Can Radar Remote Life Sensing Technology Help to Combat COVID-19?

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***Abstract*— This article will provide an in-depth discussion about potential scopes of this unobtrusive respiration sensing technology to combat the COVID-19 pandemic. It will focus on several application areas of this sensor technology which can be beneficial and interesting to combat this pandemic. First, respiration sensing technology by Radar in a home setting can help to understand the risk factor of patients so that emergency response can be faster. Radar-based occupancy sensing and continuous identity authentication technology can also help to implement lockdown restrictions more strictly so that the spread of the virus can be reduced. Since this unobtrusive sensor does not require any physical contact to provide accurate respiratory measurement, this sensing solution is intrinsically hygienic which also provides additional protection against the spread of infection and disease. Furthermore, this radar sensor can be installed at homes, hospitals, factories, airports, public transports, and borders to cut down the risk of exposure for both medical and non-medical professionals.**

I. Introduction

Coronavirus disease (COVID-19) is now a globally pandemic disease and pneumonia of unknown cause detected in Wuhan, China was first reported to the world health organization (WHO) on 31st December 2019. Since then it has infected more than 18 million people all over the world and almost 4.77 million people in the United States. The world is facing unprecedented challenges due to COVID-19 that jeopardizes the priority of ensuring the health and safety of the people during this pandemic isolation time. It has been proven in various clinical investigations that most of the people who are infected in COVID-19 experiencing mild to moderate respiratory illness and even in some cases deadly breathing-related problems. Governments in different countries are imposing a travel ban, social distancing, and personal hygiene awareness. However, the deadly virus is increasing at a rapid rate which also imposes a lot of restrictions in our day to day life. As more and more countries are on lockdown due to COVID-19 and an increasing number of people are living in isolation, so the installation of the in-home respiratory monitoring system may be a potential solution for tracking vital signs. Effective screening and isolating patients quickly can help to reduce the number of infections. In addition to that, the immediate medical response by patients through monitoring their vital signs by themselves in a home environment can be also beneficial. Existing technology and solutions need to be brought quickly in diagnosis, monitoring, and molecular development to combat the current pandemic. Technologies need to be unobtrusive to identify outbreak hotspots, can determine the number of occupants, reduce the need for less physical contact in diagnostics, and even work towards developing a vaccine. Thus, remote vital sign sensing using microwave Doppler radar can have the potential to provide breathing-related information unobtrusively during this pandemic isolation time. A modified battlefield radar into biomedical purposes can see inside the human body with clothes and track breathing rate, heart rate, tidal volume, and pulse pressure which could help ease coronavirus lockdown restriction. In addition to that, this unobtrusive remote sensing of respiration technology can monitor pulse, heart rate variability, and respiratory rates of the patients which can also indicate the early-stage of COVID-19 symptoms. Moreover, the radar sensor technology has proved its initial efficacy for recognizing people from their breathing pattern and it can also be used to count the number of occupants in a room that can potentially also be used for security and surveillance applications to implement lockdown restrictions properly. Furthermore, this radar sensor can be installed at homes, hospitals, factories, airports, public transports, and boarders to cut down the risk of exposure for both medical and non-medical professionals.

II. How Does COVID-19 Affects the Heart and Respiration System?

The effect of COVID-19 on lung and heart is quite well-known and as the pandemic continues more information about the role of the virus on damaging human respiratory will be much clearer. It has been proven in various clinical investigations that during sever SARS-COV-2 infection, heart function decreases because of direct viral infection in the heart. Prior study and during recent pandemic experiences, it is quite clear that COVID-19 is a respiratory-related disorder when there is a severe infection that occurs in the lung. In general, there are two dominant cardiac issues related to COVID-19. One is heart failure which occurs when the heart muscle doesn't pump blood and another one is abnormal heart rhythms that can be infected or to the effect of medications used to treat the virus. In the case of older patients, heart failure is occurring due to coronary artery disease or hypertension as body decreased cardiac reserve capacity. On the other hand, for younger patient's heart failure is occurring due to inflammation of the heart muscles and

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heart's electrical system. Shortness of breath is another common symptom of COVID-19 when patients should seek medical attention. In addition to that, medical professionals need to interact directly with the patients to conduct exams for monitoring vital signs which have associated risk of infection. Thus, remote respiration sensing using microwave Doppler radar can help to understand the severity of the disease and minimize the risk of getting infected by the medical professionals due to close contact. Shortness of breath and mild chest pain is an initial symptom of a medical emergency. Hence, Radar-based respiration monitoring system can track breathing rate and heart rate in the home environment unobtrusively to ensure the quick response of the infected person to the hospital. The radar-based identity authentication system is also gaining attention and can be one of the potential technologies to track different infected persons whether they are maintaining quarantine or isolation properly or not. The rest of the part of the article will focus on different potential aspects of the Radar sensor system for physiological sensing and security/ surveillance to fight the COVID-19 pandemic.

III. BASIC PRINCIPLE OF RADAR-BASED PHYSIOLOGICAL SENSING

Doppler radar first emerged in 1930 and it was employed for physiological sensing research since 1971. Radar stands for radio detection and ranging. Radar is a transceiver which contains a transmitter and receiver. It sends an electromagnetic signal to track the distance, velocity, and spatial position of the target by analyzing the different characteristics of the reflected signal. The same Doppler principle is shown in Fig. 1 is used everywhere, where reflected signal phase shift occurs due to tiny movement of the chest surface. due to cardio-respiratory activities that induced effect by breathing and heartbeat, without any direct contact of the sensor attached to the human body. Remote life sensing of humans with Doppler radar has been widely used and reported in several research articles, with proof of concepts demonstrated for various applications. This non-contact and non-invasive form of measurement has several potential advantages especially for neonates or infants at risk of sudden infant death syndrome, adults with a sleep disorder, and burn victims because of its non-contact and unobtrusive measurement. This form of respiration monitoring reduces patients' discomfort and distress as electrodes need not be attached to the body. The inherent advantage of this unobtrusive non-contact measurement technique has increased its area of potential applications in occupancy detection, energy management in smart homes, baby monitoring and has also opened the door to many indoor applications only limited in imaginations. In the last decade with the growing interest in health and life sciences in the engineering community, many researchers have been contributing to the development of new front end architecture, baseband signal processing methods, and system-level integration in biomedical radar to improve detection accuracy and robustness. Moreover, Doppler radar has also been implemented to monitor the health and behavior of land and sea animals including lizards and fish. Sleep monitoring is another emerging application that alleviates the use of obtrusive devices such as spirometers that can change the sleeping pattern. A clinical study was performed to monitor patients with sleep apnea problems using radar sensors in conjunction with traditional sensors. Sleep monitoring devices are the first commercial devices that recently received FDA approval for commercial use in the United States. As radar can track the sleep apnea events and sleep stages so any kind of breathing disorder can be easily tracked by this biomedical Doppler radar. Considering all these achievements motivated us to provide a clear picture of how this sensor technology can help to fight against the COVID-19 pandemic.

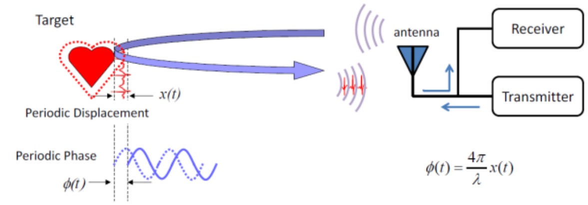

Fig. 1. Doppler effect for physiological signals that have periodic movement but zero net velocity. Phase change of the reflected signal is directly proportional to the tiny movement of the chest surface due to cardiorespiratory activities. From [4].

IV. MATERIALS AND METHODS OF RADAR-BASED PHYSIOLOGICAL SENSING

Basically, for this type of application, a typical Doppler radar transceiver is required for sensing physiological information like tracking the tiny movement of the chest surface due to cardio-respiratory activities. A Doppler radar with an ISM band around 2.4 GHz to 24 GHz can be used for this type of biomedical application. A radar transceiver consists of a transmitting antenna, receiving antenna. The transmitting antenna sends an electromagnetic signal and when the signal is being reflected from the human subject it is received by the receiving antenna. When the signal is being reflected it is down converted into a baseband signal by mixing the signal with the transmitting signal and then it relates to the Low noise amplifier for removal of noise and interference. When the signal is down-converted it is multiplied with the same phase signal and quadrature version of the transmitted signal. We receive two different types of channel signals; one is called the in-phase signal (I channel) and another one is the quadrature-phase signal (Q channel). Then we digitize the signal using a data acquisition system (DAQ). Finally, a customized digital interface can capture the respiration pattern. Fig. 2 shows the typical block diagram of the Doppler radar transceiver for physiological sensing. After capturing the signal, we can process the signal using some traditional software and can find breathing rate and heart rate. Fig. 2 (b) illustrates the time domain signal of the I and Q channel. If we perform fast Fourier transform (FFT) which is the basic signal processing technique for extracting the spectrum from the time-domain signal. If we perform FFT we can see two different dominant peaks. The first peak is the respiration and the next dominant harmonic peak is the heartbeat. During respiration activities, our breathing is controlled by heart movement, so the heartbeat signal is superimposed on breathing signal. Over the last four decades may researchers worked on miniaturizing the radar sensor system for

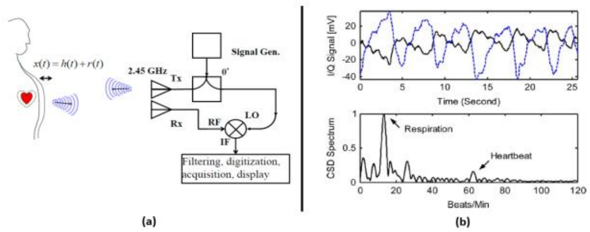

Fig. 2. (a) A typical single channel Doppler radar trasnceiver (b) spectrum detected from human subject at 1.5 meter away from Radar. From [5].

Considering the inherited advantages of this sensor technology the system can have some potential to fight with COVID-19. If the Doppler radar system is installed into the home environment will be able to detect tiny movement of the chest surface. During pandemic isolation time if someone breathing problem occurs or breathing stops an alarm can go off to warn the patients that he may need emergency contact with the medical team. Similarly, it can track breathing-related any problems such as if it crosses a certain threshold rate then it would produce some alarm to warn the occupant in a room that he is facing some breathing issue. In that way, an early response to the hospital can be ensured especially at the early stage of breathing problems so that medical professionals can take care of it which can also help to reduce the fatality rate. In addition to that, proximity to an infected person during measuring vital signs greatly increases the chance of the likelihood of contagion. Non-contact radar-based vital sign monitoring may thus allow greater control of viral speed. However, there are some technological challenges in installing this sensor system in a multi-subject environment. There is likely a presence of multi-subject in a hospital environment or in-home environment. So, we will describe in detail in the next paragraph about some technical achievements in solving multi-subject challenges.

V. CHALLENGES FOR RESPIRATION SENSING IN MULTIPLE SUBJECT ENVIRONMENT

When there is a multi-subject present in front of the radar this type of sensor gets a combined mixture of breathing patterns which is the interference of respiration pattern. Separating individual respiratory signature from a combined mixture is an acritical challenge to implement this sensor technology into the real-world of applications. However, it works well for dedicated single subjects especially when subjects are following social isolation. Early response to the hospital can be ensured especially at the early stage of breathing problems so that medical professionals can take care of it which can also help to reduce the fatality rate. As in a home environment or the hospital, there is the probability of the presence of multi-subject so when there are two subjects present in front of the radar it gets a combined mixture of breathing patterns which is hard to separate. Prior attempt focused on utilizing separate antenna for each different occupant which is not scalable in realistic scenarios. In our recent attempt, we proposed an intelligent decision algorithm for integrating two different approaches to separate independent respiratory signatures from combined mixtures. ICA is a signal processing technique which can extract independent signals from a combined mixture of breathing pattern. We also utilized the Direction of arrival (DOA) technique for estimating the spatial position of the subject. Based on their location we can switch the antenna beam in different directions to isolate respiratory signatures. As our group work demonstrated the efficacy of utilizing this sensor in a multi-subject scenario in a realistic environment so it encourages the scientific community that this technology can be utilized in a hospital environment or in-home environment also.

During COVID-19 pandemic hospitals are experiencing overwhelming patients so tracking vital signs using traditional contact sensors increases the probability of being infected by medical professionals due to close contact. Radar-based respiration sensing technology can help to overcome this problem due to its unobtrusive and non-contact form of respiration sensing methodology. In addition to that. Radar can also provide an alarm if some patients breathing rate changes abruptly so that ventilator can be used quickly for emergencies. Thus, the fatality rate and the spread of the virus probably can be minimized by utilizing this sensor technology.

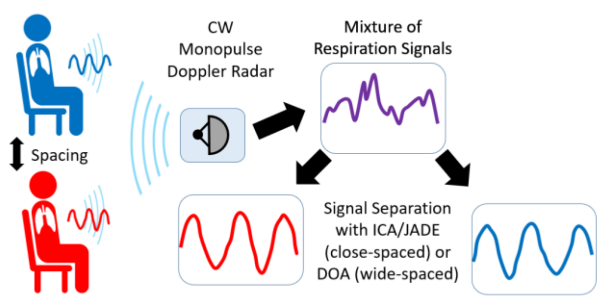

Fig. 3. Concurrent respiration monitoring of multiple subjects by radar integrating two different approaches (Independent component analysis (ICA) and Direction of Arrival (DOA)). Recently our group Biosensing Lab at the University of Hawaii at Manoa published this article which shows promising results for concurrent respiration monitoring of multiple subjects using Radar. From [7].

VI. RADAR-BASED CONTINUOUS IDENTITY AUTHENTICATION

Artificial intelligence (AI) is mostly used by different countries to support the fight against the viral pandemic that has affected the entire world since the beginning of 2020. China, the first epicenter of this disease used authentication technology like facial recognition to restrict the movement of the populations which also helps to stop the spread of the virus. In addition to that, cybercrimes are increasing rapidly and thousands of coronavirus-related websites a day, with most, used to host phishing attacks. This can potentially steal their password, ID, and social security card information too. Thus, multi-factor authentication can also help to fight against this type of unprecedented situation during the COVID-19 pandemic. Social distancing and good implementation of lockdown can help to prevent the spread of the virus.

Thus, the Radar-based identity authentication system has certain potential to overcome the challenges faced by users and the government of the country to implement lockdown properly. Identity authentication using microwave Doppler radar is also gaining a lot of interest and it is another emerging potential field where researchers are trying to explore more because the camera and fingerprint-based biometric system have several privacy issues. The existing biometric-based authentication system is far from satisfactory and not trustworthy also as it is one pass validation system. People need to intentionally engage themselves such as scan a fingerprint or use their password after a certain interval of time. To replace the traditional biometric system or bring a continuous authentication system as a multi-factor authentication scheme, researchers have tried using different physiological traits Considering all these limitations unobtrusive form of measurement cardiac motion-based security system is gaining more popularity and many types of research are exploring on that particular new way of a biometric system. Doppler radar-based non-contact cardiorespiratory identity authentication system can open a new door for this technology by integrating with traditional biometric authentication systems to make it an unobtrusive multi-factor authentication system.

The basic idea of this unobtrusive identity authentication technology is that different people breathe differently in terms of their tidal volume, airflow profile, breathing depth, and energy. It has also been proven in various investigations that different people breathe in different ways. The complete cardiac motion consists of five different stages including (1) ventricular filling (VF) 2) atrial systole (AS), 3) isovolumetric ventricular contraction (IC), 4) ventricular ejection (VE), and 5) isovolumetric ventricular relaxation (IR). Based on the hypothesis previous attempts by different research groups tried to illustrate that these heart-based geometry changes from person to person due to change in size, position and anatomy of the heart, chest configuration, and various other factors. Many researchers have proved the efficacy of this concept as radar can track breathing-related dynamics and extracting unique features and integrating with machine learning classifiers (ML) or artificial intelligence helps to recognize different participants. Some of the research group also published papers on emotion recognition from radar captured respiration patterns. Fig. 4 below illustrates the proposed radar-based identity authentication system and different groups published articles on this also.

So, the overall radar-based identity authentication system can help to recognize people unobtrusively for implementing lockdown or tracking one person with this technique can be helpful too. The multi-factor authentication system can

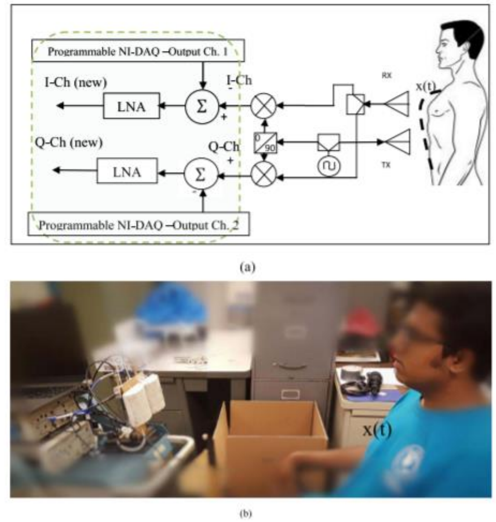

Fig. 4. Radar-based continuous identity authentication system. Experimentation performned by Biosensing Laboratory at the University of Hawaii at Manoa. From [11].

reduce the vulnerability of malicious system adversaries (stealing personal information, ID, and social security) during this pandemic time. Unobtrusive identity authentication can also track a person's presence in an isolated place and health monitoring together.

VII. RADAR-BASED BUILDING OCCUPANCY ESTIMATION

Radar is an attractive approach for estimating the number of occupants in the building and its gaining attention. The detection of human cardiopulmonary motion using microwave Doppler radar can be a potential way of recognizing the number of occupants in a room. Conventional occupancy sensors ate mostly motion sensors. A significant drawback of this conventional occupancy sensor is the high rate of false detection rate as it just tracks the motion. Even when subjects are stationary in a home environment traditional occupancy sensor cannot determine the true presence of humans. The detection of human cardiopulmonary motion with Doppler radar could provide a promising approach to overcome the problems of the false trigger and dead spots when human is static in conventional sensors. Radar sensors measures uniquely modulated backscattered electromagnetic signals rather than IR or ultrasonic signals. Previous attempts also demonstrated the efficacy of this technology as the number of participants increases in a room it also affects the received signal strength (RSS) of the received signal. Thus, the RSS method has the potential to count the number of occupants in a room. Fig below illustrates the diagram of occupancy detection using the Radar system. There are several advantages to this technique. It is unobtrusive, non-contact and it can also track when the person is static. During this COVID-19 pandemic governments in different countries are struggling enough for implementing strict lockdown in their countries. Occupancy detection using the Radar system can help to track the number of occupants in a room and at the same time if some new people come to anyone's house it can produce some alarm. So, strict social isolation and quarantine can be implemented by installing this intelligent radar-based physiological sensing system.

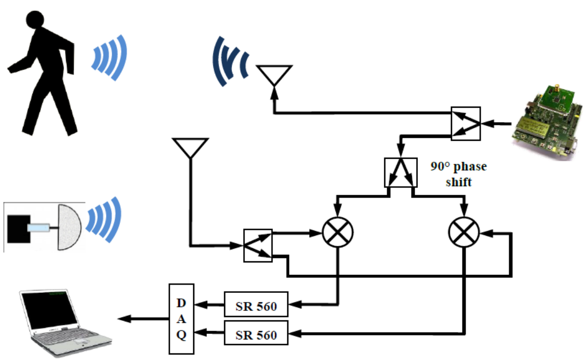

Fig. 5. Experimentation on Radar based occupnacy detection. A typical quadrature transciever for estimating the number of occupants. Taken from [10]

VIII. RECENT EFFORT BY INDUSTRY AND ACADEMIA TO IMPLEMENT RADAR SENSOR TECHNOLOGY AGAINST COVID-19

Israel's military radar system is being adapted to remotely monitor the vital sign of patients suffering from COVOD-19. Israel defense company Elbit system and Vayyar, a tech company working together to develop this technology and already demonstrated the efficacy of this technology to fight against COVID-19 pandemic. They also conducted an extensive clinical study with Rabin Medical Center to test the efficacy of this noon-contact respiration sensing technology for monitoring the vital signs of COVID-19 patients at the point of diagnosis and during treatment. The goal of their project is their medical teams are at the forefront of this fight so non-contact sensing of respiration will help to reduce the number of infections by not being in close contact with patients.

In another attempt, MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL) in collaboration with the Boston clinical team also reported some promising results of remote sensing of respiration of COVID-19 patients using this technology. MIT developed a WiFi like a box called Emerald that analyzes the wireless signal in the environment using artificial intelligence to infer people's vital signs, sleep, and movement. This signal emits roughly 1000 times less radiation than a standard cell phone so there are no known health hazards of this technique also.

Many other research groups and industries working hard to bring this potential sensor technology into the real world to combat COVID-19.

IX. DISCUSSION

This COVID-19 pandemic has disrupted and impacted the lives of hundreds of thousands of people and continues to bring new challenges every day. During these times of uncertainty, high tension and anxiousness, it's more important to bring this technology into the door of common people so that at least anxiousness and spread of the virus can be minimized. Researchers and industry should work together to bring this sensor technology into real-world implementation to reduce the distress of common people who are passing remote isolation life.

Radar is an attractive approach for sensing breathing rate and heart rate remotely so installing this sensor in a home-environment and hospital environment can help to reduce the risk of potential exposure due to being close contact with infected persons for measuring their vital signs. In addition to that, in the in-home environment, we need to keep track of our breathing rate and heart rate to make sure that we are not infected. In case we are infected being in a continuous monitoring system can help us to respond quickly for medical emergencies. At the same time, the telemedicine system can be integrated with the radar system to send the respiration related all information to the doctor so that the patients need not be worried about an emergency visit to the hospital.

For implementing lock-down and social isolation restrictions strictly radar-based occupancy sensing can also provide potential help. Radar can determine the number of occupants in a room or a house. So, if there is an intruder or any social gathering then it can create some alarm to make sure that people are following social isolation and quarantine rules strictly. Maintaining strict social isolation and quarantine can help to reduce the spread of the virus which also help to reduce the number of fatality rate too.

For proper implementation of lockdown and travel ban, a radar-based ID system can track a person if this type of sensor system is integrated with a cell phone. Many countries are struggling when visitors are traveling from an infected area. The government also imposed a 14-days quarantine rule for the visitor. However, in reality, it is hard to track each visitor and visitors are also visiting for their recreation time. Thus, a radar-based unobtrusive recognition system can help to implement this type of quarantine rule more strictly so that the spread of the virus can be reduced.

Over the last four decades, there has been significant improvement in Doppler radar-based physiological sensing technology. Many researchers are contributing and contributed significantly to improve the hardware, new signal processing techniques. This is the high time where industry and researchers should work together to bring this sensor technology for the benefit of humanity during this unprecedented

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