promising as in the interviews all stakeholders viewed the idea as positive and the evaluation of the prototype was also considered a success. Our future work will focus on developing the concrete version of the system along with conducting an extensive evaluation study involving home quarantine people and members of the surveillance team. The developed technology may be adopted to be in use also after the COVID-19 pandemic is over in, for example, the monitoring of the health and location of Alzheimer patients.

7 Example Interview Responses

See Table 3.

8 Prototype of User Interfaces

See Figs. 5 and 6.

9 Example Questionnaire

9.1 Questions to Patients

1. Tell us about yourself and your family.
2. Tell us about your IT resources at home (e.g., PC, smartphone, Internet connection).
3. Have you ever used any kind of wearable device?
4. Will you be comfortable to use a wearable device while you are in home quarantine?

Table 3 The categories and codes with example quotes from interview

Categories	Codes	Example quotes (after translation)
Need for an IT based home quarantine system	Quarantine	"All returnees from abroad will be checked and will remain under a two-weeks mandatory quarantine" [participant from IEDCR]
	Distant surveillance	"Maintaining proper quarantine at home is very difficult in the social context of Bangladesh. Distant surveillance is required." [participant from IEDCR] "Monitoring every home quarantined person is very difficult by current system Distance monitoring system will be very much useful" [local administrator]
	Lack of quarantine centers	"Throughout the country there are limited quarantine centers for suspected persons mainly due to the limited time and resources" [local administrator]
	Lack of administrative personals	"It is not possible to effectively monitor all the persons who are in quarantine centers due to lack of human resource." [local administrator]
	Lack of resources	"It requires a lot of resources to ensure proper utilities to all persons staying in quarantine centers, In some cases, it may not be possible to arrange the require services in time" [local administrator]
Monitoring disease specific health related data	Body temperature	"We need to check the body temperature of COVID-19 patient to understand the current health status of the patient." [Doctor]
	Heart rate	"Heart rate monitoring is important to understand the possibility of cardio vascular disease that may take place due to COVID-19″ [Doctor]
	Blood pressure	"Patients with hypertension appear to be at a higher risk of dying from COVID-19" [Doctor]

(continued)

Table 3 (continued)

Categories	Codes	Example quotes (after translation)
	Blood oxygen level	"COVID-19 is killing with silent hypoxia: Patients' oxygen levels fall dangerously low but they don't have shortness of breath that usually signals the life-threatening condition; hence blood oxygen level of the patients shall be monitored" [Doctor]
	ECG	"ECG need to be monitored for infected COVID-19 patients having heart disease It can be used to investigate symptoms of a possible heart problem, such as chest pain, palpitations (suddenly noticeable heartbeats), dizziness and shortness of breath." [Doctor]
	Respiratory rate	"Respiratory rate is one of the most important metric to monitor if someone is infected by COVID-19″ [Doctor]
Barriers to adopt the IT based device	Lack of Technology experience	"I am not familiar with using wearable devices. That's why it will be very much difficult for me to use that kind of wearable device." [Patient]
	Wearing for long time	"Wearing a device for a long time will very much disturbing for me and I will not be comfortable with this while sleeping or in relaxation time." [Patient]
	Charging	"Due to a lot of load shedding in my locality, it will be very much challenging for me to charge the device properly." [Patient]
	Internet connectivity	"In my home I don't have internet connection. Also, it will not be possible for me to be within internet connected area all the time." [Patient]
	Continuous monitoring	"I will feel very much uncomfortable if I know that I am continuously being monitored by local authorities for consecutive days" [Patient]

(continued)

Table 3 (continued)

Categories	Codes	Example quotes (after translation)
Design and functionality considerations	Accurate position	"We need to check whether the infected patients are staying at their respective home address or not" [Local Administrator]
	Unique identification	"Each patient must have an unique identification number, otherwise it will not be possible for us to monitor each patient uniquely" [Local Administrator]
	Data accuracy	"Data collected from each device must have to be accurate for remote health diagnosis" [Doctor]
	Light weighted device	"If the wearable device is light-weighted, then I will be comfortable to use that device continuously while staying in home quarantine," [Patient]
	Easy-to-use	"System usability should be given high priority for designing such kind of monitoring system, so that by little training a surveillance team can be formed." [Local Administrator]
	Easy-to-learn	"System should be designed in such a way that any new user can easily learn the functionalities of the system" [Local Administrator]
	Protect privacy	"No one should have access to the patients' health data except the surveillance team and the concerned doctors." [Local administrator]
	Cost effectiveness	"Development cost of the device shall be considered for large scale production" [Local administrator]
	Portability	"Device shall be portable so that while wearing the device patient can carry on his/her normal movement" [participant from IEDCR]
	Reusability	"Device need to be reusable so that it can be given to another person after fourteen days" [Local administrator]

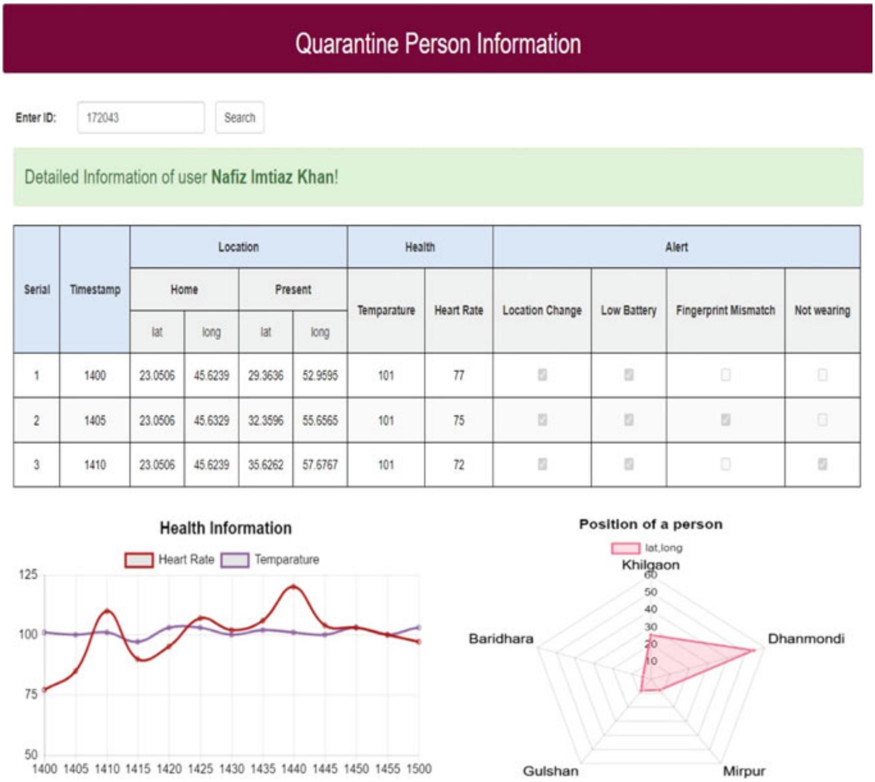
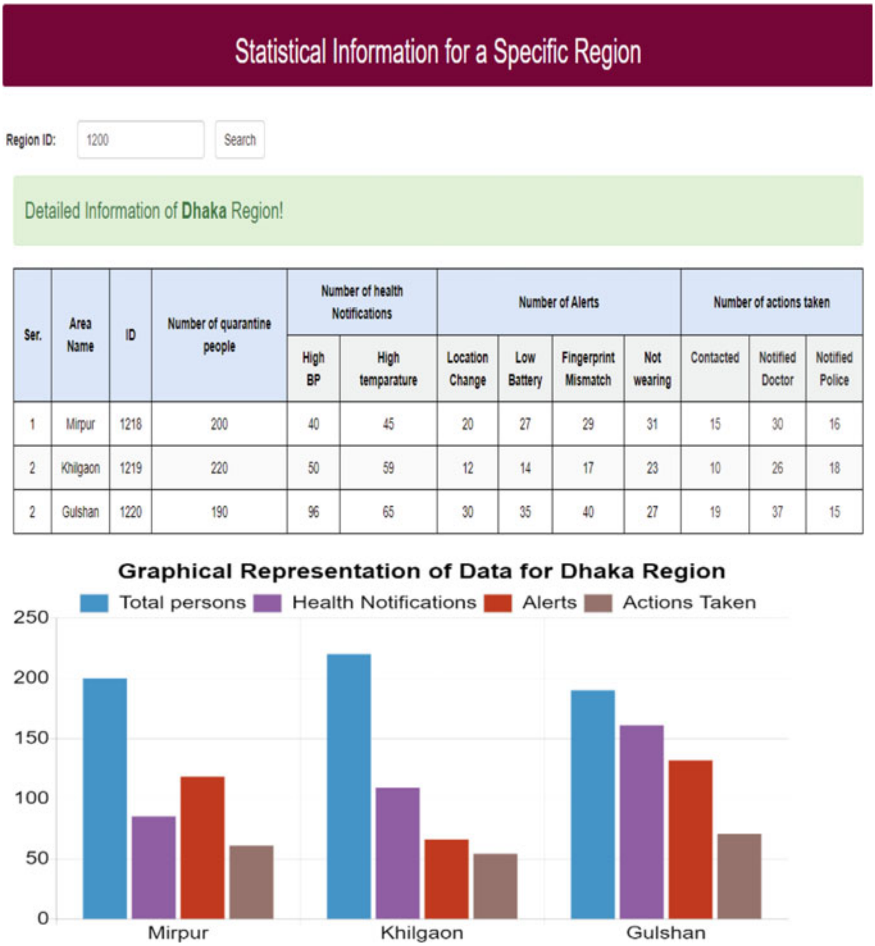


Fig. 5 User interface to show the information of a quarantine person

5. How do you feel about the situation that you have been staying in home quarantine and are constantly being monitored rather staying in isolation centers?
6. How important it is for you that the surveillance team constantly monitors your activity if you are infected with COVID-19?

9.2 Questions to Doctors

1. What are the challenges and limitations you feel serving in a pandemic situation?
2. What are the risks you have while you are treating patients affected by a highly contagious virus?
3. If a COVID-19 infected patient is staying in home, what are the health parameters that need to be checked frequently?
4. What do you think about remote health diagnosis? To what extent do you think it is effective in a pandemic situation?



Ser.	Area Name	ID	Number of quarantine people	Number of health Notifications		Number of Alerts				Number of actions taken		
				High BP	High temparature	Location Change	Low Battery	Fingerprint Mismatch	Not wearing	Contacted	Notified Doctor	Notified Police
1	Mirpur	1218	200	40	45	20	27	29	31	15	30	16
2	Khilgaon	1219	220	50	59	12	14	17	23	10	26	18
2	Gulshan	1220	190	96	65	30	35	40	27	19	37	15

Fig. 6 User interface to show the statistical information of a specific region

5. What are the criteria on which you classify condition of a patient as critical?
6. Why do you think temperature and heart rate need to be checked frequently?

9.3 Questions to Administrative Personals

1. Please explain the current challenges that you are facing to fight the pan- demic.
2. How do local administration ensure that all the suspected patients are main taining home quarantine properly?
3. To what extent do you think that any wearable device can be helpful to constantly monitor the activity of home quarantine people?

4. What things shall be considered for developing a home quarantine surveillance system for minutely monitoring the health and the movement of quar- antined COVID-19 patients?

9.4 Questions to IEDCR Personals

1. What guidelines are you giving to the persons who return from abroad?
2. How do you monitor the health condition of a suspected person?
3. How useful the central surveillance system is to efficiently monitor the suspected patients?
4. What functionalities the central surveillance system should have in order to monitor the health and movement of quarantined COVID-19 patients?

References

1. Laato, S., Najmul Islam, A.K.M., Islam, M.N., Whelan, E.: What drives unverified information sharing and cyberchondria during the covid-19 pandemic? Eur. J. Inf. Syst. 1–18 (2020)
2. WHO Coronavirus (COVID-19) Dashboard. Available on https://covid19.whoint. Last accessed 30 Sept 2021
3. Larsen, J.R., Martin, M.R., Martin, J.D., Kuhn, P., Hicks, J.B.: Modeling the onset of symptoms of covid-19. Frontiers Public Health **8**, 473 (2020)
4. Utku, A.C., Budak, G., Karabay, O., Gu¨¸clu¨, E., Okan, H.D., Vatan, A.: Main symptoms in patients presenting in the covid-19 period. Scottish Med. J. **65**(4), 127–132 (2020)
5. Toit, A.D.: Outbreak of a novel coronavirus. Nat. Rev. Microbiol. (3), 123–123 (2020)
6. Wilder-Smith, A., Freedman, D.O.: Isolation, quarantine, social distancing and community containment: pivotal role for old-style public health measures in the novel coronavirus (2019-ncov) outbreak. J. Travel Med. (2020)
7. A Farooq, S Laato, and AKMN Islam. The impact of online information on self- isolation intention during the covid-19 pandemic: A cross-sectional study. *Journal of Medical Internet Research*, 2020.
8. Islam, M.N., Inan, T.T., Najmul Islam, A.K.M.: Covid- and the rohingya refugees in bangladesh: the challenges and recommendations. Asia Pac. J. Public Health **32**(5), 283–284 (2020)
9. Eskeziya, A., Endashaw, H. et al.: Poor sleep quality and associated factors among individuals in covid-19 quarantine center, southern ethiopia, 2020. J. Mental Health Issues Behav. (JMHIB) **1**(01), 1–11 (2021). ISSN: 2799–1261
10. Haque, A.: The covid-19 pandemic and the public health challenges in bangladesh: a commentary. J. Health Res. **34**, 563–567 (2020)
11. Udaya Bahadur, B.C., Pokharel, S., Munikar, S., Wagle, C.N., Adhikary, P., Shahi, B.B., Thapa, C., Bhandari, R.P., Adhikari, B., Thapa, K.: Anxiety and depression among people living in quarantine centers during covid-19 pandemic: a mixed method study from western nepal. PloS One **16**(7), e0254126 (2021)
12. Arni, S.R., Rao, S., Vazquez, J.A.: Identification of covid-19 can be quicker through artificial intelligence framework using a mobile phone-based survey in the populations when cities/towns are under quarantine. Infect. Control Hospital Epidemiol. 1–18 (2020)
13. Islam, M.N., Islam, I., Munim, K.M., Najmul Islam, A.K.M.: A review on the mobile applications developed for covid-19: an exploratory analysis. IEEE Access **8**, 145601–145610 (2020)

14. Islam, M.N., Najmul Islam, A.K.M.: A systematic review of the digital interventions for fighting covid-19: The bangladesh perspective. IEEE Access **8**, 114078–114087 (2020)
15. Ting, D.S.W., Carin, L., Dzau, V., Wong, T.Y.: Digital technology and covid-19. Nat. Med. 1–3 (2020)
16. Islam, M.N., Inan, T.T., Rafi, S., Akter, S.S., Sarker, I.H., Najmul Islam, A.K.M.: A systematic review on the use of ai and ml for fighting the covid-19 pandemic. IEEE Trans. Artif. Intell. (2021)
17. Quer, G., Radin, J.M., Gadaleta, M., Baca-Motes, K., Ariniello, L., Ramos, E., Kheterpal, V., Topol, E.J., Steinhubl, S.R.: Wearable sensor data and self-reported symptoms for covid-19 detection. Nat. Med. **27**(1), 73–77 (2021)
18. Shubina, V., Ometov, A., Lohan, E.S.: Technical perspectives of contact-tracing applications on wearables for covid-19 control. In: 2020 12th International Congress on Ultra Modern Telecommunications and Control Systems and Workshops (ICUMT), pp. 229–235. IEEE (2020)
19. Jahmunah, V., Sudarshan, V.K., Oh, S.L., Gururajan, R., Gururajan, R., Zhou, X., Tao, X., Faust, O., Ciaccio, E.J., Ng, K.H., et al.: Future iot tools for covid-19 contact tracing and prediction: a review of the state-of-the-science. Int. J. Imaging Syst. Technol. **31**(2), 455–471 (2021)
20. Weizman, Y., Tan, A.M., Fuss, F.K.: Use of wearable technology to enhance response to the coronavirus (covid-19) pandemic. Public Health **185**, 221 (2020)
21. Tripathy, A.K., Mohapatra, A.G., Mohanty, S.P., Kougianos, E., Joshi, A.M., Das, G.: Easy-band: a wearable for safety-aware mobility during pandemic outbreak. IEEE Consum. Electron. Mag. (2020)
22. Tavakoli, M., Carriere, J., Torabi, A.: Robotics, smart wearable technologies, and autonomous intelligent systems for healthcare during the covid-19 pandemic: an analysis of the state of the art and future vision. Adv. Intell. Syst. 2000071 (2020)
23. Karasikov, N., Tamir, D., Bar-On, R.N.: Remote monitoring system for alzheimer patients. US Patent App. 11/913,439
24. Islam, M.N., Rabi-Ul Islam, M., Rafiqul Islam, S.M., Bhuyan, S.A., Hasib, F.: Locsoldiers: towards developing an emergency troops locating system in military operations. In: 2018 4th International Conference on Electrical Engineering and Information and Communication Technology (iCEEiCT), pp. 264–267. IEEE (2018)
25. Islam, M.N., Promi, N.T., Shaila, J.M., Toma, M.A., Pushpo, M.A., Alam, F.B., Khaledur, S.N., Anannya, T.T., Safeband, M.F.R.: A wearable device for the safety of women in bangladesh. In: Proceedings of the 16th International Conference on Advances in Mobile Computing and Multimedia, pp. 76–83 (2018)
26. Black, M., Smith, R.G.: Electronic Monitoring in the Criminal Justice System (2003)
27. Di Tella, R., Schargrodsky, E.: Criminal recidivism after prison and electronic monitoring. J. Polit. Econ. **121**(1), 28–73 (2013)
28. Roy, S.: Five years of electronic monitoring of adults and juveniles in lake county, Indiana: a comparative study on factors related to failure. J. Crime Justice **20**(1), 141–160 (1997)
29. Marouf, F.E.: Alternatives to immigration detention. Cardozo L. Rev. **38**, 2141 (2016)
30. Howell, J., Nag, A., McKnight, M., Narsipur, S., Adelegan, O.: A low-power wearable substance monitoring device. In: 2015 IEEE Virtual Conference on Applications of Commercial Sensors (VCACS), pp. 1–9. IEEE (2015)
31. Erez, E., Ibarra, P.R., Lurie, N.A.: Electronic monitoring of domestic violence cases-a study of two bilateral programs. Fed. Probation **68**, 15 (2004)
32. Payne, B., Gainey, R.: The electronic monitoring of offenders released from jail or prison: safety, control, and comparisons to the incarceration experience. Prison J. **84**, 413–435 12 (2004)
33. Zaman, A., Islam, M.N., Zaki, T., Hossain, M.S.: Ict intervention in the containment of the pandemic spread of covid-19: an exploratory study (2020). arXiv:2004.09888
34. Azim, A., Islam, M.N., Spranger, P.E.: Blockchain and novel coronavirus: towards preventing covid-19 and future pandemics. Iberoam. J. Med. **2**(3), 215–218 (2020)

35. Khan, S.R., Rownok, M.R.A., Prithula, S.R., Rifat, F.Y., Islam, N.N., Islam, M.N.: mvote: A mobile voting system to conduct election during covid-19 pandemic. In: 2020 IEEE International Women in Engineering (WIE) Conference on Electrical and Computer Engineering (WIECON-ECE), pp. 235–238. IEEE (2020)
36. Islam, M.N., Khan, S.R., Islam, N.N., Rownok, M.R.A., Zaman, S.R., Zaman, S.R.: A mobile application for mental health care during covid-19 pandemic: development and usability evaluation with system usability scale. In: International Conference on Computational Intelligence in Information System, pp. 33–42. Springer, Berlin (2021)
37. Vaishnavi, V.K., Kuechler, W.: Design Science Research Methods and Patterns: Innovating Information and Communication Technology. CRC Press (2015)
38. Chatterjee, S., Byun, J., Dutta, K., Pedersen, R.U., Pottathil, A., Xie, H.: Designing an internet-of-things (IOT) and sensor-based in-home monitoring system for assisting diabetes patients: iterative learning from two case studies. Eur. J. Inf. Syst. **27**(6), 670–685 (2018)
39. Meth, H., Mueller, B., Maedche, A.: Designing a requirement mining system. J. Assoc. Inf. Syst. **16**(9), 799 (2015)
40. Blendon, R.J., DesRoches, C.M., Cetron, M.S., Benson, J.M., Meinhardt, T., Pollard, W.: Attitudes toward the use of quar- antine in a public health emergency in four countries: the experiences of hong kong, singapore, taiwan, and the united states are instructive in assessing national responses to disease threats. Health Affairs **25**(Suppl1), W15–W25 (2006)
41. Majumder, S., Mondal, T., Deen, M.J.: Wearable sensors for remote health monitoring. Sensors **17**(1), 130 (2017)
42. Shehav-Zaltzman, G., Segal, G., Konvalina, N., Tirosh, A.: Remote glucose monitoring of hospitalized, quarantined patients with diabetes and covid-19. Diabetes Care **43**(7), e75–e76 (2020)
43. Unger, J.D.: System for monitoring patient location and data. US Patent 5,458,123 (1995)
44. Miles, M.B., Huberman, A.M.: Qualitative Data Analysis: An Expanded Sourcebook. Sage (1994)