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Internet of (Healthcare) Things Based Monitoring for COVID-19+ Quarantine / Isolation Subjects using Biomedical Sensors, A Lesson from the Recent Pandemic, and an Approach to the Future

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ABSTRACT The COVID-19+ pandemic has brought into keen focus the necessity to enforce digital infrastructure for remote patient monitoring based on IoT (Internet of Things) technology since quarantines and isolations are playing a vital role in containing its spread. As of date, many vaccines are in use while few drugs are in experimental stages, but there is always need for increasing reliability of disease detection and monitoring at both levels of individual and society, and such aim can be supported by wearable biomedical sensors devices. Previously, wearable devices have been used to monitor physiological parameters during daily human living activities. Still, the investment of such technologies toward predicting infection by COVID-19+ remains essential to alert potential patients and start sequence of health systems intervention. Aim in this perspective review, we have proposed an IoT based system to monitor the quarantine / isolation subjects during COVID-19+ and similar future pandemic. This wearable prototype, associated with the bundled mobile app, acts to reports and tracks/monitoring the quarantined individuals. Contribution: our suggested system will contribute to lowering risk of exposure to transmittable pathogens because IoT based quarantine/isolation monitoring system is contact-free that could benefit especially healthcare professionals and overall community. Current manuscript describes clinically relevant physiological human parameters that can be measured by wearable biomedical sensors and monitored based on IoT technology. Conclusion: This paper is a step towards initiation of an approach among front-line healthcare workers as well as biomedical engineers for developing digital healthcare platforms of monitoring and managing such pandemic.

INDEX TERMS COVID-19+, IoT (Internet of Things), wearable devices, quarantine / isolation, digital healthcare, remote / tele health monitoring, biomedical sensors.

I. INTRODUCTION

The Coronavirus Disease 2019 (COVID-19+) also was known as (2019-nCoV), first confessed in December 2019 in Wuhan, China, was the trendy respiratory disease pandemic and still currently afflict global health. On March 11, 2020, the WHO has announced the pandemic of novel coronavirus disease (nCoV or COVID-19+ or SARS-CoV-2). Then, causative agent was discovered be the novel coronavirus, severe acute respiratory syndrome coronavirus- 2 (SARS-CoV-2), which is morphologically resembling the virus that causes SARS. Also, COVID-19+ case as pneumonia is characterized by the four criteria of: (1) fever, (2) pneumonia image on radiography, (3) leukopenia and/or lymphopenia, (4) no relief of symptoms although 3 days of treatment [1], [2]. Nonetheless, hypoxic respiratory failure is the leading cause of death in COVID-19+

patients [3] . And as of December 20, 2022, there has been more than 6,648,457 confirmed infections, 6,576,088 deaths confirmed deaths and spread in almost all countries [4], [5] .
Previous similar outbreak causing viruses such as SARS-CoV virus in 2002 and 2003 then virus of Middle East Respiratory Syndrome (MERS) in 2012 put a huge challenge on public and on health care systems, but they were even hugely surpassed by the outbreak of the COVID-19+ virus [1], [6], [7]. It was proved in several studies about spread of COVID-19+, number of new infected person was increased in manner of exponential growth function [6]. Thus, measures such as social distance, isolation and quarantine are pivotal to minimize the virus spread.
Various healthcare studies, e.g., Boillat et al., (2018) [8]; Brannon et al., (2016) [9]; Loos and Davidson, (2016) [10]; and Sung et al., (2005) [11], they suggested wearable device in order to improve patient compliance to medical advices and rules. Thus, we have proposed wearable biomedical sensors connected with IoT based application, for monitoring the quarantine/isolated subjects in real-time base during future outbreak of infectious pathogen like COVID-19+ virus. Advantages of such devices include the improving both privacy and legitimacy of the data of the subjects during quarantine/isolation period while observing their movements on the global positioning satellite (GPS) based geofencing [12].
Recovery of human communities to get back to normal life after and even during times of future outbreaks depends on the effective diagnosis and isolation of infected patients which can be simplified and sophisticated through use of wearable biomedical sensors systems [13]. It is known that antibody tests as well as Polymerase chain reaction (PCR) techniques are valuable in diagnosis and measuring the number of infected cases but it is not appropriate for early detection of infection (before patient can spread it widely), so, here is a significance of wearable biomedical sensors and IoT based remote monitoring in order to detect earlier sign of infection and monitor isolation of patients (Figure 1) [14]. Importantly, higher risk to acquire infection and to express harsher symptoms are those groups of patients that are suffering from persistent chronic illnesses such as diabetes, hypertension, and heart disease, although they usually under report their symptoms, hence, using wearable biomedical sensors to observe such patients is by far an effective healthcare by alerting patients, doctors and nursing staff remotely about potential infection before emerging of severe symptoms [15].

Additionally, by these technologies, hospitals can develop local, de identified data to track both severity and spread of the infection without violation of patients' privacy [16], [17]. This technology of wearable health parameters biomedical sensors is highly applicable nowadays due to already spread of wearable devices such as smart watches that are used by more than 52.8 million individuals in the United States alone. Besides, parameters like temperature, pulse and sleeping patterns were monitored through smartphone and displayed in an online interactive map to observe community suffering from influenza-like illness (ILI) among more than 10,000 volunteers, and this was by support from Robert Koch Institute, Germany and results were useful in assessment of distribution and prevalence of infections [18]. Other study from the United States indicated using of smartwatches for monitoring sleep data as well as rest heart rate to determine community infection status and hot spot geographical regions [19]. Therefore, aim of this paper is participation in initiation of an approach among front-line healthcare workers as well as biomedical engineers for developing digital healthcare platforms of monitoring and managing COVID-19+ and similar pandemic. Thus, by lowering risk of infection and infection spread, such technology and clinical applications of wearable biomedical sensors will be highly helpful in cases of future pandemics. It ensures contactless healthcare providing which increased safety of both patients and healthcare providers. Besides, even during absence of pandemic, these biomedical sensors will help in health providing for individuals who are suffering from immobility conditions by minimizing need for transportation facilities.

II. METHOD

In this review paper we use "PubMed" and "google scholar" search engines to explore COVID-19+ pandemic quarantine and burden as well as current and past research papers about developing and using wearable biomedical sensor devices for remote healthcare providing by implementing IoT technologies. Then, we discussed and organized collected information to introduce for this initiation among healthcare providers, biomedical engineers, and healthcare clients to adopt developing and using wearable biomedical sensors for remote health care purposes.

III. COVID-19+: ISOLATION & QUARANTINE

Social distancing, isolation, and quarantine were among community containment procedures used in the beginning of COVID-19+ outbreak and they are still useful for future similar outbreaks [20]. 'Isolation' is the process of segregation of human how are diagnosed with a contagious microorganism to avoid contact with uninfected human to avoid spread of the infectious pathogen to the healthy individuals and this isolation is performed usually in hospitals [21]. Difference in length of incubation period between different viruses affect success of isolation procedures as longer incubation period offer a longer time to identify and isolate infected people before being able to spread the microorganism to other persons [1]. Quarantine can be defined as the process of restricting the movement of potentially infected persons even without appearance of symptoms [22]. Moreover, quarantine was followed since ancient times, and it is considered as the most effectual method in infection and outbreak control. For instances, quarantine method was used in Italy during the fourteenth century for protecting Venice port from ships arriving from any plague infected ports by quarantining for 40 days in the sea before landing (in Italian language: quaranta is the number 40) [23]. Also, quarantine was performed successfully during the time of SARS epidemic back in 2003 [24]. Besides, quarantine is highly important part of pandemic plans against influenza. Furthermore, quarantine may be used at both levels i.e., community level and /or individual level by restriction of movement and stay at home or other similar equipped places. Quarantine can be mandatory or voluntary according to the case. Also, each person should be monitored for symptoms during the quarantine period and if any deteriorating symptom appears on a person, then that person should be isolated in a hospital or hospital-like facilities. Success of quarantine procedure depends on the speed of cases detection and speed of listing and tracing persons contacted to the infected individual.

IV. QUESTIONS IN THIS CONTEXT

A. Why do we propose this system?

This system enables health care workers for remotely observe infection movement as well as emerging and progressing symptom hence virtually engaging with patients to advice, modify medications and to offer education, according to the changes in the patient's parameters. Such remotely connected healthcare technology is highly helpful for providing large scale and individualized health care during times of future pandemics that might like what happened in COVID-19+ pandemic by using digitally connected non-invasive biomedical sensors. Health care providers can communicate updates and modifications in treatment plans and other self-care instructions to the patient and deliver answers to quarantined/isolated patient questions. However, upon medically significant progression of symptoms, health care systems can intervene physically by reaching out to the patient or bringing patients in an ambulance.

B. What is Remote Patient Monitoring?

Remote patient monitoring is the process of continuous and real time measuring patients' parameters that related to the symptom progression by using wearable biomedical sensors connected distantly with health care system and health care personnel. This remote patient monitoring is highly helpful during times of outbreak and/or other situations where medically individuals should observe social distance for example during COVID-19+ time or similar situations in future. Examples of non-invasive remote patient monitoring devices include thermometers or sensors for body temperature, sensors for pulse, blood pressure and oximeters [25].

C. Why is Remote Patient Monitoring Necessary?

Patients with diseases such as COVID-19+ or similar distant care necessary due to, for example, infectious hazard or any other reason are in high demand for remote monitoring for assessment of potential intensification of symptoms. And according to the present guidance from the Centers for Disease Control and Prevention (CDC), the majority of COVID-19+ patients can recover at home, but symptoms of breathing difficulty must be monitored carefully. Also, regular monitoring of partial oxygen pressure (SpO2) by pulse-oximeter is recommended for observing progression of the disease and to avoid patient anxiety. Besides, according to the World Health Organization (WHO), the onset of severe pneumonia is associated with the SpO2 level of less than or equal to 93 percent and this is much easier for most patients than to ask them to define what is the breathing difficulties. Fortunately, remote patients monitoring allows patients themselves to measure the SpO2 [4].

D. How is Remote Patient Monitoring Conducted?

Remote monitoring can be ordered by a patient's physician. Then, this order can automatically generate a sequence of home delivery process as well as sequence of at-home set up of equipment. Another way is health care worker to schedule an in-person visit to the patient's home to provide the biomedical sensors and to educate the patient about the device, symptoms, and the treatment plan. Patient will be aware about how to use the device and communicate effectively with the health systems and personnel. Still, demand for equipment of remote patient management (RPM) is high hence there are always shortages of supply. To meet these shortages, the FDA, on March 20, announced a guidance that updated on October 2020, to facilitate faster market entry of new equipment of remote health monitoring [26].

E. What does the government need to do to ensure patients can receive this service and mitigate potential device shortages?

During the time of COVID-19+, clinicians all over the world were rapidly accepting and practicing health care processes by depending in the RPM rather than in-person care to minimize spread of infections among other reasons (Hudson, 2020; Hagland, 2020). Before the COVID-19+ pandemic, Medicare coverage of RPM services was restricted to only patients with one or more chronic conditions. But, after situation of encouraging and/or ordering patient to stay at home, need for remote monitoring for both acute and chronic patients became obvious, thus, for instances, in the United States, Centers for Medicare and Medicaid Services (CMS) declared that RPM could be used for patients with both types of illnesses i.e., acute and/or chronic (Federal Register, 2020).
CPT codes stand for devices of RPM, which include: CPT Code 99453: is for remote monitoring of biological parameters, for example, pulse oximetry, blood pressure, rate of respiratory flow. And weight. Besides, CPT Code 99454: is for devices of daily recordings or automatic alert transmission to health system about patients' conditions. Also, CPT Code 99457: is for services of remote parameters' monitoring and management of treatment. Finally, CPT Code 99091: is for collection and interpretation of patients' data that can be stored electronically and sent to the health system. Therefore, monitoring of patients remotely is an important step in

advancing healthcare services in complementary role with IoT based health care monitoring system and other measures that allow for healthcare professionals worldwide to access to all the information they need to make the well-informed healthcare decisions for the benefit of their patients.

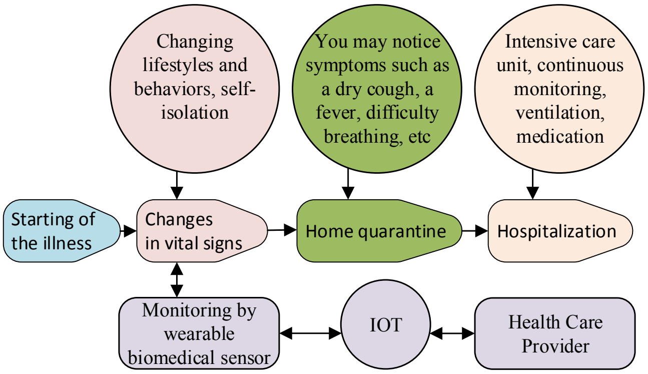

FIGURE 1: A correlation between clinical symptoms and the immune response to COVID-19+, as well as predictive analytics for monitoring COVID-19+ using wearable sensors.

Technology of Early Detection Algorithm (EDA) is highly recommended for health monitoring during situations like what happened within Covid-19+ pandemic. This gives an ability to detect parameters' changes by using wearable devices even before patient can notice and before it exaggerated into serious illness. We suggest that wearable devices can be used for the purposes of detection and alerting infected patients and health system and healthcare personnel through application of early detection algorithm (EDA).

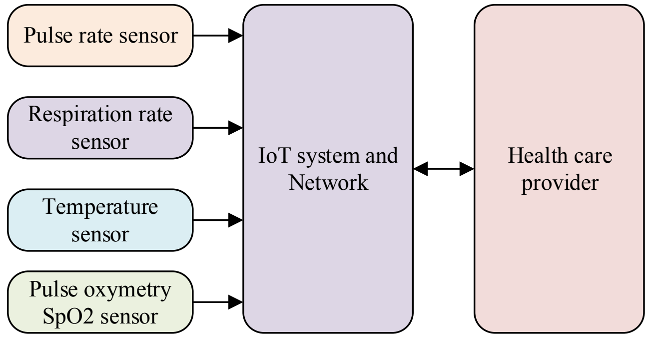

FIGURE 2: Tiered architecture for IoT (Healthcare).

This provides patients with the ability of self-isolation, seek care or diagnostic testing, and take other steps to mitigate transmission of the infection during a critical period of the disease process. Additionally, such wearable devices will be useful for monitoring and managing patient remotely especially in mild to moderate cases, thus, patients can report their parameters from home which is totally beneficial for patients and the health systems by saving critical resources for hospitals and minimizing the hazard of both nosocomial infection as well as infection of health care providers. A collection of the parameters, as listed above, will result in a quite enough high signal to noise ratio (SNR) that can be considered as an indicator for early viral and/or bacterial infection or risk of infection. Therefore, creating an EDA of high specificity and sensitivity is necessary for translation of this technology to be used for remote monitoring of patients. Also, nurses at intensive care units as well as other health care staff can use early-warning devices to get alerted if individuals are at risk or further risk of complications [27]. Moreover, we support that IoT based monitoring of patient remotely by using wearable biomedical sensors technology can be an asset in improving health care effectiveness by balancing nurse-patient care ratios, offering an effective and on-time

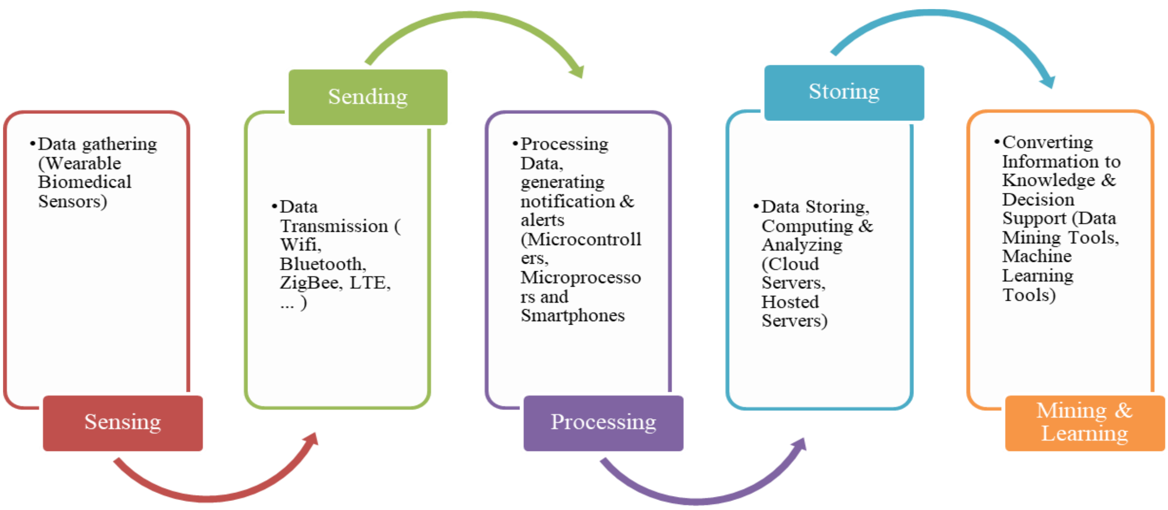

FIGURE 3: Bloc diagram for suggested wearable biomedical sensors.

interventions to help patient, and at the same time decreasing costs by eliminating unsuccessful medica

V. IOT-BASED APPLICATIONS IN HEALTHCARE

Remote monitoring, managing, support, and early detection and effective health care providing for individuals without compromising their convenience and preference of living independently outside the hospital; are goals that can be achieved by applying technologies of IoT especially during times of infectious diseases outbreak and quarantine such as during COVID-19+ and similar future infections. Additionally, patients with chronic diseases, disabilities, geriatric conditions will greatly benefit from IoT technology of remote health care.

A. Healthcare and the internet of things

The Internet of Things prevails a comparatively new field of scientific research, and its effective use for healthcare providing is a topic still in its rising stage. Several pioneering works towards emerging healthcare systems of IoT were introduced. Building on the related themes from these works, we propose a standardized model for future end-to- end IoT healthcare systems targeting improvement of sensing and helping individuals during future times of pandemics, individuals of chronic illnesses, and individuals with need and/or preference of remote healthcare services.

The elementary definitions of the Internet of Things (IoT) can be summarized as group of devices connected in a network and communicating with each other through system of machine to machine (M2M) interactions, with the aim of collecting and exchanging of data [28]–[30]. Many industries used this technology for purpose of automation, as well as allowing for the collection and dealing of huge data [31]. Examples of areas that commercially used IoT technology included smart parking, smart water usage management, precision agriculture, and nonetheless health care systems [32][33][34]. Moreover, Extensive multidisciplinary scientific research has also been performed to introduce using of IoT in creating intelligent systems for many areas e.g., smart grids, minimization of traffic congestion, manufacturing crash-avoiding cars, and nonetheless systems of monitoring healthcare [35][36][37][38]. Although, these examples include fields that appear huge different from applications in healthcare, but they contain scientific research that proves the credible of an IoT-based healthcare system. For instance, existing systems in other than healthcare fields showed to how much is monitoring of objects remotely, with collection and managing huge data are executable and of great useful outcomes. This allows for adaptation, expansion, and use of remote monitoring and managing for healthcare purposes.

B. IoT Tired Architecture (IoTTA)

For implementation of IoT-based applications like we proposed above, many parts will be used collectively, and these parts include cloud computing, sensor networks, wireless communications, and digital data processing. The integration of such technologies in an IoT system can be described as depicted in IoTTA. We host this architecture as five layers, first is Sensing Layer, second is Sending Layer, third is Processing Layer, fourth is Storing Layer, and fifth is Mining and Learning Layer. The sensing layer aims at gathering reads of different physiological/pathophysiological parameters from subjects affected by COVID-19+ or other similar future infections and then sending these collected signals to the processing layer for aim of pre-processing. Then, for further analysis data will continue to be transferred to the storing layer. Tools in the mining and learning layer are used for continuous analysis and for storing. Also, sending layers can perform transmissions of data between these different layers.

1. Sensing Layer

This layer contains an assembly of biomedical sensors or wearable devices for recording health parameters of subjects. Vital signs such as pulse rate, respiratory rate, blood pressure, body temperature, and oxygen saturation (SpO2) are the most common collected parameters [39]. However, more other different parameters can be included according to the purposes of the application. For instance, cardiovascular disease-related patients require monitoring for parameters of: heart rate, ECG, oxygen saturation (SpO2), and weight [40]. Whereas diabetic patients require organized measurement of blood glucose level [41]. Furthermore, a combination of gyroscopes and accelerometers can be used for gathering data in many devices of health monitoring for purpose of predicting the subject activity and tracking [42]. Besides, some applications use actuators for adjusting the environmental parameters or ,importantly, for triggering alerts among healthcare providers [43]. Previously, sensing of respiratory rate depending on the movement of the thoracic cavity was applied by Miyagi et al., 2020 [44]. Currently, huge development has been achieved in many types of smart biomedical sensors that can be used in applications of IoT based healthcare systems [45]. In addition, solutions of patient monitoring and tracking that are based on networks of wearable biomedical sensors allow for monitoring a large number of patients simultaneously and generating large amounts of relevant data. For designing the sensing layer of an IoT, it should be taken into consideration the aspects of energy consumption of sensing devices, size, cost, characteristics of the sensor, communication capability of the sensors, and how to organize and deploy the sensors [46].

2. Sending Layer

This layer contains the designed protocol for connecting and sharing data among assets of the system. Also, the sending layer allows for availability and retrieving data from associated Information Technology (IT) infrastructure [47]. Communications within IoT system can include both worldwide and local levels of communications [48]. Wireless technology is often employed for data transmission within such monitoring systems, and in same context, standards of wireless communication are suitable for establishment of compatibility and standardization and in health monitoring systems depending on IoT. Additionally, Bluetooth or ZigBee can be used in the sending layer for implementation of local communication between the sensing layer and the processing layer [49][50]. Bluetooth technology take consider as both advantages of low power consumption as well as less cost technology for transmission of data within short distances using the frequency of 2.4GHz [51]. Besides, ZigBee technology is also providing transmission of data with low power consumption but has not achieved widespread usage compared to Bluetooth. Moreover, Radio Frequency Identification (RFID), ultra-wide bandwidth (UWB), as well as Near Field Communication (NFC) can be also used as protocols of communication instead [52] [53]. Furthermore, connection between the processing layer and storing layer can use internet communication and cloud computing, as the unique choice that can be established by using cellular mobile networks and/or WiFi (Wireless Fidelity) technology, notably, by using of the radio waves WiFi can transmit data within the 100m range [54]. Fortunately, smart devices can exchange and communicate the collected information through WiFi without the requirement of a router [55]. And many health monitoring systems worked by standard wireless communications such as 3G, 4G, and Long-Term Evolution (LTE) [56].

3. Processing Layer

This layer executes the three processes which are aggregation of data from the sensing layer, then transferring data to the storing layer, and processing the acquired data. This layer contain software applications and processing units thus can apply the computational part of the application [57]. Processing hardware and software elements could be smartphones, microcontrollers, microprocessors, Field Programmable Gate Array (FPGA), System on Chip (SOC), or hardware platforms. Hardware platforms such as Raspberry Pi, Phidgets, BeagleBone, Arduino, Intel Galileo, Gadgeteer, or Cubieboard along with operating systems (OS) such as Android, iOS, Contiki, LiteOS, and TinyOS [58]. In this layer, the collected data is processed to be ready and available for purposes of further analysis, generating alerts, decision making, feedback, and generating notifications.

4. Storing Layer

Large storage capacity is needed for the IoT systems because of the large number of physical objects that can be connected to this system. These objects will collect and generate a huge amount of data that needs coherent and efficient storage and in IoT-based health applications, the data collected from the biomedical sensors at the sensing layer are needed to be stored for evaluation, assessment, and further analysis. Cloud computing platforms are used for storing data collected by IoT systems such platforms as GENI, Amazon, Google Cloud, ThingWorx, and OpenIoT [59]. Physical servers and cloud servers in the storing layers are used for three purposes of storing, analyzing, and computing data. These three functions are performed by using cloud computing technology to extract beneficial knowledge and detecting trends [60]. The blooming of cloud computing technologies, i.e., the challenge of managing and maintaining the huge and complicated medical data is transposed to the cloud which remarkably improved efficiency and effectiveness of management and storage of the health data. At the same time, worldwide healthcare has been also improved by using cloud computing [61]. For example, concern healthcare providers and patients are permitted to share and check and evaluate the health data remotely.

5. Mining and Learning Layer

Eventually, this layer contains tools that support processes of machine learning and data mining. Servers and/or processing units can use these tools within the storing layer or processing layer, respectively, for purposes of converting information to knowledge and support the decision making. Data mining includes discovering innovative, interesting, and relevant patterns from large data sets and employing algorithms for the aim of extraction of veiled information. Additionally, this layer performs tasks of clustering, classification, association, outlier analysis, and time series [62]. Techniques of machine learning are highly valuable in healthcare applications because these techniques enable for learning from data, managing huge clinical databases, and make better through practice and learning [63]. Prospective evolution can utilize IoTTA for real-time clinical feedback beside monitoring especially for management of the COVID-19+ and similar future cases. Furthermore, to reduce human error in this proposed system, feedback should come from the machine and from the learning layer rather than from individual healthcare provider as in current applications of IoT healthcare.

VI. MEASUREMENT OF PATHOPHYSIOLOGICAL PARAMETERS COLLECTED FROM WEARABLE BIOMEDICAL SENSORS FOR COVID-19+ MONITORING:

COVID-19+, like other viral and infectious diseases, is associated with several pathophysiological alterations that can be checked by using wearable biomedical sensors (Table 1). Many parameters related to heart functions such as heart rate (HR), resting heart rate (RHR), heart rate variability (HRV), and respiration rate (RR) are considered as essential markers of COVID-19+ infection and are already measured by using wearable biomedical sensors devices. Besides, alterations in electrocardiogram (ECG) results can be suggestive for an infection. Fortunately, many wearable biomedical sensors are able to detect more complex parameters e.g., sleep, activity, recovery, and stress, which are produced by calculations that using combinations of accelerometer derived metrics along with cardiac metrics. In this way and due to integration of multiple measurements, these metrics should contain an aggregate of higher signal to noise ratio (SNR) than individual raw signals alone and, thus, have higher predictive value.

Oxygen saturation (SpO2) and Core body temperature are of important clinical value due to the high prevalence of respiratory symptoms and fever in COVID-19+ disease. Therefore, and taking the patient-centered quality metrics in consideration, we support that wearable biomedical sensors devices can decrease need for invasive metrics derived from arterial blood sampling for gases and troponins (used for detection of lungs functions in providing oxygen to the blood, and detection of myocardial injury, respectively) [64]. Wireless Body Area Network (WBANs) have been used as a major component of Internet of Things technology for healthcare systems. Development of accurate sensors with low form factor is essential for the successful implementation of such a system. In this article, we focused on biomedical sensors to monitor the quarantined / isolated subjects to help during COVID-19+ and similar future outbreaks that are non-invasive and non-obtrusive; we exclude invasive biomedical sensors like implantable ones. Five fundamental biomedical sensors are considered here – three for monitoring the vital signs of body temperature, pulse, and respiratory rate beside two biomedical sensors for monitoring blood oxygen and blood pressure, both are regularly recorded in a clinical healthcare.

A. Pulse rate Sensors

For all we know, pulse rate is the most commonly measured vital sign, and it can be used for detection of a wide range of emergency cases, e.g., cardiac arrest, vasovagal syncope, and pulmonary embolisms. Also, biomedical sensors of the pulse rate are widely used for clinical purposes and for fitness tracking purposes. Additionally, reading of the pulse rate can be taken directly from the chest, fingertip, earlobe, and wrist among other places. Notably, high accuracy the readings of the pulse rate are from earlobe and fingertip although these two areas are not highly wearable. Reading of the pulse rate from the wearable chest devices is available, but wearing the biomedical sensors in the wrist is the most comfortable area [65][66]. Especially for our proposed system to monitor quarantine / isolation subjects for 14 days. In addition, several devices like wrist watches for fitness monitors and chest straps are available and have the ability for measuring the pulse rate. For instances, TomTom Spark Cardio, FitBit PurePulse, H7 by Polar, and HRM-Tri by Garmin, [67]. However, all of these devices are not for clinical use according to the disclosure from each manufacturing company. Thus, these devices cannot be used for monitoring critical health cases. Furthermore, myriad researches have been performed to invent a suitable methods for sensing the pulse rate. These advanced methods of measuring the pulse rate include photoplethysmographic (PPG), pressure method, radio frequency (RF), and ultrasonic frequency (UF) biomedical sensors. PPG sensors operate by transmitting LED light into the artery, and a photodiode for receiving the amount of light that is not absorbed by the blood, as exhibited in Figure 2. The changing in the amount of the light is then recorded and the pulse rate is detected [68]. It is an advantage of the PPG sensors that it can give three measurements at the same time i.e. Blood oxygen pulse rate, and pulse rate variability all are by using one small biomedical sensors wearable on the wrist. Along with these biomedical sensors, accelerometer can be added to the device to eliminate effect of motion on accuracy of pulse rate reading. For example, if movement is high, then the device can enter into the lower state of power to stop recording of the pulse rate [69].

B. Respiratory rate sensors / Monitoring of Respiration:

The Respiration rate (RR) is the most critical value in lung infection due to COVID-19+ cases and future similar diseases because of the severe alteration in lung and its functions in the course of the pulmonary illness. In most cases COVID-19+ disease appear as a lower-respiratory tract infection that can cause shortness of breath, coughing, and severe inflammation within the lung tissues [70]. Overall efficiency of the lungs is reduced because of the damage occurred in the respiratory system during COVID-19+ and this leads to increase of the RR to compensate need for oxygen [71]. Significantly increased RR is not as common in cases of other viral illnesses such as influenza or the common cold because these viruses typically affect the upper respiratory tract. COVID-19+ It may be already in the advanced stage at the time of patient suffering from tachypnea, thus, it is highly useful to detect symptoms before they get worse by using biomedical sensors to detect and assess changes in respiratory function that can change before appearance of clinically relevant symptoms in form of shortness of breath, wheezing, and shallow respirations. Importantly, Luo et al. found that about 70% of the health care workers in the frontlines had positive test result of COVID-19+ [72]. This hazard can be reduced during future similar situations by using biomedical sensors wearable devices in exploring the infectious cases before its advanced stages occur. In addition, these frontline health care workers dealing with cases of COVID-19+ patients can minimize the risk of being infected by the advantage of remote monitoring the patients [73]. In a study conducted by team from WHOOP, they came into hypothesis of ability of using biomedical sensors to detect patterns of respiration rate during the time of sleeping and this patterns can exhibit changes indicative for abnormal behavior respiratory system in patients of COVID-19+ before appearance of the severe symptoms [74]. In this context, biomedical sensors devices such as the Fitbit and data from the Apple Health app were used for monitoring oxygen levels, HR, levels of activity, and sleep patterns, during a period of one year to detect if there is risk of COVID- 19 disease among individuals under research conducted by researchers from Duke University in the study named the "CovIdentify" study [75] [76].

C. Body temperature sensors / Temperature

Temperature of the human body is a vital sign that can be used as indicative for many health conditions and health problems such as fevers, infections, heat stroke, and hypothermia. Thus, human body temperature is a diagnostics tool that is highly recommended to be measured among parameters recorded by wearable healthcare devices. Some previous works in the field of the measurement of human body temperature and all used thermistor sensors [77], [78]. Also, temperature sensors that depend on the negative-temperature-coefficient (NTC) were used, and at the same time other type of sensors were considered i.e., positive-temperature coefficient (PTC) sensors [79]. Additionally, temperature measurement of the subject is highly important to COVID- 19 and similar future viral or bacterial infection outbreaks. During past COVID-19+ pandemic check for temperature was used worldwide for travelers or other individuals to isolate febrile people from the community on the base of suspicion of COVID-19+ infection. Currently, wearable devices with function of continuous measurement of skin temperature are used and examples of these devices include VivaLNK Fever Scout, Oura ring, TempTraq, and QardioCORE. From these instruments, TempTraq was used as wearable sensor of skin temperature continuously for 72 hours to monitor the temperature of frontline healthcare workers at University Hospitals of Cleveland Medical Center [80], [70]. Besides, in one study that performed by Stanford University, they used different biomedical sensors devices such as Scanadu Scout, MOVES, Basis Peak, Basis B1, iHealth-finger,Masimo, Withings, and RadTarge. In the results, they found an increase in human temperature along with increase of RHR and HR before and during the time of COVID-19+ infection [81]. Therefore, COVID- 19 and similar future infections can be predicted before appearance of symptoms by combining this multi changes of these three parameters of temperature, HRV, and RHR. Additionally, continuous monitoring of fever during course of diseases can be achieved by using wearable devices by patients and person of high risk to get the infections, although difference noticed between core temperature and body temperature reading by about 12◦F [81]. Moreover, the most valid indicator for the core temperature is obtained by rectal thermometry rather than any other places of measuring the human temperature such places include oral, temporal, axillary, and aural, because temperature in these places of human body are highly subjected to change due to exvivo factors in the environment tor due to human behavior [82]. Measurement of temperature from the body core is more stable ground for patient assessment and it is more reliable than skin temperature for indication of health alterations because it gives an inside look into febrile conditions for monitoring of patients remotely. Additionally, and according to findings by researchers at UT Southwestern Medical Center, circadian rhythm can be regulated by the fluctuations of core body temperature [70][83][84]. Although rectal thermometry is considered as the gold indicative for temperature of the body core, this type of measuring temperature is not useful for continuous monitoring for human body temperature, thus non-invasive and unobtrusive method of measuring temperature is needed. Many researches has shown that temperature of the body core can be dependably predicted by using of Kalman filters or other machine learning (ML) algorithms applied on the readings of the temperature from the skin along with reading of HR. [85] To be used for medical purposes, this technology still requires more research and development, then these algorithms are of great benefit as a non-invasive technique for monitoring febrile diseases depending on measuring the temperature of the body core in person and remotely [70].

In addition, reading temperature, HR, sleep pattern and levels of activity by using Qura devices studied in research with collaboration with the University of California, San Francisco aiming to detect COVID-19+ infection and its results worldwide are promising in alerting individual about possibility of infection by voice of a ringing associated with the device [86] [70]. It was reported that an Qura user in Finland claimed that the ring alerted him that he was displaying symptoms of COVID-19+ based on decreased recovery levels (from 80 to 90% to 54 coupled) and an increase in skin temperature of ∼1◦C. These changes prompted the individual to get tested, the test results confirmed, that while asymptomatic, the individual had COVID-19+ [70]. Collecting and gathering previous technology is a way to invent new more effective algorithms for both predicting and monitor spread of infection remotely.

Previous studies indicate an acceptable error limits in using the thermistors for measuring human body temperature [87]. Accordingly, it is highly recommended to use this sensor in designing future health monitor devises. Upon increase distance of sensor from the human body, the accuracy of measurement decrease [88]. Thus, many researches were performed in area of manufacturing biomedical sensors printed onto highly thin and flexible polymers materials associated with an adhesive back to be fixed directly in the skin. Study of Aqueveque et al., (2017) find that accurate measuring of human body temperature can be achieved by embedding of the biomedical sensors of temperature in a textiles [77]. So, textiles are recommended for embedding the biomedical sensors as a second option and not as alternative for the flexible polymer because textiles have less advantage compared to the flexible polymers.

E. Pulse oximetry sensors / SpO2

Blood oxygen saturation (SpO2) is of great importance in assessing health conditions related to respiratory system such as COVID-19+ and other similar future cases because of hypoxia associated with such pneumonias can be etiolating for shock and even death. For instance, resting level of SpO2 is significantly less in COVID-19+ late stages than non-infected individuals and this condition is supported by CT scan along with clinical signs and symptoms. SpO2 levels below 90% on admission was found in COVID-19+ patients who were suffering from severe inflammation according to their inflammatory markers and increased rate of mortality [89],

[90],[91]. Many devices are available for measuring SpO2 at clinics but very few available for home patients use, although, some studies indicated use of smartphone applications for measuring pulse oximetry by using camera and/or plug-in probe [92]. Also, many devices are available and use PPG technology in measuring SpO2 by wearable devices of pulse oximetry as well as fingertip oximetry but still below the acceptable limit of accuracy to be used for medical purposes [93]. Although, such technology can be used for monitoring individuals remotely especially during times of isolations and spread of infections to minimize number of infection and to help elder individuals who are recommended to stay at home as well as many other benefits [70]. Blood oxygen level is not one of a vital sign, although, it is highly important in assessing functions of the respiratory system and in diagnosis of health conditions leading to hypoxia (low oxygen reaching the body's tissues) such as COVID-19+. So, pulse oximetry can be a valuable part of remotely monitoring devices. For determining the blood oxygen saturation, the instruments of oximeters collect the PPG signals, and two LEDs directed through the skin are usually used, one of them is the red one and the other is the infrared one. Then part of these light waves will be absorbed by the blood and the remaining part will be transmitted and received by the photodiodes. The difference between lights that are detected by the photodiodes will be calculated to find out oxygen saturation percentage. So, LED light waves can either be passed through a transmittable part of human body (usually a finger) then after transmitted lights arrived at the photodiode on the opposite side, and this way is called absorbance-mode PPG. Another way is to emit the lights at an angle to make reflection of the lights on the photodiodes that are fixed at the same side and this way is called reflectance -mode PPG [94]. To reduce power consumption, two techniques can be used. The first is the technique of minimum SNR tracking which act for continuously calculating current signal-to-noise-ratio (SNR) and accordingly adjusting the length of time that spent by the LED in the on-state to give accurate readings. The second is the technique of the PLL tracking which act for estimating the sharp time of the troughs and peaks of the PPG signal are happening, and measure only at these times to give accurate reading of the most important information. Both techniques are effective because of two reasons, first power using is effective as they consume up to 6x less power, and the second is the accuracy as the error limit of both techniques is less than 2%. Furthermore, an in-ear reflective pulse oximeter was previously designed [95][96]. This ear pulse oximeter was manufactured to detect levels of blood oxygen especially if patients are suffering from illnesses such as hypothermia, shock and/or other health conditions that may cause blood to be centralized and hence power of the pulse is reduced to the degree of being undetectable by devices fixed on the fingers. For this purpose, oximeter instrument will be fixed inside the ear canal without complete sealing to avoid disturbance of the hearing ability. Although remarkable accuracy in measuring blood oxygen saturation by ear oximeter on patients at surgical departments, it was recommended to use both ear and finger oximeters concurrently [97]. The most preferable site for wearing the oximeter biomedical sensors is the wrist because many persons are familiarized with wearing watches and/or bracelets comfortably [98]. Also, oximeter that use reflectional mode was designed originally in concave shape to eliminate external light and to reduce noise and suitable to be worn on the wrist, and size was large then the size of the instrument was reduced by carrying out data processing off-node. Like this wrest wearable biomedical sensors device can be used to measure, pulse, oxygen saturation (SpO2), as well as temperature of the skin [99].

VII. REMOTE MONITORING OF PATIENTS: COVID-19+ PANDEMIC AND SIMILAR FUTURE HEALTH CHALLENGES

Remote patient monitoring (RPM) is a useful method for observing patients and diseases especially communicable diseases and increase level of health safety by minimizing need for contact between health care workers and patients as well as between patient to patient and patient to other biological environment members including human, animals, and/or other objects. Times like COVID-19+ pandemic and similar future infections outbreak are indicative for importance and effectiveness of RPM systems [100].

VIII. CONCLUSION.

In preparation for future infectious diseases pandemics, health care systems can use advanced technologies of wearable biomedical sensors connected to IoT syestms and apply it for purposes of continuation and improving health care services during pandimic times as well as minimizing risk of infection spread. Also, these biomedical sensors can be used in cases of immobility health conditions for remote healthcare providing even during non pandemic times.

IX. RECOMMENDATIONS FOR FUTURE CONSIDERATIONS: TO EMBRACE TECHNOLOGY OF WEARABLE BIOMEDICAL SENSORS WITH IOT IN REMOTE HEALTH MONITORING.

Development happened in the technological integration of biomedical sensors with IoT allowed for effective monitoring and managing patients and disease spread remotely. Thus, minimizing burden of infectious diseases and detecting possible cases at earlier stages. The scope of influence of this technology is broad because it can be used to identify quarantined individuals that in needs for an advanced level of health care. Also, when a community needs early health intervention, the technology of remote monitoring associated with IoT will be of great help. At the same time, issues like privacy of data and sharing of data, as well as issue of underreporting of health conditions should be considered and improved through application of RPM/IoT technologies [101]. So, we recommend healthcare providers, polisy makers and stack holders to adopt sustainable plan for developing and implementing remote patients monitoring attached to the Iot and make it ready to be adjustable for detection potential future pandemics.

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