Wi-Fi Signal Analysis for Heartbeat and Metal Detection: A Comparative Study of Reliable Contactless Systems

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***Abstract*—In this survey paper, we present various proposals of Wi-Fi applications which can benefit society, namely through detection of vital signs and detection of suspicious objects. Based on the previous research conducted in this field, we analyze how heart rate detection using Wi-Fi dependent technologies compare to older, sensor-based methods and the necessity of modern implementations especially in the medical field. People can have heart problems such as tachycardia and bradycardia at any instance, thus systems which do not require contact are most practical in detection of vital sign irregularities. Sensor-based systems may depend on Wi-Fi technologies only for the communication between different components in the system, such as in the Message Queuing Telemetry Transport System. However, the presence of a sensor in these systems can be replaced by Wi-Fi technologies to detect the presence of people and monitor their corresponding heart rates in a contactless manner. Additionally, Wi-Fi dependent systems such as Vital Radio and Wi-Sleep can monitor the heart rates of multiple people at once. Therefore contactless, Wi-Fi based systems are most efficient and practical for daily use. Moreover, although contactless systems demonstrate the benefits of technological advancements, these systems can still be further improved since they tend to produce higher accuracy rates from shorter distances, as demonstrated by the UWB radar system and the Fresnel model. Contactless systems can be enhanced to detect multiple users at once at extended distances. After providing details of contact requiring and contactless systems for heart rate detection, we also provide other useful applications of Wi-Fi technology, such as in the field of metal detection, human fall detection, etc.**

***Index Terms*—Wi-Fi signals, Channel State Information, Contactless systems, Reliability, Heartbeat Detection, Metal Detection**

I. Introduction

Technological advancements can yield several benefits to facilitate our daily lives, such as detection of vital signs, dangerous objects, and human queues. Vital signs include heart rate and respiration rate. Wi-Fi can be used to make such detection quickly and at a low cost. In contrast, older methods, such as techniques which depend solely on sensors, are not the most practical approach for everyone. Although wearable sensors can detect vital signs, these signs can be more accurate with the use of Wi-Fi and it would facilitate the process of making such detection possible in one's home. Detection of vital signs can reduce the number of heart attacks that occur and aid people suffering from sleeping disorders, such as sleep apnea [8,20,25]. As cardiac arrest and other irregularities can occur at any instance, we can leverage contactless system implementations to reduce the number of deaths which occur from heart failures. Moreover, detection of suspicious objects can ensure a safe environment since guns, bombs, etc. are detected by the devices, which notify people if there are harmful objects inside of the bag [12]. It is not necessary for the bags to be open or transparent in order for this process to occur as Wi-Fi has the ability to travel through material. Wi-Fi can also ensure a safer environment as drivers can be notified of pedestrians in not-line-of-sight (NLOS) and blind spots [27]. We can also detect human fall using W-Fi, thereby reducing the number of deaths which occur due to falling, especially among elderlies [26, 31-37]. These are some ways in which Wi-Fi implementations can provide a safer environment.

Over 17 million people die from heart attacks each year worldwide. Our advancements in technology can be used to prevent deaths from heart attack by warning the individual when their vital signs are abnormal. Using wireless technology, a person's default heart rate and respiration rate at rest can be collected and stored in a database. Such data can be used to compare to the individual's current rates for heartbeat and respiration. For instance, this method can determine whether a person's current heart rate is significantly higher or lower in comparison to their normal rate. Furthermore, a patient suffering from sleep apnea experiences difficulty with sleeping and breathing simultaneously. Instead of having another individual monitor the patient while he or she sleeps or forcing the patient to wear sensors throughout the night, Wi-Fi detection of respiration can track the breathing patterns and alert the patient if his/her breathing rate decreases significantly. Once a person has an irregular heart rate or breathing rate and it has been detected, a sound can be emitted from the device to notify the patient. Recently, researchers have created Wi-Fi dependent systems to detect vital signs which can combat such issues. One application which demonstrates this is Breathfinding, a wireless network that observes and locates breathing in one's home [20]. The system observes and identifies the movement of one's body when breathing. Another approach is the Ubibreath Wi-Fi based breathing estimator which leverages the changes in the Wi-Fi RSS patterns to estimate ubiquitous non-invasive respiratory rates and detect sleep apnea. The modulated Wi-Fi signal resulting from one's breathing can provide useful information to analyze one's breathing pattern

[25]. Therefore, strategically utilizing the advancements of Wi-Fi technology can reduce the number of deaths from illness such as heart attack or sleep apnea.

There are several methods which can accomplish these goals. We analyze applications such as Vital-Radio, IoT heartbeat recognition system, Arduino, Message Queuing Telemetry Transport (MQTT), wearable sensors, Wi-Sleep, camera of a smartphone, Channel State Information, UWB Radar System, etc. The most successful and practical techniques incorporate the use of Wi-Fi in their systems for higher accuracy in results and allow for more practical use in people's homes. Contactless systems utilizing Wi-Fi are the most efficient.

In this paper, we introduce the topic for this survey regarding an interesting field of research. In section II, we provide a background to help readers understand the necessity of Wi-Fi systems for various detections. We compare and analyze the algorithms and procedure for Wi-Fi based systems and sensors and illustrate why contactless systems for vital signs detections are more useful and practical in Section III and IV. We discuss metal detection applications using Wi-Fi in Section V and related works in the general Wi-Fi applications field in Section VI. Then, we highlight and suggest some issues that researchers can focus for future studies in Section VII. Section VIII consists of the conclusion and in the final section, we list all of the references used for analysis in this survey paper.

II. Preliminaries

Wi-Fi is a form of technology which uses radio waves, allowing users to connect to the Internet and devices to communicate with each other wirelessly. Its signals are used to carry information from the transmitter to the receiver (may be referred to as TX-RX). Wi-Fi has the capability to travel through walls and people, making it the most practical way to measure vital signs, check for suspicious objects in baggage, etc. Signals can also be filters to allow more accurate readings of vital signs.

Bradycardia is a condition in which the heart rate is lower than normal. In contrast, tachycardia is a condition in which the heart rate is higher than normal [3]. Heart rate differs among people of different age groups, thus the technology used must store the person's regular heart rate and then compare their current rate to the average rate. If it is significantly greater or lower, this indicates that a person's health is in danger. It is important to detect vital signs to ensure that one's health is in a good state. We can use wireless detection methods to know if a person is suffering from such conditions. The technique will be able to alert others to make them aware of the issue immediately upon detection, and potentially save lives by doing so. Irregular breathing may also occur especially among older people and sufferers of asthma and sleep apnea. Hence, detection of irregular breathing can reduce the number of asthma attacks as the system can alert those nearby once irregularities are detected.

Not only can we detect vital signs from wireless technology, but we can also identify the presence of harmful objects in bags without even opening them. This technique will be especially useful to implement in populous cities since this will be able to keep track of multiple bags and the safety of a large number of individuals in an environment will not be threatened. There have been incidents in the past which emphasize the necessity for more effective method of security and metal detection. Increasing threats to security were caused by guns, homemade bombs, and explosive chemicals [12]. For instance, a gunman opened fire in Las Vegas in 2017 and was responsible for approximately 60 deaths and almost 550 injuries. Additionally, there have been numerous school shootings recently in the United States, further proving how it is vital to prevent such deaths with modern technology. One example of this is the shooting at Florida High School, resulting in 17 deaths. The campus only allows students to bring transparent school bags for careful inspection. However, this invades the privacy of students as the researchers stated, thus object detection via Wi-Fi can provide a better alternative [12].

Tracking human queues can also be achieved with wireless technology. Researchers have concluded that we can track human queues in order to be informed about which lines are shorter when grocery shopping, aiding those who are in a hurry. We can also track people at airports and other locations with the implementation suggested by the researchers [9].

III. State-of-the-Art/ Comparative Studies Taxonomies on Contact Requiring Systems

In this section, we provide the comparative studies. First, we provide infrared transmitter and receiver and Arduino based System. Second, we provide overview of wearable chest sensors using smartphone. Then, we discuss the heart attack and heart rate detection using finger sensor, photodiode, and LED. Next, we discuss Tmega328 micro-controller and node and microcontroller unit. Finally, we discuss index finger placed on smartphone to retrieve data of vital signs.

Some researchers have presented ways in which sensors can be implemented in order to measure vital signs, whereas others have used contactless, Wi-Fi dependent implementations in their approach. Contactless systems are modern and practical; thus, implementations of those systems are more efficient.

In this section, we discuss implementations of requiring contact for heart monitoring:

- Sensor Based System using IR TX-RX and Arduino
- Wearable Sensors/ Smartphone Sensors
- Message Queuing Telemetry Transport
- Index Finger Placed On Smartphone to Retrieve Data of Vital Signs

A. Infrared Transmitter & Receiver and Arduino Based System

Heart rate can be calculated using microcontrollers, such as Arduino and pulse sensors. This method requires the sensing mechanism to be placed around the fingertip of the patient. The Infrared Transmitter and Receiver pair module, also known as IR TX-RX, was used to collect the heart rate signals [5]. This is made possible by the amplification of the signals, and

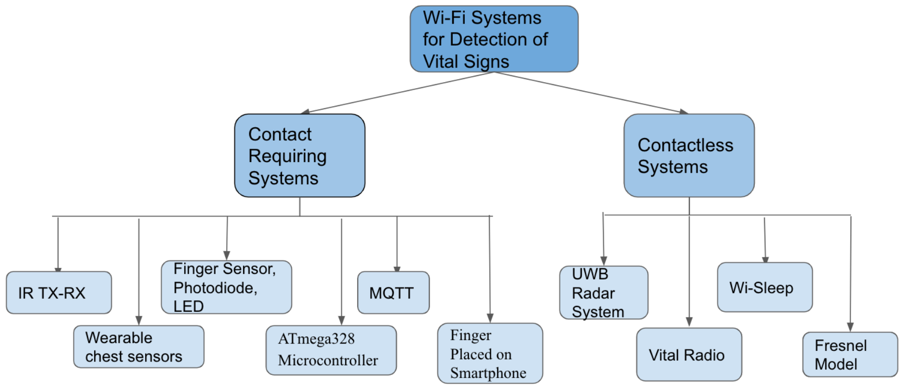

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Fig. 1. Flow Chart Depicting System Discussed in the paper

filtering background noises in the environment to improve accuracy of the data collected by IR TX-RX. A microcontroller, ATmega8L, counts the rate and results are displayed on an LCD. The photoplethysmography (PPG) technique is used to detect the heartbeat rate per minute before it gets processed by the microcontroller. PPG is also responsible for sending SMS messages to family members, alerting them that the patient is in need of attention [5].

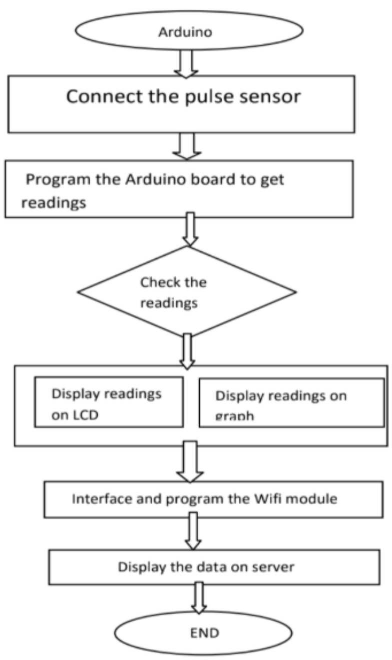

Fig. 2. Flow chart of heart rate monitoring system using IOT

Although this monitoring system allows Arduino Uno to collect data from heart rate and body temperature in a way that can be measured in real time and remotely, it can underestimate or overestimate a person's average heart rate. The results of using this method portrays that the system defaults to 72 bpm (beats per minute) as the average heart rate for any individual. Any heart rate under 60 beats per minute will display that a person has bradycardia and any heart rate above 90 beats per minute will display that a person had tachycardia. However, this may not be the case since heart rate can greatly vary among different people. There are several significant factors which can influence a person's average heart rate a rest, one of which is age. Children tend to have faster heartbeat rates, whereas adults have slower rates [10]. Hence, if a child that is 10 years of age has a heartbeat of 100 beats per minute, it is still considered normal for those in this age range. Despite this fact, the sensor machine would display "tachycardia" as the result in such a case. Additionally, the system requires contact with the user. Thus, it is not the most efficient because if the user is not in contact with the sensor and has a heart condition, the system is unable to notify the patient or other individuals nearby.

B. *Wearable Chest Sensors using Smartphone*

Smartphones and sensors may be used in one system to retrieve data. One specific method was designed for cardiac patients so that they know their heart rate, blood pressure, and other information that may be useful [7]. The researchers have implemented a system in which the patient places the wearable sensor on his/her chest, and the information from the sensor is transmitted to an android based listening port. Then, this port sends the information to a web server that processes the data [7].

Fig. 3. Flow chart of heart rate monitoring system using IOT

The android smartphone can communicate over Wi-Fi networks. The patient's heart rate data is stored in a database on MySQL via Wi-Fi. This proposed system can measure heart rates of several patients at once, making it time efficient. However, the patients would be required to wear the sensor across their chest, which may be uncomfortable.

C. Message Queuing Telemetry Transport

MQTT (Message Queuing Telemetry Transport) is an inexpensive model based on Wi-Fi connectivity [6] and requires minimal contact from the user. MQTT is an open OASIS and ISO network protocol which runs over the transmission control protocol (TCP) and transports messages between devices. Infrared light and a photo detector are used to detect the heartbeat signal in this heart rate detection system. This data is wirelessly sent to the MQTT running on a Raspberry pi, which is a small, low-cost computer that is about the size of a credit card.

Heart rate sensor is placed over the user's finger and it measures the amount of infrared light which is reflected off of the circulating blood inside the patient. The amount of infrared light emitted from the LED increases when the user's heart pumps [6]. Several sensors can connect to the MQTT Broker which will transfer the data to MQTT client software as shown in the figure below:

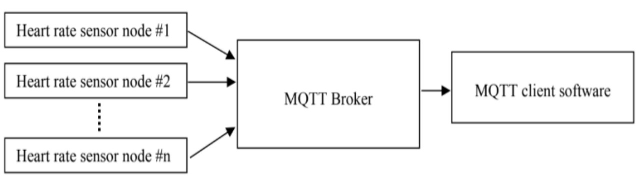

Fig. 4. This figure illustrates how the system is implemented. Many sensor nodes can send the information retrieved to the MQTT Broker, which transfers the data to MQTT client software

The Raspberry Pi, sensor nodes, and the ESP8266 with built-in antenna, effectively communicated with each other because they were on the same network via connection o the same router. The monitored heart rate was displayed using Node.js. Although the results illustrate that the strength of the received signal decreased with increasing distance of sensor nodes, we can receive strong signals from extended distances using a high-power router.

The results of the MQTT based system display errors ranging from 2.74-5.56 percent when comparing beats per minute calculated by the sensor module and the actual heart rate (measured manually). Although the error rate is no too high and the system requires very little contact, the user may not always place their finger on the heart rate sensor. For detection of irregularities at any given time, contact-free Wi-Fi dependent systems are more effective.

D. Index Finger Placed On Smartphone to Retrieve Data of Vital Signs

A smartphone can be used to detect heart attack in advance without the presence of wrap-around sensors, unlike the system proposed by researchers mentioned in section B of this survey. The person can place their index finger on the mobile camera. The smartphone will detect the peak of blood at a given time and choose a maximum set from the peak. The average distance between adjacent peaks is taken for calculation of the heart rate [10].

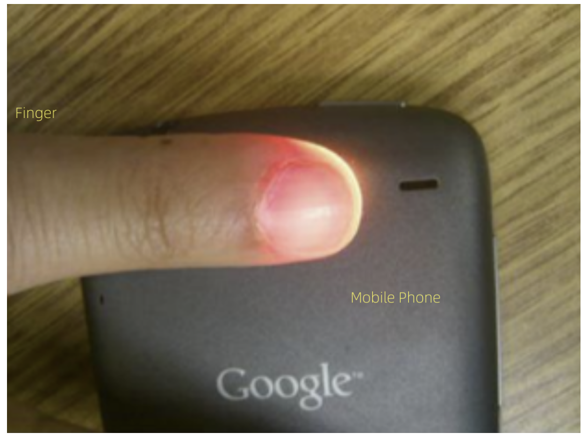

Fig. 5. The patient holds their index finger on the camera lens, showing minimal contact in order to detect the heart rate vital sign

The first system that is mentioned in this article utilizes the signal differentiation and the mobile device is used to capture frames. A different algorithm utilizes heartbeat sound to detect one's heart condition. 3-10 seconds of heart activity is recorded, and it is compared to the normal heart activity which is stored in the database. If the recorded data matches with the sound stored in the database, there will be a message displayed informing the user that his/her heart is normal. If the recorded heart sounds are not normal, the user will be informed since there will be a display stating that the heart is abnormal [10]. The user is required to use a headphone to hear the heart sound and save it if they need such data for future reference.

Though this method is not completely contactless, it requires minimal contact and saves the data in a convenient device, the smartphone. This aspect of the system can be useful since patients can keep track of their health over a period of time. The use of smartphone to detect vital signs is convenient since many individuals own one and use it daily. However, a contactless version of this smartphone-dependent system can be popular application in the near future.

IV. Comparative Studies on Contactless Systems

In this section, we emphasize the importance of Wi-Fi dependability in the following contactless heart monitoring systems:

- UWB Radar System
- Vital Radio
- Wi-Sleep
- Fresnel Model

A. UWB Radar System

The implementation of (Ultra-wideband) UWB Radar System [13] provides a solution to some of the issues which may arise with methods that require contact to retrieve data on the vital signs. Reflection from static objects is removed to produce the clutter-removed signal, which is processed for detection of movements and breathing. The figure below represents how some researchers gathered data utilizing this ultra-wideband radar system.

To monitor breathing, two Vivaldi antennas are placed in parallel with a distance of 12 centimeters. The person sits on a chair and aims to have a distance of 24 centimeters between his or her chest and the outer edge of the antennas. The raw signal is filtered, clutter is removed, a person's presence is detected via movement detection, and finally the counting result is collected in this procedure. 60 seconds of the user's continuous movement serve as the input raw data to be processed.

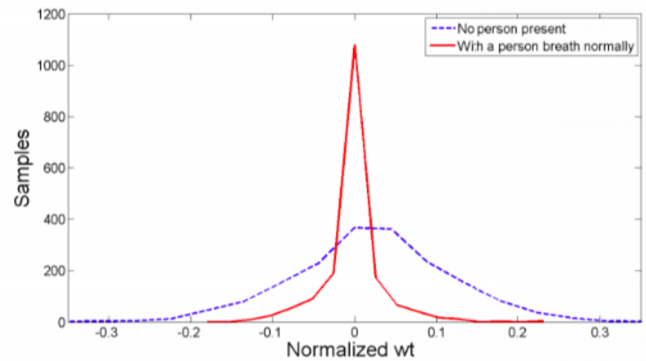

Fig. 6. Movement detected by the system portrayed in the figure [13]

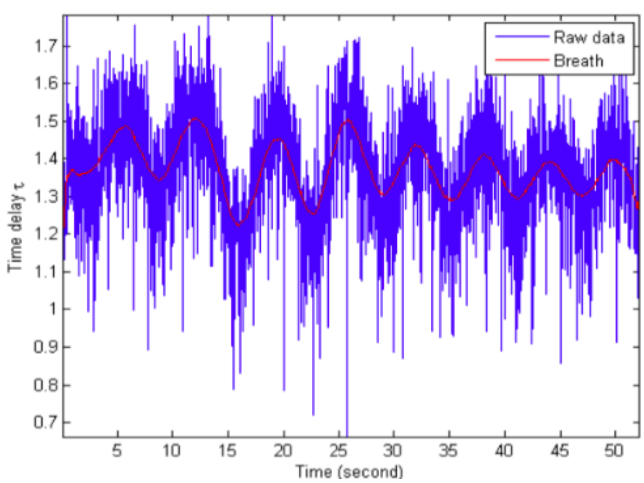

Fig. 7. Figure shows the breath signal reconstruction in the span of 55 seconds[13]

The algorithms in this paper focus on the time shift between two consecutive measurements. When the patient exhales, this time shift measurement is positive. When the patient inhales, it is negative [13].

Regarding heartbeat detection, the human heartbeats are initially emulated by using a vibrating corner reflector. A function generator, a vibrator, a corner reflector, and the UWB system are all utilized for heart rate detection in this case. To rule out jamming from other sources, some signal processing (SP) algorithms were used. The experimental setup (with the exception of the desktop computer) was positioned in a magnetic shielded room. For the clutter removed signal, two methods were applied, namely EMD and Wavelet packets. The results demonstrate that human heartbeat as well as small human movements can be detected by this system.

This shows that a Wi-Fi based implementation can minimize the time it takes to find such results. UWB is a radio technology used for short range data communications over a large portion of the radio spectrum. UWB transmissions generate radio energy at specific time intervals occupying a large bandwidth. To generate the UWB signal, it is common to transmit pulses with short duration as demonstrated in this method of heart rate detection. UWB systems are used to detect the presence of people and objects through walls and do not require direct connection, unlike sensors. However, UWB systems are expensive and are only limited to military use [14, 22]. Thus, we present systems such as Vital-Radio and Wi-Sleep which are more practical.

B. Vital Radio

One way of approaching this more efficiently is with a Wi-Fi based system called Vital-Radio. This wireless sensing technology measures vital signs without body contact. The researchers directly revealed the accuracy of this technology within their article, explaining that this had a median accuracy of 99 percent [1]. The only limitation is that the users remained within 8 meters from the Wi-Fi device in order to achieve high accuracy. To further improve this system, we can analyze how the algorithms can be manipulated to increase the distance while maintaining high accuracy rate.

The Vital-Radio works by measuring the reflection time, which is determined by how long it takes for the signal to be received by the device [1]. The farther the person is from the device, the longer the reflection time is. If a person is facing towards the device, the chest expands during inhalation, moving closer to the device. When the user exhales, the chest moves slightly away from the device. The researchers also stated that when the individual is not facing the device, data can still be extracted since wireless signal can traverse through their body. This makes it more practical for everyday use since a person may not always face the device, especially when sleeping. Emergencies can occur when the person is in any position, so it is important to accurately detect abnormalities.

Unlike previous methods, Vital-Radio separates different objects, or reflectors of the wireless signal, into different "buckets" [1]. These buckets organize the objects into different categories, so one reflector will not be mistaken for another. Below is a figure which depicts this separation:

The operation of Vital-Radio contains three steps: it eliminates reflections from objects which are static, identifies which signals are from breathing and heart rate, and it analyzes these signals to extract information regarding one's breathing and heart rate.

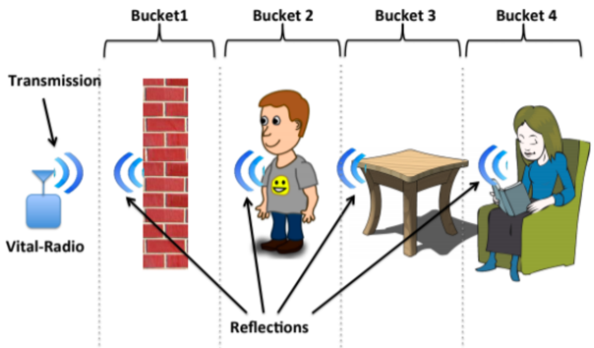

Fig. 8. People and objects are separated into different "buckets" so that Wi-Fi can easily distinguish the data received from different reflectors[1]

The researchers claim that there was high accuracy regardless of orientation. However, accuracy was slightly higher when the user faces the device since there is 99.1 percent accuracy for breathing and 98.7 percent accuracy for heart rate. When the user has their back towards the device, the accuracy drops at most 3 percent [1] making it a reliable option for most scenarios. This method can be especially useful for people suffering from sleep apnea.

C. *Wi-Sleep*

We can also monitor sleep using Wi-Fi signals. PSG (polysomnography) is known as the "gold standard" of monitoring one's sleep, and it includes many techniques including EEG, ECG, airflow, and pulse oximetry [8]. Electroencephalography (EEG) records electrical activity of the brain. Electrocardiography (ECG) is the process of recording electrical activity of the heart using electrodes placed on the skin. The airflow entails the patient's breathing rate and patterns, and the pulse oximetry measure the oxygen level of the blood. The PSG method encompasses all of these techniques, but this system usually requires the patient to wear wristbands, headbands, and probes to collect data of their vital signs. The article mentions that PCG requires lots of equipment, which does not make it the best method for clinical settings. Therefore, the researchers have introduced Wi-Sleep, an alternative method which can be used to measure one's sleep patterns, total amount of sleep, and breathing during sleep [8]. This can be especially useful for patients experiencing sleep apnea, the inability to sleep and breathe at the same time.

Wi-Sleep identifies the breathing rate and sleeping positions as well. It has a 85.7 percent breath detection rate, which can hopefully be improved by future studies. It also identified 48 out of 56 breathing pauses according to the researchers. Although there is no need for body contact in this system, it needs to be improved for easy use in the comfort of one's own home. If we can raise the accuracy rate with proper changes in the algorithms, then this may be possible in the future.

Sleep monitoring is achieved using CSI (channel state information). It is a wireless feature that was chosen instead of RSS (received signal strength) since CSI is a much more sensitive indicator than RSS for tracking one's respiration [8]. RSS measurements originally formed a stair-like pattern, indicating low sensitivity of RSS to typical respiration. Because RSS measurements can be dominated by errors and electronic noise, the respiration detection accuracy decreases significantly.

This system uses one compliant AP (TP Link WR740) as the transmitter sending 20 data packets per second, and a laptop computer (Dell M2300) using a commercial Network Interface Controller (NIC) as the receiver. The equation used in the CSI sleep-monitoring technique represents a 30-by-m matrix, where m is the number of data packets received [8]. Ripple-like patterns of the amplitudes corresponds to the movement of the chest. The phase of the signal wave, however, has no relation to the breath detection in the system. The Wi-Sleep system was tested on 6 different sleeping positions to determine the accuracy of breath detection in Wi-Sleep. False positive and false negative rates are lower than 7 percent in the "soldier" and "starfish" sleeping positions, according to the researchers. However, sleeping on one's side yielded the highest false positive and false negative rate, as these rates were up to 27 percent for this particular sleeping position.

The accuracy for breathing pauses was determined by the Channel Frequency Response (CFR) sequences in the experiment. The person held their breath for 10 seconds and GLRT (Generalized Likelihood Ratio Test) method to detect the two 'change points' associated with sleep apnea at the 15 seconds mark and the other at 25 seconds. The GLRT is able to correctly identify these change points and identifies whether the person exhibits symptoms of sleep apnea while sleeping.

D. *Fresnel Model*

The Fresnel Model is another contactless system which detects human respiration rates from commodity Wi-Fi devices. A Fresnel zone is defined as a cylindrical ellipse drawn between transmitter and receiver, and the size of the ellipse is determined by the distance between the two sites as well as the frequency of the operation. Fresnel zones are useful when calculating reflections and diffraction loss between a transmitter and receiver.

Researchers proposing this Fresnel model mentioned that there are two common methods which can be used to measure continuous respiration rate in clinics, namely pneumography and capnography [14]. Pneumographs are devices which record velocity and the force of chest movements during respiration, while capnography measures the concentration of carbon dioxide in respiratory gases. However, the researchers state that these models are expensive and not practical for elders to have inside of their home. The researchers also mention that systems such as UWB radar, Doppler radar, and FMCW radar yield high accuracy results but they are also expensive and impractical for home settings.

As shown in the figure above, the Fresnel model consists of ellipses with 2 foci, represented by P1 and P2. The Fresnel Zone Number can be calculated using:

$$| P1Qn | + | QnP2 | - | P1P2 |= nw/2$$

where n is the number of Fresnel Zones and w is the wavelength of the signal.

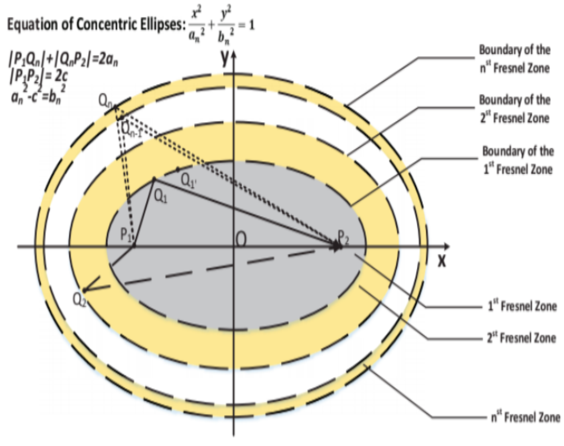

Fig. 9. The ellipses and geometric shape of Fresnel model[14]

There can be a number of Fresnel Zones, n, based on the number of ellipses. A larger value of n indicates greater distance from the radius and focal points. Amplitude and phase of the shift in signals are calculated as P1 sends a radio signal to P2. [14] For calculating respiration, the human body as seen as a "reflection surface" and the researchers observed how the chest displacement that occurs during respiration affects the radio frequency (RF) signal. [14] The displacement of the chest is viewed as a moving object in this system.

There were 9 participants involved in the study. The researchers were not able to detect respiration when the subjects in the experiment were 2 meters beyond the LOS distance (the LOS distance = 1 meter as stated in the paper), which is typically the 110th Fresnel Zone. Thus, the human respiration can successfully be detected up to the 109th Fresnel zone, but these zones only extend to a few meters in total. Additionally, user orientation also affects the accuracy of the system. Participants were placed from 0 degree to 135-degree angles. The researchers concluded that the best case is when the user is at the 0-degree angle since the human body blocks the chest reflection surface after the 90-degree point [14]. Limitations include the fact that it may not detect respiration when other users nearby are moving. Additionally, it may be difficult to distinguish the breathing rates of people with different breathing patterns.

V. Metal Detection Using Wi-Fi

As mentioned in Section II, Wi-Fi can also be used for metal detection. We can identify the presence of harmful objects in bags without even opening them using Wi-Fi detection. The CSI complex value in this system includes amplitude and phase information, which examines the object's dimension and determines the risk level based on the reconstructed CSI complex of the signals reflected by the object [12]. The results of the experiment show that the system, developed by students and professor at Rutgers University, is able to detect 95 percent of suspicious objects in different types of bag. The system is also capable of identifying 90 percent of dangerous material types [12]. Objects are currently detected using X-rays in airports, courts, etc., but we can use modern technology in the future to facilitate the process of checking bags and identifying potentially harmful objects. This study demonstrates that we can maintain high accuracy when detecting harmful objects using good communication networks.

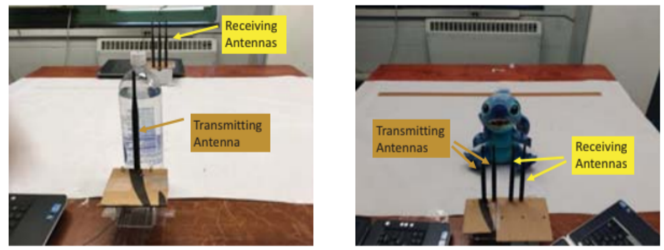

Fig. 10. Model of Metal Detection System [12]

Rutgers University's implementation of object material identification and risk level estimation used by two experimental systems. The researchers used CSI measurements available in Wi-Fi devices to collect the inputs from the CSI from a Wi-Fi transmitter and receiver. The procedure involved two steps for the material classification and the signal-reflection based object risk estimation. Using the KNN (K Nearest Neighbor) based feature selection data mining algorithm, good subcarriers for CSI complex were selected. KNN is a supervised learning technique in which k is selected to be an odd number and we can observe data points in relation to others based on distance. We can use mean square error and classify an object's material type based on the classification results of other objects with similar characteristics. This is an instance-based algorithm which takes very little learning time, but a relatively long evaluation time. Moreover, based on the extraction reflection of the signal of the object, risk level for this particular object is estimated after the material type of the object is classified.

For future system implementations regarding metal detection, we can use a myriad of designs which are useful in heart rate detection. For instance, in the Wi-See System [18], signals are bounced off of walls to collect data on human gestures. We can utilize this concept to retrieve information on an object's material type to predict whether or not the object is harmful. We can use Wi-See to leverage the properties of Doppler Shift, which is defined as the change in a wave's frequency as is source moves relative to the observer. However, the researchers mentioned that from human motion, we only receive a very small Doppler shift. This may result in difficulties when detecting from a typical wireless transmission [18]. Thus, we can use some aspects of this system while integrating modern technologies in the future for stronger detection.

Additionally, the Fresnel model demonstrates that the angle at which the person is turned can affect the accuracy of vital signs. The reason for this occurrence is that user location and body orientation influence the quality of CSI signals, which affects the system performance when detecting human respiration. However, the angle at which weapons and metals are facing may not influence the system's ability to correctly classify harmful objects since it would be better at reflecting the RF signals than the human body. Thus, we may create a system which is able to classify harmful objects from all angles by using the Fresnel Model. Moreover, data can be extracted using a method similar to Vital-Radio since the orientation of the object did not significantly affect the signal in that system. The signal can traverse through bags and through the object to retrieve the necessary information. Furthermore, Vital-Radio separates people into "buckets," and this idea can be used to separate the various objects in a room. By using this method, we can ensure higher accuracy as one object's composition will not disrupt the classification of other objects. Additionally, multiple objects can be detected at once and classified based on its potential to be harmful. Using the KNN algorithm in combination with one of these systems can yield accurate results for metal detection and classification.

VI. Related Works in the Subject of Detection Using Wi-Fi

People can also be tracked using modern technology. For instance, some researchers claim that Wi-Vi technology is efficient and requires less power and size than other ways of seeing through walls, such as with radar and sonar [11, 30]. The two innovations that the researchers discuss include the use of MIMO interfacing to nullify the effect of static object and focusing on the receiver on a moving target and motion of a human body is treated as an antenna and resulting radio frequency (RF) beam is tracked [11, 30]. Researchers emphasized how one can track a human by treating the motion of a human body as an antenna array and track the resulting RF [30] to monitor multiple people at the same time and gesture-based communication [11]. Gestures are identified via reflections of the RF signals. The see-through-wall devices that this Wi-Vi system utilizes operates in the ISM band. Without carrying any transmitting device, the user is also able to directly communicate with Wi-Vi. Moreover, tracking people with Wi-Fi can be especially useful during earthquakes and other natural disasters. Some people may not be found after such events; thus, Wi-Fi can be used for the purposes of tracking people and potentially saving their lives [15]. As some researchers presented, radars can sense the presence of earthquake survivors so that they can be rescued. Furthermore, MIMO can also be incorporated into systems in order to hear people with Wi-Fi. For instance, the Wi-Hear systems leverages MIMO technology and it has a 91 percent detection rate of a single speaker and up to 74 percent for no more than 3 people speaking simultaneously [19]. Using such systems may enable us to hear those who are in dangerous situations so that others can receive important messages via Wi-Fi.

Activity recognition can be achieved using fine-grained Wi-Fi signatures. E-eyes is a method which uses the features from channel state information in order to classify various activities such as eating, studying, washing dishes, etc. The true positive rate for this system was shown to be 96 percent, thus 96 percent of the activities the user accomplished were correctly identified by the system [24]. In addition, the physics of Wi-Fi propagation can be strategically used to localize a wireless client in indoors by analyzing on the signal strength of its transmitted packets as received on access point in the Wi-GEM system [29]. There is no specific training phase, saving effort in pre-deployment stage of the Wi-GEM system design. Future studies can integrate both of these concepts to locate an individual and recognize the activity as an individual's specific location may significantly affect the type of activity that is being performed, such as eating in a restaurant, washing dishes in the kitchen, etc.

Moreover, human motion can be detected using Wi-Fi to reduce the occurrence of violent acts. Intense movements such as punching, kicking, etc. can be the result of school bullying or street violence. If we can identify such movements using Wi-Fi, it is possible to stop the event before a person gets severely injured in the situation. Researchers have presented a system in which the intense human motion detection rate is 90% [16]. The system uses CSI technology, which conveys that such wireless technology can not only be used for sleep monitoring and metal detection, but it can also detect human motion. Wi-Track is a similar system which tracks human motion, but one of its limitations is that it is unable to identify and distinguish between different body parts [21]. Thus, we can improve these systems to identify the motion specific body parts as it can help us find out the details of violent acts for crime investigation. Another approach is the multi-person localization system, which depends on Wi-Fi signals to track one's movements [23]. This system is able to detect movements even if the user is behind a wall or obstruction, and it localizes multiple users by disentangling the reflections of wireless signals that bounce off their bodies. Gait recognition [28] can also be accomplished using Wi-Fi signals to recognize humans based on the fine-grained gait patterns captured by Wi-Fi devices.

Using human motion detection, we can also detect the fall of elderly people. In indoor environments, we can monitor Wi-Fi channel state information to detect changes in movement as human movements change the propagation characteristics of the environment. Thus, it can alert the CSI of the received signal [26]. Long short-term memory (LSTM) learning algorithm performed the best, although the accuracy rate was still only 80 percent. An enhanced version of such implementation would save several lives each year as fall is one of the primary causes of death for elderly people [17]. According to some researchers, an elderly receiving institutionalized care due to high risk of falling can cost approximately $3,500 per month. A large number of elderlies can't get up by themselves after the fall, and even without any direct injuries, 50% of those who had a long time of being on the floor (longer than one hour) died within six months after the falling" [17]. If we can detect the fall using a system, others can be alerted immediately so elderly people would not have to lie on the floor for long periods of time. Hence, system implementations for fall detection would be more cost efficient and beneficial to human life as we can reduce medical bills and expand on life expectancy.

VII. Future Studies

Future studies can focus on creating more Wi-Fi based contactless systems that are inexpensive and have high accuracy rates. There are many implementations of contact-based systems, but much fewer systems which do not require user contact. In order to monitor heart rates all the time, a contactless system would be more practical since we cannot when the patient may require medical attention. If we can develop more systems like Vital-Radio and Wi-Sleep, we can make such usage common in the future so that people can monitor their health from the comfort of their home. Future studies can focus on how to track the vital signs of multiple people at extended distances so that users are not limited to areas that are in close proximity to the Wi-Fi devices.

Moreover, future studies can use concepts from vital signs detection to improve metal detection. Since we can detect humans based on the movement created during breathing, we can detect objects based on their stillness and absence of movements created from breathing. We can also categorize each object in a room by separating them into ”buckets” for faster detection. Using KNN algorithms, we can classify objects as harmful or harmless based on their material composition. Additionally, the human body orientation can affect the quality of the CSI signals, which in turn results in lower respiration detection rate as shown in the Fresnel model. Thus, the orientation of an object may also affect accuracy in metal detection. To combat this issue, future studies can investigate how to receive stronger signal strengths regardless of which angle the object is facing and the distance of the object from the Wi-Fi device. Such implementation of metal detection systems using Wi-Fi can allow us to check backpacks and suitcases efficiently. Using Wi-Fi to conduct such detections will allow the process to complete much more quickly and can yield high accuracy rates, as mentioned previously.

VIII. Conclusion

In this paper, we have compared and analyzed contactless systems and systems which require user contact. We also emphasized the significance of vital signs detection as it can save millions of lives annually. The contactless systems which are heavily dependent on Wi-Fi and do not require the use of sensors are most effective as it can detect irregularities in real time at any instance. Among the contactless systems, UWB radar system is limited to military, thus Vital-Radio and Wi-Sleep are some examples of systems which perform well, can be accessible to common people, and can be further enhanced to implement in the homes of people. This will especially those who suffer from tachycardia, bradycardia, or sleep apnea. The limitations of such systems are that they are currently unable to detect vital signs at extended distances. Thus, they can be improved to successfully track the vital signs of multiple people even when they are not in close proximity to the Wi-Fi device. Metal detection is another major field which can utilize Wi-Fi technologies in order to ensure the safety of people in schools, courts, airports, etc. We provided insights on how future studies can integrate some concepts from vital signs systems in order to identify and classify objects as harmful or harmless. The results of the contactless vital signs systems and metal detection systems introduced in this survey demonstrate a promising future for Wi-Fi application development in these fields. However, there are still many limitations and challenges that must be resolved as it can further enhance the capabilities of such systems.

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