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REVIEW ARTICLE

# Contactless methods to acquire heart and respiratory signals—A review

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## ABSTRACT

The vital sign is the most important parameter for the internal health status of any subject in time. Every person is witnessed of COVID-19 global pandemic viruses. The world population has faced this problem globally. Collecting the infected person's sample data in a contact-based approach may lead to the spreading of the disease. On the other hand, if we use a non-contact-based approach for the collection, it is somehow far better and breaks the chain of virus spreading. This radar-based technique is preferred in non-contact vital sign detection so that any person gets to their health status prior and according to that doctor can diagnose the proper treatment. The radar-based signal is targeted to the subject's chest. Due to the chest wall displacement main vital sign parameters of the heart and respiration of the individual's health are being captured. These captured signals are called vital signs, with this it is very helpful that the pre-diagnosis and treatment can be recommended by doctors or health service providers. Some patients due to their movement may be older or children for a long-time use skin irritation or allergy type of problems may face. On the other hand, some patients may be COVID-19 infected disease and burn patients. Hence, it is not possible to connect as both cases are unexpected for the required purpose. For constant and continuous measurement, existing contact-based methods are not fruitful hence non-contact-based approach is adopted. Non-contact-based vital sign detection is preferably due to several problems occurring. This paper presents a state-of-the-art review of recent monitoring methods and techniques for health monitoring in medical fields of operations. These methods and techniques are used as a tool to acquire, visualize and analyze the sampled data collected in any environment either indoor or outdoor.

***Keywords:*** Healthcare; Non-contact; Doppler Radar; Continuous Wave; Techniques and Methods; Vital Sign Detection; Respiration and Heart Beat Detection

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## 1. Introduction

Vital signs are clinical measurements that indicate the basic body functions and can help healthcare providers in assessing a person's overall health status. The four primary vital signs include body temperature, heart rate or pulse, respiratory rate, and blood pressure[1]. Body temperature is a measure of the body's internal heat, which is usually taken using a thermometer. A normal body temperature is typically between 97.8 °F and 99 °F (36.5 °C to 37.2 °C), but can vary depending on the individual's age, gender, and activity level[2]. Heart rate or pulse is a measure of how many times the heart beats per minute, and is usually measured by feeling the pulse at the wrist or neck. A normal heart rate ranges from 60 to 100 beats per minute, but can also vary depending on age, physical fitness, and other factors[3–5]. Respiratory rate is a measure of how many times a person breathes per minute, and is usually assessed by observing the chest rise and fall. A normal respiratory rate for an adult is 12 to 20 breaths per minute, but can vary depending on factors such as age, physical activity, and underlying medical conditions[6]. Blood pressure is a measure of the force of blood against the walls of the arteries and is usually measured using a blood pressure cuff. Blood pressure is expressed as two numbers, with the first number representing the pressure when the heart beats (systolic pressure) and the second number representing the pressure when the heart rests between beats (diastolic pressure). A normal blood pressure reading is typically around 120/80 mmHg, but can vary depending on age, gender, and underlying medical conditions[2–5].

Monitoring vital signs is essential in healthcare settings, as it can help healthcare providers detect early signs of illness or disease, monitor response to treatment, and make decisions about patient care. In recent years, technology has advanced to the point where vital signs[1–7] can be monitored remotely using wearable devices, making it possible for individuals to monitor their own health at home or in other non-clinical settings. Remote vital sign monitoring[5–8] can also be useful in telemedicine, where healthcare providers can assess patients in real-time without the need for an in-person visit. There are two types of vital sign monitoring methods (**Figure 1(a)**) contact based and (**Figure 1(b)**) non-contact based methods; these are further discussed.

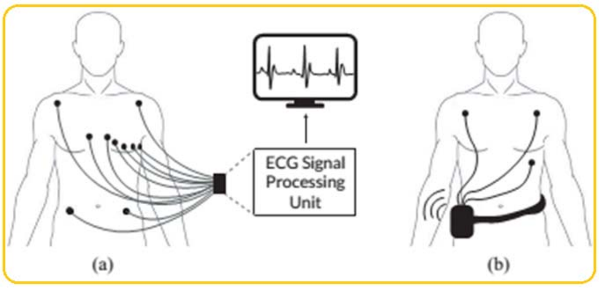

**Figure 1.** Representation of two popular Electrocardiography (ECG) system based on: **(a)** 12-lead clinical ECG setting; **(b)** 3-lead ECG ambulatory device[3,7].

## 1.1 Contact-based methods

A variety of electrodes are attached to a subject's skin during the electrocardiography (ECG), a straightforward and common clinical procedure that measures the heart's electrical activity. It is one of the most popular and practical methods for diagnosing cardiovascular diseases (CVD) in the clinical setting. Clinically and practically, the portable ambulatory ECG devices and the conventional 12-lead clinical ECG[6–9] are the two most used ECG acquisition methods (**Figure 1**). The placement of electrodes, which reflect the variations in electrical potentials recorded in two sites in space, yields an ECG lead. Ten electrodes are attached to the limbs and chest in the 12-lead ECG, which results in the derivation of up to 12 sets of ECG data[7–10].

These reliable measurements are often carried out in a medical setting, where information is gathered via cables and then directly linked to a signal processing unit. Ambulatory ECG monitoring devices[10], in contrast, are designed to be portable and smaller so that users may observe ECG data over a longer period of time[4]. Because they allow users to evaluate the recorded ECG data while engaging in regular activities outside of a clinical context, these devices are more sensitive to identify CVD conditions[11]. However, because ambulatory ECG devices typically only have three leads and their signals are often distorted by motion artefacts, they offer less information.

Despite this, with the advancement of technology, new methods for designing devices for ambulatory, system-on-chip, and commercial ECG systems have been suggested. Some of the improvements made to wearable ECG systems include real-time monitoring software processors, more elastic and dry capacitance electrodes[12–14] for long-term monitoring, and wireless raw data transfer using Bluetooth (BLE) or Bluetooth technology between electrodes and the main computer.

An optical method called photoplethysmography (PPG) is utilised to find changes in blood volume in human tissues[8]. It is an easy, inexpensive, and non-invasive technique[9] used to monitor cardiovascular impulses at the skin's surface. Applications for broad health monitoring that use this technology include digital blood pressure monitors, vascular exams, pulse oximeters, and others[10].

A simple PPG system[8] has two main optical components: a source of light (one or more) to illuminate the cells and a photodetector to track minute fluctuations in light intensity caused by changes in blood volume[11]. For measuring blood oxygen levels, the light sources frequently operate at red and/or near-infrared wavelengths. For HR measurements, however, the green led is the best choice. The peripheral pulse that is timed to heartbeats is the most distinctive waveform feature (**Figure 2**). However, these signals contain various types of information in addition to cardiac information. Thermoregulatory activity, sympathetic nervous system activity, and respiration are a few of the lower frequency signals that may be isolated from PPG data and processed as an increased health parameter[12].

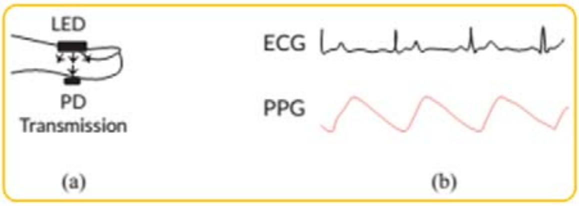

**Figure 2.** Illustration of Photoplethysmography (PPG) finger technique and resulted waveform signal: **(a)** LED and Photodetector used for transmission and reflectance of light; **(b)** comparison between an electrical ECG signal and a pulse PPG signal[13–15].

RR may be detected using further and more precise methods in addition to the earlier approaches that can detect respiration modified by cardiac impulses. Depending on their manner of operation and intended function, these technologies can be classified into many kinds[13]. Through respiratory airflow measurements, additional sensors may be utilized to monitor the volume and/or velocity of air that is inhaled and expelled during breathing. Fibre optic sensors[16], anemometers, and flowmeters can all be used to collect data on the temporal trend of volume or velocity to determine RR[17]. The properties (**Figure 3**) of the air that is breathed and expelled, such as carbon dioxide ($CO_2$), humidity, and temperature, may also be used to measure the human breath. Sensors placed to airways in close proximity to one of the nasals are frequently used to capture these parameters using external sensor devices[18].

Respiratory activity (**Figure 3**) can also be detected using acoustic sensors, such as microphones. Small microphones on patients are able to capture changes in air pressure brought on by sound waves originating from the nose or trachea, in contrast to standard airflow devices that typically feature uncomfortable facemasks, adding additional and needless airway resistance. The diaphragm contracts and relaxes repeatedly as a result of breathing, which causes the chest to move and enlarge circumferentially[22–24].

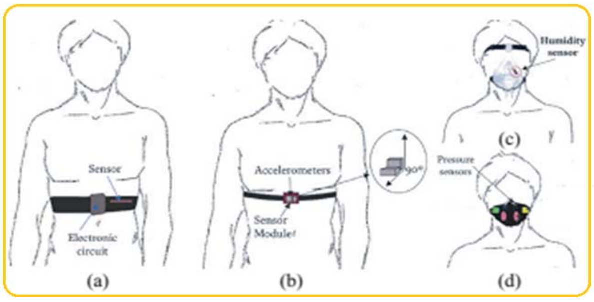

**Figure 3.** Methods used for respiration monitoring based on: **(a)** piezoresistive sensor; **(b)** accelerometer sensor; **(c)** humidity sensor masks; **(d)** impedance facemask based on forced oscillation techniques[19–21].

As a result, respiration signals relying on strain, impedance, and thorax movement patterns measurements, retrieved from chest bands and accelerometers sensors, have also been acquired using equipment for the actual movement detection of the chest wall[3,25,26]. The subjective manually counting of patients' respiration rates using person or business that provides or observation skills is still the approach utilised the most in clinical practise, notwithstanding the approaches previously stated. Access to health monitoring has changed drastically over the world as a result of the quick technology progress. In order to encourage individuals to monitor and control their health condition in everyday living routines, new sturdy, pleasant, and adaptable wearable designs have been made possible by the shrinking of electronic equipment[27]. Some of the earlier methods discussed here have subsequently been incorporated into more compact wearables, such smartwatches and smartphone health apps. These commonplace gadgets are equipped with a wide range of sensors that may be applied to smart health applications. For instance, apps that measure pulse rate using a camera and LED have previously proven to be accurate in this regard[28,29].

Spirometry tests, which play a crucial part in the identification of respiratory disorders, have previously been conducted using pressure applications coupled to mobile phones. Future remote patient monitoring solutions are made possible by these technological advances and their integration into wearable technology[30,31].

## 1.2 Contactless methods

Depending on the methodology utilised, contactless vital sign monitoring techniques fall into one of three categories: ballistocardiography, optical, or radar[13,32]. Due to the physiological characteristics of the heart and lungs, ballistocardiography (BCG) is a non-invasive method used to measure the body's vibrations[13]. This technique analyses mass movements, which in the case of the circulatory system correspond to the regular motions of the human body brought on by the accelerated blood as it is expelled from and transported into big channels (**Figure 4**).

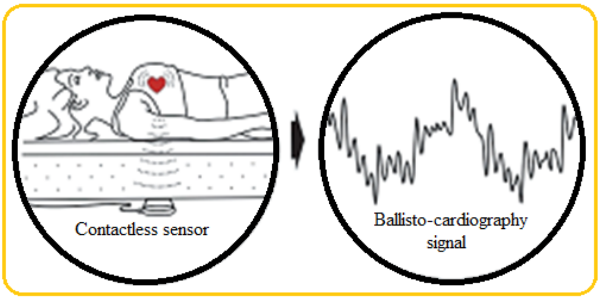

**Figure 4.** Ballistocardiography system installed under the bed for physiological contactless vital sign monitoring[13,33].

Contrary to other widely used and validated cardiological tests used in everyday medical practise, BCG has historically struggled to demonstrate its value. Some of the explanations given for the loss of the early enthusiasm for BCG include economic concerns and its challenging use in clinical settings. However, the BCG approach is now being looked at again after being ignored for a while, states that the use of machine learning algorithms to the signals allowed for a unique bed-embedded heart and respiration noninvasive device to be tested with an emphasis on the beat-to-beat health monitoring task and a maximum overall detection of 83.9%. BCG has been effectively used in several disciplines, including the identification of sleep apnea condition[4,9,34].

Imaging techniques, including video-based and Infrared (IR) thermal technologies, are another area of noninvasive vital signs monitoring techniques (**Figure 5**). One such technique, called Eulerian video magnifying, makes advantage of video frame sequences to amplify movements brought on by breathing and fluctuations in skin tone produced by blood perfusion[35–37]. This method visualises subtle colour and movement changes in common films by statistically analysing small changes which are too small to notice with the human eye. Additionally, this method might be used with just a high-quality smartphone camera for capturing vital signs[38]. Other common video approaches, including Eulerian Video Magnification, have already shown promise in cardiorespiratory signal monitoring with inexpensive laptop RGB cameras[39]. Nevertheless, effective camera-based techniques require favourable lighting conditions. As a result, they are unable to cover every scenario, particularly while people are sleeping at night when there is typically no light. As a result, IR methods might be a great replacement for camera systems that use video and similar thermal imaging techniques to evaluate the breathing rates of newborn infants. The measurement of temperature changes that take place in the vicinity of the nose and mouth during inhalation and exhalation is the basis for this technique[40]. In order to extract respiratory information using these approaches, high computational picture signal processing techniques are often required; however, this procedure might be made simpler by using innovative algorithms.

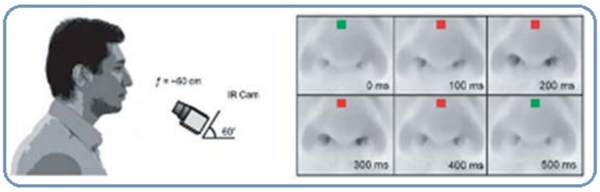

**Figure 5.** Thermography setup developed for contactless respiratory monitoring applications. Inspiration and expiration are marked by red and green squares, respectively[13,41].

Using merely pixels instead of picture segmentation or nostril tracking, for instance, was utilized in the study of Bella *et al.*[39] to record breath from a human nose. The intranasal surface has pixels that are brighter and darker depending on when we exhale and inhale. Finally, one approach that has been identified as being promising for measuring vital signs is radar technology. When using radar sensors, the ability to detect vital signs depends on the modulation impact that the human body has on the transmitted radar signal. This modulation is obtained from the movement of the human target's chest caused by mechanical respiratory and cardiac activity signals, as well as by typical outside sounds from electronic databases and background intermediate conditions[42–44].

## 2. Materials and methods

The detection of the target's range or angle, its size and shape, as well as its linear and rotational velocity, may all be determined depending on the radar systems design and the kind of sent signal[45,46]. Additionally, multiple radar topologies may be used based on which of these properties are thought to be crucial to capture, and even the distance and kind of the targeted item. Here are a few examples of radar topologies.

### 2.1 Continuous-wave (CW)

This device cannot determine range, but it can identify moving targets through the use of the Doppler shift of something like the received signal. When a target's rotational velocity has to be determined, CW systems are frequently used. Due to the difficulty of detecting and interfering with pure CW radar systems, police radar systems normally measure the speed of moving vehicles[47].

The mathematical equations involved in CW radar are based on the principles of the Doppler effect. The Doppler shift, also known as the Doppler frequency, is the change in frequency of the RF signal caused by the motion of the target. The Doppler shift can be expressed mathematically as:

$$\Delta f = 2fv/c$$

where,

$\Delta f$ is the Doppler frequency shift in Hertz (Hz),

f is the frequency of the RF signal in Hertz (Hz),

v is the velocity of the target in meters per second (m/s),

c is the speed of light in meters per second (m/s).

To estimate the target's velocity, the Doppler shift is measured by mixing the received signal with a reference signal and filtering the resulting beat frequency signal. The beat frequency, fb, can be expressed mathematically as:

$$fb = 2fD\ 4fv/c$$

where,

fD is the Doppler frequency shift in Hertz (Hz).

By measuring the beat frequency, the velocity of the target can be estimated using the following equation:

$$v = fb*\lambda/4$$

where,

$\lambda$ is the wavelength of the RF signal in meters (m).

Once the velocity of the target is estimated, its vital signs such as heart rate and respiration rate can be calculated using appropriate signal processing techniques.

### 2.2 Frequency-modulated continuous-wave (FMCW)

Frequency modulated continuous wave (FMCW) radar is a type of radar that emits a signal with a linearly increasing frequency and receives the reflected signal. The frequency difference between the transmitted and reflected signals, also known as the beat frequency, is used to estimate the distance to the target. FMCW radar can also be used for vital sign detection by measuring the Doppler shift in the reflected signal caused by the motion of the target. The mathematical equations involved in FMCW radar can be expressed by the transmitted signal, can be represented as a linear frequency sweep over time, given by:

$$s(t) = \cos[2\pi(f_c t + k_f t^2/2)]$$

where,

$f_c$ is the center frequency of the transmitted signal,

$k_f$ is the frequency sweep rate.

The received signal can be represented as:

$$r(t) = As(t - \tau)\cos[2\pi(f_c t + k_f(t - \tau)^2/2)]$$

where,

A is the amplitude of the received signal,

$\tau$ is the time delay between the transmitted and received signals due to the target's distance.

By mixing the transmitted and received signals and filtering the resulting beat frequency signal, the range of the target can be estimated using the following equation:

$$\tau = 2R/c$$

where,

R is the range of the target,

c is the speed of light.

The Doppler shift in the reflected signal caused by the motion of the target can be calculated using the following equation:

$$\Delta f_D = 2v/cf_c$$

where,

v is the velocity of the target.

Once the Doppler shift is estimated, the target's vital signs such as heart rate and respiration rate can be calculated using appropriate signal processing techniques.

## 2.3 Pulsed-wave (PW)/UWB radar

This technology permits sending and receiving data at various periods. So, because echo signal is significantly less than the broadcast signal, this topology is used when it is difficult to detect the received signal while the transmitted signal is present. When the transmitted signal's peak strength must be significantly higher than its average power, PW radar is also helpful. PW radar may be classified into three main categories: pulse compression radar, moving target indicator (MTI) radar, and pulsed Doppler radar. The mathematical equations involved in pulsed radar can be expressed by the transmitted signal and represented as a rectangular pulse of duration $T_p$, given by:

$$s(t) = A_p \,\mathrm{rect}(t/T_p)\cos(2\pi f_c t)$$

where,

$A_p$ is the amplitude of the transmitted pulse,

$\mathrm{rect}(t/T_p)$ is the rectangular function with duration $T_p$,

$f_c$ is the carrier frequency of the transmitted signal.

The received signal can be represented as:

$$r(t) = A_r\cos[2\pi f_c(t - \tau)]\,\mathrm{rect}((t - \tau)/T_p)$$

where,

$A_r$ is the amplitude of the received signal,

$\tau$ is the time delay between the transmitted and received signals due to the target's distance.

By correlating the transmitted and received signals, the time delay can be estimated using the following equation:

$$\tau = 2R/c$$

where,

R is the range of the target,

c is the speed of light.

Pulsed radar can also be used for imaging by transmitting a series of pulses and measuring the time delay and direction of the reflected signals. The resulting data can be processed using appropriate algorithms to produce an image of the target. Pulsed radar has the advantage of high accuracy in range measurements, but it also has some disadvantages such as limited range resolution and susceptibility to interference from other sources. Ultra-Wideband (UWB) radar is a type of radar that uses a wideband signal to achieve high resolution and accuracy in target detection and tracking. In UWB radar, the transmitted signal is typically a short-duration pulse or series of pulses with a bandwidth that is much larger than the center frequency. The mathematical equations involved in UWB radar can be expressed using the In-phase/Quadrature (I/Q) representation. The transmitted signal can be represented as a complex waveform in the I/Q plane, given by:

$$s(t) = I(t) + jQ(t)$$

where,

I(t) is the In-phase component of the transmitted signal,

Q(t) is the Quadrature component of the transmitted signal,

j is the imaginary unit.

The received signal can be represented as a complex waveform in the I/Q plane, given by:

$$r(t) = A(t)\exp[j\varphi(t)] = I(t) + jQ(t)$$

where,

A(t) is the amplitude of the received signal,

$\varphi(t)$ is the phase of the received signal.

By correlating the transmitted and received signals, the time delay and amplitude can be estimated using the following equation:

$$\tau = 2R/c$$

where,

R is the range of the target,

c is the speed of light.

The In-phase and Quadrature components of the received signal can be separated using a mixer and filters, and then processed to estimate the distance and velocity of the target. UWB radar has the advantage of high resolution and accuracy in target detection and tracking, as well as the ability to penetrate through obstacles such as walls and foliage. However, it also has some disadvantages such as susceptibility to interference from other wireless systems and limited range due to regulatory restrictions on the allowed power level.

## 3. Related work

The purpose of this work is to demonstrate the feasibility of non-contact or remote vital signs sensing or monitoring using a new concept called “harmonic radar”. The proposed demonstrator is based on the use of system components (VCO, coupler, antenna, LNA, and mixer) operating at both the fundamental frequency (12 GHz in this work) and its second harmonic frequency (24 GHz). The designed radar transmits and detects both fundamental and second harmonic waves that are used to create frequency diversity for parametric detection and estimation. Numerical and experimental results are presented to validate the proposed concept. It is shown that the accurate detection of vital signs can be obtained with such a remote harmonic radar technique. Furthermore, results obtained by using wideband antenna are compared with those obtained with two substrate integrated waveguide antennas operating at two different frequencies, namely 12 GHz and 24 GHz[48–51].

This paper presents a theoretical and experimental analysis of multi-frequency radar systems for monitoring vital signs. The main advantage of using multi-frequency architecture is the possibility to improve the detection sensitivity of heart beats and breathing rate while cancelling the body movement with signal processing. Simulations were carried out using ADS software for three systems operating at 5.8 GHz, 24 GHz and 35 GHz. Different parameters such as antenna gain, mixer conversion loss and LNA gain were considered in the simulations for each system in connection with their system effects. It is shown that by using adequate correlation functions of received signal, it is possible to improve the detection accuracy. Experimental results are presented to validate the analysis and proposed approach[52].

To detect vital-sign data from people, a real-time heartbeat sensing radar with an adjustable transmitting power for a long-time monitoring application is described. The radar in the transmitter utilizes pulse width modulation to adjust the sensing energy, there-by enhancing the signal-to-noise ratio (SNR) and increasing sensitivity. This is particularly beneficial in challenging sensing environments, where ideal conditions are not present. We concentrate on two situations with varied probing pulse widths and anticipate receiving the echoes for respiration signal monitoring in order to strengthen the radar’s flexibility and validate its conceptual framework. The observed findings demonstrate that by modifying the propagation pulses, the resultant SNR may really be enhanced[53].

Wireless healthcare detection, which involves the painless detection of motion and heart rhythm signals, has recently been shown to be an effective way to keep track on targets’ health conditions. In comparison to traditional continuous-wave (CW) radar systems, self-injection locked (SIL) radar systems provide a number of beneficial benefits, such as minimal system complexity, high sensitivity, and excellent clutter immunity. There are several methods for employing SIL radar systems to find heart rhythm signals and locations. The advancements in the localization and detection of vital signs are outlined in this study. Finally, some findings from the use of SIL radar systems to find animals are provided[31].

In general, the source of data collection from literature for a review article drawn from various sources such as online databases PubMed, Web of

Science, and Scopus. The search criteria for document retrieval depend on the research topic and can include keywords, publication years, language, type of publication, and more. For example, keywords can be used to search for relevant literature on a specific topic, while publication years can be used to limit the search to recent publications as done in google scholar search.

# 4. Proposed methodology

## 4.1 COVID-19

The COVID-19 pandemic has a significant impact on human well-being and daily activities worldwide, with hundreds of thousands of people testing positive for the virus. To address this issue, a device combining an infrared sensor and microwave radar[54] has been developed. This device allows for the remote detection of early signs of COVID-19, such as a mild fever, shortness of breath, or irregular heart rhythm. Additionally, by balancing the processor RAM and Doppler spectrum, this technology enhances the resolution of images when individuals are in close proximity to each other. It is important to note that the use of powerful microwaves and infrared sensors in the COVID-19 detection system has implications for human health. In addition, this system (**Figure 7**) combined several methods to improve the resolution of a picture with two people adjacent to each other.

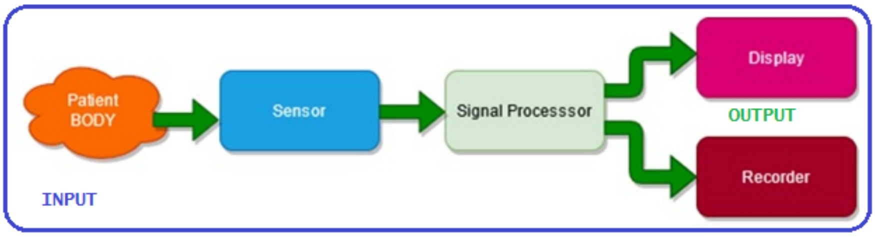

**Figure 7.** Vital sign monitoring system.

Now, we have the capability to detect the early signs of life-threatening COVID-19 from a comfortable distance. This system employs an infrared sensor and radar, enabling us to check for COVID-19 without physical contact or interaction. We are thrilled to introduce this product, which is essential for the health and safety of all individuals. Our focus is on real people's stories, empowering everyone to take control and protect their families from infectious diseases[55,56].

## 4.2 Signal processing flow diagram

Despite the fact that several algorithms have been created, they all have a similar signal processing framework.

From **Figure 8**, after receiving the backscattered signals, any unwanted noise components need to be eliminated. The types of signals are then retrieved after determining the target's distance within the radar's range. The hardware radar employed determines the output of echo signals. Both complex baseband signals produced by I/Q channel transformers and RF signals sampled by quick analog-to-digital converters (ADC) modules can be used to represent backscattered signals. The benefits of complex I/Q representation for signal processing make it widely employed[57,58].

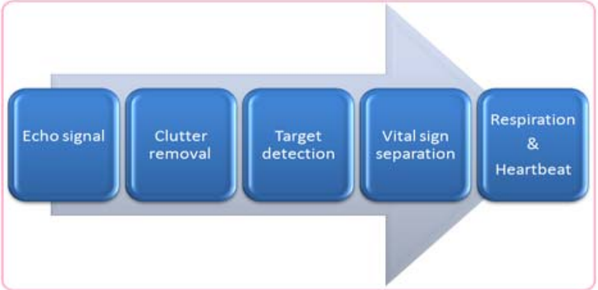

**Figure 8.** Signal processing flow diagram to extract vital signs from radar-range signals.

**Table 1.** SNR of respiration and heartbeat signal using FIR filter and proposed method

| Parameters | FIR | Proposed Method |
|---|---|---|
| Respiration SNR | 4.44dB | 12.03dB |
| Heartbeat SNR | −53.52dB | −48.70dB |

The **Table 1** shows a comparison of the signal-to-noise ratio (SNR) for respiration and heartbeat signals using a finite impulse response (FIR) filter versus a proposed method. The SNR is a measure of the quality of a signal relative to the noise in the signal. A higher SNR indicates that the signal is stronger and more easily distinguishable from noise. In this case, the proposed method has a significantly higher SNR for the respiration signal compared to the FIR filter (12.03 dB vs. 4.44 dB). This means that the proposed method provides a stronger and clearer respiration signal. However, for the heartbeat signal, the FIR filter has a slightly higher SNR compared to the proposed method (−53.52 dB vs. −48.70 dB). This indicates that the FIR filter may be better at filtering out noise from the heartbeat signal.

The existence of the cardiac and respiratory cycles makes a human target easy to see. The extractions of vital signs depend on the objectives study. Periodic breathing and heartbeat are detected in the data gathered over time from the target area. In order to extract individual information, the signals need thus be separated. This separation may be carried out in either the frequency or time domain, as has been demonstrated. When compared to cardiac signals, the breath signal may be easily retrieved due to the magnitude difference between the two signals. This paper discussed emerging trends in the field of vital sign monitoring by comparing the application prospects of non-contact radar with traditional vital sign monitoring methods. The article also highlights the challenges faced during the implementation of non-contact radar in vital sign monitoring.

Non-contact radar has the potential to revolutionize vital sign monitoring by enabling remote and continuous monitoring without the need for contact-based sensors. One major application prospect of non-contact radar is in the field of telemedicine. With the rise of telemedicine, there is a growing need for remote monitoring of vital signs in patients who are not physically present in a healthcare facility. Non-contact radar technology can enable remote monitoring of vital signs such as heart rate and respiration rate in a non-invasive manner, improving patient comfort and reducing the risk of infection transmission. However, non-contact radar also faces several challenges in its application. One major challenge is the issue of signal processing and noise reduction. Non-contact radar signals are often contaminated by environmental noise, making it difficult to extract accurate vital sign information. Another challenge (shown in **Table 2**) is the need for validation studies to ensure that non-contact radar technology is as accurate and reliable as traditional contact-based methods.

Non-contact radar technology has the potential to greatly improve the accuracy and convenience of vital sign monitoring. Further research is needed to overcome the challenges associated with this technology and validate its effectiveness in clinical settings.

**Table 2.** Comparison of traditional and non-contact methods with application prospect and challenges faced

| Comparison | Non-contact | Traditional |
|---|---|---|
| **Application prospect** | | |
| Accuracy | Non-contact radar can provide accurate vital sign measurements without the need for physical contact. | Traditional methods may have limitations in terms of accuracy due to factors such as movement artifacts or incorrect sensor placement. |
| Comfort | Non-contact radar does not require physical contact, making it more comfortable for patients, especially those with sensitive skin or who are in pain. | Traditional methods may cause discomfort or irritation due to adhesive sensors or tight straps. |
| Mobility | Non-contact radar allows for continuous monitoring without the need for patients to wear cumbersome sensors or devices. | Traditional methods may require patients to wear sensors or devices, limiting their mobility. |
| **Challenges faced** | | |
| Distance | Non-contact radar measurements may be affected by distance, requiring careful positioning and calibration. | Traditional methods may not have distance limitations, but require physical contact. |
| Environmental interference | Non-contact radar may be susceptible to environmental interference such as electromagnetic signals, requiring careful calibration and signal processing. | Traditional methods may also be susceptible to interference from external sources, but to a lesser extent. |
| cost | Non-contact radar technology may be more expensive than traditional methods, requiring a significant investment in equipment and training. | Traditional methods may be more cost-effective, but may require more frequent sensor replacement or maintenance. |

### 4.3 Potential application of non-contact radar in patient vital sign monitoring

Non-contact radar technology has the potential to revolutionize patient vital sign monitoring in hospitals and other medical settings. Here are a few potential applications of this technology in patient monitoring:

- **Contactless monitoring:** Non-contact radar technology can measure vital signs without the need for physical contact with the patient's body. This means that vital signs such as heart rate, respiration rate, and even blood pressure can be monitored without the need for invasive or uncomfortable procedures. This can greatly improve patient comfort and reduce the risk of infection.
- **Continuous monitoring:** Non-contact radar technology can provide continuous monitoring of vital signs, allowing healthcare professionals to detect changes in real-time. This can be particularly useful in critical care settings, where rapid response to changes in vital signs can be critical to patient outcomes.
- **Remote monitoring:** Non-contact radar technology can be used for remote monitoring of patients, allowing healthcare professionals to monitor vital signs from a distance. This can be particularly useful for patients who are in quarantine, or who are unable to leave their homes due to illness or disability.
- **Early detection of health issues:** Non-contact radar technology can detect changes in vital signs that may indicate the onset of health issues such as sepsis or cardiac arrest. Early detection of these issues can greatly improve patient outcomes and reduce the risk of complications.
- **Improved efficiency:** Non-contact radar technology can automate the process of monitoring vital signs, reducing the need for manual monitoring by healthcare professionals. This can improve efficiency in hospitals and other medical settings, allowing healthcare professionals to focus on other important tasks.

Non-contact radar technology has the potential to greatly improve patient monitoring in hospitals and other medical settings. With its ability to provide contactless, continuous, and remote monitoring, this technology can improve patient comfort, detect health issues early, and improve the efficiency of healthcare operations. This article focuses on the potential application of non-contact radar in patient vital sign monitoring. In addition to the software method described in this article, there are also other types of hardware facilities available for non-contact radar. Non-contact radar has the potential to revolutionize patient vital sign monitoring by offering numerous advantages over traditional contact-based methods. It allows for continuous, remote monitoring of patients without requiring physical contact, reducing the risk of infection and discomfort. Non-contact radar can also detect vital signs such as heart rate, respiratory rate, and blood pressure more accurately and reliably than traditional methods. It can be used to monitor patients in a variety of settings, including home care, hospitals, and ambulances. It has the potential to improve patient outcomes and reduce healthcare costs by allowing for earlier detection of critical health events.

There are several types of hardware facilities available for non-contact radar, including:

- **Doppler radar sensors:** These sensors are used to measure the motion of objects, including the motion of the chest wall during respiration.
- **FMCW radar sensors:** These sensors use a continuous wave signal that is modulated with a linear frequency ramp. They are used to measure the distance to an object and can also be used for vital sign monitoring.
- **UWB radar sensors:** These sensors use a very short duration pulse to measure the distance to an object. They are also used for vital sign monitoring and can provide high-resolution data.
- **IR-UWB radar sensors:** These sensors use ultra-wideband signals in the infrared range to measure vital signs.
- **Microwave radar sensors:** These sensors use microwave signals to measure vital signs and can provide high accuracy and precision.

These hardware facilities (shown in **Table 3**) can be integrated into various devices, such as standalone radar systems or wearable devices, to enable non-contact vital sign monitoring.

**Table 3.** Comparison of traditional and non-contact methods for hardware and software-based facilities

| Facility type | Non-contact | Contact-based |
|---|---|---|
| **Hardware** | | |
| Doppler radar | Measures motion of objects, used to measure heart rate and respiration rate. | Measures changes in blood flow, used to measure heart rate and blood pressure. |
| FMCW radar | Uses varying frequency continuous wave signals to measure distance and speed, used to measure respiration rate and blood pressure. | Measures changes in blood flow, used to measure heart rate and blood pressure. |
| TDR radar | Uses pulse signal to measure time delay and amplitude of reflected signal, used to measure heart rate and respiration rate. | Measures changes in blood flow, used to measure heart rate and blood pressure. |
| Ultra-wideband radar | Uses short pulses of energy to measure distance and position, used to measure respiration rate and heart rate. | N/A |
| Microwave radar | Uses microwave frequencies to measure motion and position, used to measure heart rate and respiration rate. | Measures changes in blood flow, used to measure heart rate and blood pressure. |
| **Software** | | |
| Signal processing | Analyses radar signals and extracts vital sign data such as heart rate, respiration rate, and blood pressure. | Analyses changes in blood flow and extracts vital sign data such as heart rate and blood pressure. |
| Machine learning | Analyses radar data and detects changes in vital signs or patterns that may indicate health issues. | Analyses changes in blood flow and detects changes in vital signs or patterns that may indicate health issues. |
| Visualization | Displays vital sign data in a graphical or real-time format for easy interpretation. | Displays vital sign data in a graphical or real-time format for easy interpretation. |
| Data management | Organizes, stores, and retrieves vital sign data for analysis or documentation purposes. | Organizes, stores, and retrieves vital sign data for analysis or documentation purposes. |
| Mobile applications | Allows remote access to vital sign data for remote patient monitoring or monitoring patients in quarantine. | N/A |

## 4.4 Monitoring accuracy of non-contact radar signs in different literatures

Non-contact radar has been shown to accurately measure respiration rate with an error rate of less than 1 breath per minute (BPM) in several studies reported in the literature[8–11].

For heart rate monitoring, non-contact radar has been found to have a mean absolute error (MAE) ranging from 1.9 BPM to 5.5 BPM in various studies[53–55] which are very common as the basic standard.

Some studies have also explored the use of non-contact radar for blood pressure monitoring, with reported accuracy ranging from 3.8 mmHg to 11.4 mmHg for systolic blood pressure and 2.2 mmHg to 8.7 mmHg for diastolic blood pressure reported in state-of-art literature[17,38].

It's important to note that the accuracy of non-contact radar vital sign monitoring may vary depending on factors such as the specific type of radar technology used, the measurement environment, and the subject being monitored.

**Table 4.** Shows indicators and monitoring accuracy found from literature

| Conventional indicator | Reference | Monitoring accuracy |
|---|---|---|
| Heart rate | [10,11] | Root Mean Square Error (RMSE) of 2.61 beats per minute (BPM). |
| Respiration rate | [19,21,53,55,58,59] | Mean Absolute Error (MAE) of 0.32 breaths per minute (BPM). |
| Blood pressure | [8,9,17,38] | Mean Absolute Error (MAE) of 4.4 mmHg for systolic blood pressure (SBP) and 3.7 mmHg for diastolic blood pressure (DBP). |
| Sleep monitoring | [34,38] | Accuracy of 89.6% for detecting sleep onset, 91.3% for sleep onset latency, and 97.2% for wake-up time. |
| Fall detection | [4,27,39,51] | Accuracy of 95% for detecting falls and 96% for discriminating falls from normal activities. |

Some studies (shown in **Table 4**) have reported that non-contact radar can achieve high accuracy in detecting and monitoring vital signs such as heart rate, respiratory rate, and even blood pressure. For example, a study published in the Journal of Medical Systems reported an accuracy of 99.41% for heart rate detection using non-contact radar. Another study published in the journal

IEEE Transactions on Biomedical Engineering reported an accuracy of 97.5% for respiratory rate detection using non-contact radar. These studies suggest that non-contact radar has the potential to be a highly accurate and reliable method for monitoring vital signs.

## 5. Conclusion

The COVID-19 pandemic has highlighted the need for non-contact vital sign monitoring methods to reduce the risk of spreading infectious diseases. Radar-based techniques are a promising solution for non-contact vital sign detection, as they can capture vital signs without physical contact. The captured vital sign signals can provide doctors and health service providers with valuable information for pre-diagnosis and treatment. Although there are some limitations to non-contact vital sign monitoring, such as patient movement and skin irritation, the benefits of non-contact monitoring outweigh the limitations. This study has reviewed recent monitoring methods and techniques for non-contact vital sign monitoring, providing a valuable reference for researchers and healthcare professionals.

In terms of future scope, there is still room for improvement in non-contact vital sign monitoring technology. Further research and development could focus on improving the accuracy and reliability of non-contact vital sign detection methods, expanding the range of applications, and developing portable and cost-effective devices. The integration of artificial intelligence and machine learning techniques in non-contact vital sign monitoring could also lead to more accurate and automated analysis of vital sign data. Additionally, the potential for non-contact vital sign monitoring in remote patient monitoring and telemedicine should be explored further. Overall, the future of non-contact vital sign monitoring is promising and could lead to significant improvements in healthcare delivery.

## Ethics approval and consent to participate

This article studied with individual and volunteer-basis consent of human participants performed by the authors. However, it is a literature based study found only.

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## Conflict of interest

The authors declare that they have no conflict of interest.

## Abbreviation

ECG: Electrocardiography
CVD: Cardiovascular diseases
PPG: Photoplethysmography
BCG: Ballistocardiography
FMCW: Frequency Modulated Continuous Wave
CW: Continuous Wave
UWB: Ultra-Wideband
SIL: Self-injection Locked
ADC: Analog-to-digital Converters
SNR: Signal-to-noise Ratio
MAE: Mean Absolute Error
BPM: Breaths Per Minute
LNA: Low Noise Amplifier
MRI: Magnetic Resonance Imaging

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