Design of Radar-Based Portable System for Monitoring of Human Vital Signs with Renewable Energy Resources

Pushparaj, Amod Kumar, and Garima Saini

Abstract This paper presents the design of a portable radar-based system for non-invasive monitoring of human vital signs, including heart rate (HR) and respiratory rate (RR) signals. The system is user-friendly and applicable in various settings, such as hospitals, clinics, and homes. The design process involves several stages, including submodules, system requirements identification, design, prototype development, data collection and analysis, optimization, and validation. It measures physiological signals, such as heart rate, breathing rate, and body movement, using electromagnetic waves. To minimize battery replacements or charging, the system integrates renewable energy systems like solar power or kinetic energy capture. Accuracy evaluation of the system is performed by collecting and analyzing data on vital signs, including heart rate, respiratory rate, and body movement, from a group of volunteers. The proposed system provides a sustainable, portable, and non-contact solution for monitoring HR and RR signals, which can enhance the accuracy of diagnosis and treatment in various biomedical applications.

Keywords Portable · Radar system · Heart rate (HR) · Respiratory rate (RR) signals · Non-contact · Electromagnetic waves · Renewable energy systems · Accuracy evaluation · Biomedical applications · Diagnosis and treatment

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1 Introduction

The design of a radar-based portable system for monitoring vital signs [1] in healthcare applications with a renewable energy management device offers a new approach to non-invasive and continuous monitoring of human vital signs. This system utilizes radar technology to detect and measure small movements of the chest and heart, allowing for accurate calculation of vital signs such as heart rate (HR) and respiratory rate (RR).

In addition, the use of a renewable energy management device [2–4] ensures that the system is powered efficiently and sustainably. This device manages the energy consumption of the system, optimizes the use of available energy sources such as solar panels or wind turbines, and ensures that the system operates within safe and efficient limits. This type of system has significant potential to improve patient outcomes and quality of care in a variety of settings, including hospitals, clinics, and even in the home. By providing continuous and non-invasive monitoring of vital signs, medical professionals [5] can quickly detect and respond to changes in a patient's condition, leading to earlier interventions and better outcomes.

Biomedical applications have had a transformative impact on healthcare, particularly in the realm of non-contact human monitoring of vital signs. By harnessing cutting-edge technologies, healthcare professionals can now gather crucial health data without the need for physical contact or invasive procedures. This non-contact approach enhances patient comfort and compliance, reduces the risk of infections, and provides a more convenient monitoring experience.

One prominent non-contact technology utilized in monitoring vital signs [6] is thermal imaging. By capturing infrared radiation emitted by the human body, thermal cameras can measure body temperature with remarkable accuracy from a distance. This capability has been particularly valuable during the COVID-19 pandemic, enabling quick and contactless screening of individuals for fever, a common symptom of the virus.

Another non-contact method employed in vital sign monitoring is radar technology. Radar systems can detect subtle movements caused by respiration and heartbeats, allowing for precise measurement of respiration rate and heart rate without the need for any physical attachments or sensors. This non-intrusive approach is especially beneficial for patients who require continuous monitoring, such as those in intensive care units or individuals with chronic respiratory conditions [7].

Computer vision is yet another powerful tool used in non-contact human monitoring of vital signs. By analyzing video footage or images, sophisticated algorithms can extract vital sign information, such as heart rate, by observing subtle color changes in the face or other regions of interest. This non-contact approach is particularly useful in situations where direct physical contact may not be feasible or desirable, such as monitoring newborns, patients with sensitive skin, or individuals during sleep.

The real-time, continuous monitoring enabled by non-contact technologies offers significant advantages in detecting and responding to health emergencies promptly. Healthcare professionals can receive immediate alerts if there are any deviations or abnormalities in vital signs, allowing for timely intervention and improved patient outcomes [8].

Furthermore, non-contact human monitoring of vital signs has proven invaluable in scenarios where close physical proximity could pose risks, such as infectious disease outbreaks. By minimizing direct contact and reducing the potential for cross-contamination, these technologies enhance infection control measures and protect both patients and healthcare providers.

In summary, biomedical applications have paved the way for non-contact human monitoring of vital signs, revolutionizing healthcare. Through the use of thermal imaging, radar technology, and computer vision, healthcare professionals can gather crucial health data without physical contact or invasive procedures. This approach enhances patient comfort, improves infection control, and enables real-time, continuous monitoring for early detection of health issues, ultimately leading to better patient care and outcomes.

In the field of biomedical applications, radar-based portable systems have emerged as a promising technology for monitoring vital signs. These systems utilize radar sensors to detect and measure subtle movements caused by respiration and heartbeats, offering a non-contact approach that eliminates the need for physical attachments or invasive procedures. The portability of these systems allows for monitoring to be carried out in various settings, including hospitals, clinics, and even in remote or resource-limited areas.

One key advantage of radar-based portable systems is their ability to provide continuous, real-time monitoring of vital signs. By capturing and analyzing the radar signals reflected off the human body, these systems can accurately measure respiration rate and heart rate and even detect irregularities or anomalies. This continuous monitoring capability is especially crucial in critical care settings, where immediate intervention can be initiated in response to sudden changes in vital signs.

Furthermore, integrating a renewable energy management device into radar-based portable systems brings additional benefits. This device utilizes renewable energy sources, such as solar or wind power, to provide the necessary energy for the system's operation. By harnessing sustainable energy, these systems become more environmentally friendly and reduce dependence on conventional power sources. This is particularly advantageous in remote or underserved areas with limited access to reliable electricity grids, enabling vital sign monitoring to be conducted without significant energy constraints [9].

The combination of radar-based sensing technology with a renewable energy management device also enhances the system's portability and versatility. With a self-sustaining power source, the system can be easily transported and deployed in various locations, including field hospitals, disaster areas, and rural communities. This capability extends the reach of vital sign monitoring, ensuring that individuals in remote or resource-constrained regions can receive quality healthcare services.

Moreover, the use of renewable energy in these systems contributes to sustainability efforts within the healthcare sector. By reducing reliance on fossil fuel-based energy, the environmental impact is minimized, resulting in a greener and more sustainable healthcare infrastructure. This aligns with the growing recognition of the importance of sustainable practices in healthcare to mitigate climate change and promote environmental stewardship [10].

In this paper, we will discuss the design and implementation of a radar-based portable system for monitoring vital signs in biomedical applications with a renewable energy management device. We will explore the technical details of the system, including the radar technology used, the energy management device, and the feedback control loop used to optimize the system's performance. We will also discuss the potential applications of this system in various healthcare settings and the benefits it can bring to patients and healthcare providers.

1.1 Human Vital Sign HR and RR Measurement

Human vital signs, such as heart rate (HR) and respiratory rate (RR), are important indicators of a person's overall health and well-being. HR refers to the number of times the heart beats per minute, while RR refers to the number of breaths taken per minute. These vital signs are often used by medical professionals to diagnose and monitor various health conditions, such as cardiac and respiratory diseases.

Human vital signs, such as heart rate (HR) and respiratory rate (RR), are fundamental indicators of overall health and well-being. Heart rate refers to the number of times the heart beats per minute, reflecting the efficiency of the cardiovascular system. It is influenced by factors like physical activity, stress, and age. A normal resting heart rate for adults ranges from 60 to 100 beats per minute, although it may vary depending on individual characteristics. Deviations from the normal heart rate can indicate underlying medical conditions or physiological stress.

Respiratory rate, on the other hand, measures the number of breaths taken per minute and reflects the efficiency of the respiratory system. It is influenced by factors like exercise, emotions, and medical conditions. The average resting respiratory rate for adults is typically between 12 and 20 breaths per minute, but it can vary depending on age, health status, and other factors. Abnormal respiratory rates can indicate respiratory distress or respiratory disorders, such as asthma or pneumonia.

Monitoring heart rate and respiratory rate plays a crucial role in various healthcare settings. In clinical settings, healthcare professionals routinely assess these vital signs to evaluate a patient's overall health, response to treatment, or identify potential complications. In critical care units, continuous monitoring of heart rate and respiratory rate is particularly important for early detection of deteriorating conditions and prompt intervention [11].

Furthermore, monitoring heart rate and respiratory rate has extended beyond clinical settings with the advent of wearable devices and mobile health applications. These technologies allow individuals to track their vital signs in real-time and gain insights into their health and fitness levels. This self-monitoring approach empowers individuals to make informed decisions regarding their lifestyle, exercise routines, and overall well-being.

Moreover, advancements in technology have facilitated the development of non-contact methods for monitoring heart rate and respiratory rate. This includes the use of optical sensors, such as photoplethysmography (PPG), which measure changes in blood volume by shining light onto the skin. These non-contact approaches provide convenience and reduce patient discomfort, making them suitable for various applications, including remote patient monitoring and telemedicine [12].

In summary, heart rate and respiratory rate are essential vital signs that provide valuable information about an individual's health and well-being. Monitoring these parameters is crucial in clinical settings to assess patient health, guide treatment decisions, and detect early signs of deterioration. Additionally, wearable devices and non-contact technologies have enabled individuals to monitor their vital signs in real-time, promoting self-awareness and facilitating proactive healthcare management. As technology continues to advance, the monitoring of heart rate and respiratory rate will continue to play a vital role in maintaining and improving human health.

Traditionally, the measurement of heart rate (HR) and respiratory rate (RR) relied on manual methods, requiring individuals to physically count the pulse or breaths per minute. While effective, these manual measurements can be time-consuming and prone to human error. However, thanks to advancements in technology, automated methods for measuring HR and RR have gained widespread adoption.

Wearable devices, such as smartwatches and fitness trackers, have become increasingly popular for monitoring vital signs, including HR and RR. These devices use optical sensors or electrodes to detect changes in blood flow or electrical signals, providing continuous and real-time measurements. By leveraging sophisticated algorithms, wearable devices can accurately track HR and RR, allowing users to monitor their health and fitness levels conveniently. Furthermore, these devices often come with accompanying mobile applications that provide insights, trends, and personalized recommendations based on the recorded data [13].

In medical settings, more advanced devices are employed to measure HR and RR. For instance, electrocardiogram (ECG) devices are used to capture the electrical activity of the heart, enabling precise measurement of HR and detecting any abnormalities in cardiac rhythm. Pulse oximeters, another medical-grade device, combine a sensor placed on the fingertip or earlobe with infrared light to measure both HR and blood oxygen saturation levels. These devices provide accurate and reliable measurements, making them indispensable in clinical settings for diagnosing and monitoring various cardiovascular and respiratory conditions.

The integration of automated methods for HR and RR measurement brings numerous benefits. These methods provide objective and consistent measurements, minimizing the risk of human error associated with manual counting. The continuous monitoring capability of wearable devices allows for the detection of subtle changes in vital signs that might go unnoticed during sporadic manual measurements. Additionally, the data collected from these automated devices can be stored, analyzed, and shared with healthcare professionals, supporting better diagnosis, treatment planning, and disease management [14].

In summary, the advent of automated methods for measuring HR and RR has transformed the way these vital signs are monitored. Wearable devices offer convenient and continuous tracking, empowering individuals to take charge of their health. Meanwhile, medical-grade devices like ECG and pulse oximeters provide highly accurate measurements for clinical use. With technology playing a pivotal role, automated HR and RR measurements offer greater precision, ease of use, and data insights, contributing to improved healthcare outcomes and personalized patient care.

In this paper, we will discuss the design and implementation of a radar-based portable system to monitor human vital signs, specifically HR and RR signals, for biomedical applications. The system will be designed to be portable and powered by a renewable energy management and control system, allowing for continuous and remote monitoring of vital signs in a variety of settings, including hospitals, clinics, and even in the home [15].

1.2 Vital Sign Measurement Methods

This measurement can be broadly classified into two categories: contact-based and non-contact-based methods.

Contact-based methods: Contact-based methods [16] for measuring vital signs require physical contact with the body through the use of sensors or devices. These methods provide accurate and precise measurements and are commonly used in clinical settings. Thermometers are contact-based devices used to measure body temperature. They can be placed under the tongue, in the ear, or on the forehead to obtain temperature readings. Blood pressure measurement involves using a blood pressure cuff wrapped around the arm, which inflates and deflates to measure the pressure exerted by the blood against the arterial walls.

Electrocardiogram (ECG) sensors are placed on the chest to measure the electrical activity of the heart. This method provides detailed information about heart rate, rhythm, and any abnormalities in the heart's electrical patterns. Respiratory sensors, on the other hand, are placed on the chest or nose to measure breathing rate and depth, providing insights into respiratory function and detecting any irregularities.

Blood glucose meters are contact-based devices used to monitor blood glucose levels in individuals with diabetes. A small sample of blood obtained from a finger prick is placed on a test strip, and the meter provides an instant reading of blood glucose levels.

Contact-based methods offer precise and reliable measurements, making them essential in diagnosing and monitoring various health conditions. However, they may be less convenient and require some level of patient cooperation and involvement. Nonetheless, advancements in technology have led to the development of more user-friendly and comfortable contact-based devices, improving the overall patient experience.

Non-contact-based methods: Non-contact-based methods [17] for measuring vital signs offer the advantage of not requiring physical contact with the body. These methods utilize various technologies to remotely measure vital signs by detecting changes in physical properties of the body or its surroundings.

Infrared thermometers are non-contact devices that measure temperature by detecting the thermal radiation emitted by the body. These thermometers capture the infrared radiation and convert it into temperature readings, making them convenient for quick and contactless temperature measurements, especially in large-scale screenings.

Pulse oximeters are another non-contact method used to measure oxygen saturation. These devices emit light through a body part, such as a finger or earlobe, and measure the amount of light that is absorbed by the oxygen-carrying hemoglobin in the blood. By comparing the absorbed light with the emitted light, pulse oximeters can determine the oxygen saturation level, providing valuable information about respiratory function and overall oxygen levels in the body.

Doppler radar is a non-contact technology that detects changes in the frequency of radio waves reflected off the body. This method can be used to measure heart rate and respiratory rate without any physical contact. By analyzing the changes in frequency caused by the movement of the body, Doppler radar modules can provide real-time and accurate measurements of vital signs.

Non-contact-based methods offer several advantages, including convenience, speed, and reduced risk of cross-contamination. These methods are particularly useful in situations where close physical proximity may pose risks, such as during infectious disease outbreaks or when monitoring individuals with compromised immune systems. Additionally, non-contact methods allow for continuous monitoring without causing discomfort or disturbance to the individual.

As technology continues to advance, non-contact-based methods for measuring vital signs are becoming more sophisticated and accessible. These methods have the potential to revolutionize healthcare by providing efficient and accurate monitoring solutions that enhance patient comfort and improve overall healthcare delivery.

Both contact-based and non-contact-based methods for measuring vital signs have their own distinct advantages and limitations, and the selection of a particular method depends on the specific application and context.

Contact-based methods generally offer high accuracy and precision in measuring vital signs. They allow for direct physical interaction with the body and provide reliable measurements. These methods, such as thermometers, blood pressure cuffs, and ECG sensors, are commonly used in clinical settings where accuracy is crucial for diagnosis, treatment, and monitoring of patients. Contact-based methods also tend to be well-established and have a long history of reliable use.

On the other hand, non-contact-based methods offer convenience and ease of use. They eliminate the need for physical contact with the body, reducing discomfort and minimizing the risk of cross-contamination between individuals. Non-contact methods, like infrared thermometers, pulse oximeters, and Doppler radar, are often preferred in situations where frequent and rapid measurements are required, such as in mass screenings or high-traffic areas. They can also be useful in remote or resource-limited settings where access to contact-based devices or trained personnel may be limited.

It is important to consider the limitations of each method. Contact-based methods may require cooperation from the individual being monitored, and they may be impractical or less comfortable for certain populations, such as infants or critically ill patients. Non-contact-based methods, while convenient, may have slightly lower accuracy compared to their contact-based counterparts, and they may be influenced by external factors, such as environmental conditions or movement artifacts [18].

In summary, the choice between contact-based and non-contact-based methods for measuring vital signs depends on the specific application and context. Contact-based methods offer high accuracy but may be less convenient, while non-contact-based methods provide convenience but may sacrifice a slight degree of accuracy. Healthcare professionals and researchers must carefully evaluate the advantages and limitations of each method to ensure they select the most appropriate approach for their specific needs, taking into account factors such as accuracy requirements, patient comfort, and the resources available in the given setting (Fig. 1).

However, there are also some limitations to using Doppler radar for physiological sensing. For example, it is sensitive to movement and can be affected by changes in body position or posture. It is also less accurate than other methods, such as electrocardiography (ECG), for measuring heart rate variability. Additionally, Doppler radar [20] cannot provide information about the electrical activity of the heart, which is important for diagnosing certain heart conditions.

Contact methods generally require sensors or devices to be placed on the body, which can be uncomfortable and limit patient mobility. However, they tend to be more accurate than non-contact methods and can provide more detailed information about vital signs.

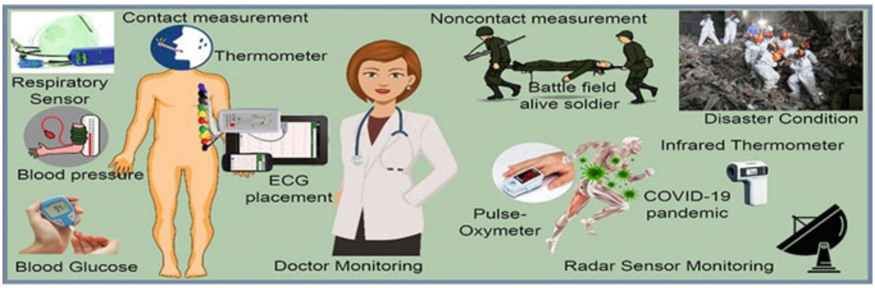

Fig. 1 Vital sign measurements [18, 19]

Non-contact methods, on the other hand, can provide continuous monitoring without the need for physical contact with the patient. They are generally more comfortable for the patient and can be used for remote monitoring [21]. However, they are often less accurate than contact methods and may be affected by environmental factors such as lighting or movement.

Here is a comparison table for contact and non-contact [22–25] vital sign parameters (Table 1).

In some cases, a combination of contact and non-contact methods may be used to provide the most comprehensive monitoring of vital signs. In summary, contact methods are generally more accurate and reliable but can cause discomfort to the patient and may be affected by external factors such as movement or ambient light. Non-contact methods, on the other hand, are more comfortable for the patient and can be used in remote or low-resource settings but may be affected by environmental factors and may require calibration for accurate measurements. The choice between contact and non-contact methods will depend on the specific healthcare setting and the needs of the patient.

Table 1 Comparison table for contact and non-contact [22–25] vital sign parameters

Vital sign parameters	Contact	Non-contact	Methods Used
Heart rate (HR)	Electrocardiogram (ECG), pulse oximeter, photoplethysmography (PPG)	Doppler radar, infrared thermography (IRT), video-based systems, microwave radar	Contact: Sensors placed on the body, usually on the chest or finger. Non-Contact: Sensors or cameras placed at a distance from the body
Respiratory rate (RR)	Chest strap, nasal cannula, respiratory inductance plethysmography (RIP)	Doppler radar, infrared thermography (IRT), video-based systems, microphone	Contact: Sensors placed on the body, usually around the chest or nose. Non-Contact: Sensors or cameras placed at a distance from the body
Distance	N/A	Ultrasonic or infrared sensors	Contact: N/A. Non-Contact: Sensors or cameras placed at a distance from the body, typically in doorways or hallways
Body movement	Accelerometers, gyroscopes	Video-based systems	Contact: Sensors placed on the body, typically on the wrist or ankle. Non-Contact: Cameras placed at a distance from the body, typically in the room or hallway

1.3 Renewable Energy Management Device for Non-contact Vital Sign Portable Monitoring System

A renewable energy management device can be a valuable addition to a non-contact vital sign [26] portable monitoring system. Such a system utilizes radar technology to detect and monitor vital signs without the need for direct contact with the patient. The system is designed to be portable, making it useful in remote or off-grid settings where traditional monitoring methods may not be feasible.

A solar-based renewable energy management device is a system that efficiently handles the utilization and storage of renewable energy sources, such as solar or wind power. When integrated into a non-contact vital sign portable monitoring system, this device allows the system to be powered by renewable energy, thereby reducing dependence on external power sources.

Solar power is a particularly popular renewable energy source, harnessing the sun's energy to generate electricity. By incorporating solar panels into the design of the non-contact vital sign monitoring system, the panels can capture sunlight and convert it into usable electrical energy. This renewable energy can then be used to power the system, eliminating the need for traditional power sources and reducing carbon emissions.

Similarly, wind power can be harnessed through wind turbines to generate electricity. Wind-powered renewable energy systems can be utilized in conjunction with the non-contact vital sign monitoring system, providing an additional sustainable energy source. By utilizing renewable energy sources, the monitoring system becomes more environmentally friendly and sustainable, contributing to a greener approach in healthcare applications.

Furthermore, the inclusion of a renewable energy management device optimizes the utilization of the generated renewable energy. This device effectively manages the storage and distribution of the energy, ensuring efficient usage and minimizing wastage. It enables the system to store excess energy for later use, such as during periods of low sunlight or wind, ensuring continuous and uninterrupted operation of the non-contact vital sign monitoring system.

The integration of a solar-based renewable energy management device into the non-contact vital sign portable monitoring system offers several benefits. It promotes sustainability by reducing reliance on traditional energy sources and decreasing the carbon footprint associated with healthcare operations. It also enhances the system's reliability and autonomy, as it becomes less dependent on external power grids and is capable of functioning in remote or resource-limited areas.

Radar topology	Vital parameter measured	Power consumption (mW)	Distance (m)	Frequency range (GHz)	Types of renewable energy module devices
Continuous wave Doppler radar (CWDR)	Breathing rate, heart rate	3.3	1–4	2.4–2.4835	Solar panels, batteries
Frequency-modulated continuous wave (FMCW) radar	Respiration rate, heart rate, movement	1–5	Up to 10 m	2.4–8.5	Batteries
Pulsed Doppler radar	Heart rate, breathing rate, blood flow	30–50	Up to 1	5.8–8.5	Batteries
Ultra-wideband (UWB) radar	Respiration rate, heart rate, movement	80–200	Up to 10	3.1–10.6	Solar panels, batteries
Multiple-input multiple-output (MIMO) radar	Respiration rate, heart rate, movement	100–400	Up to 4	2.4–8	Batteries
Frequency-shift keying (FSK) radar	Respiration rate, heart rate, movement	20–40	Up to 2	2.4–2.5	Solar panels, batteries

The paper starts with the fundamental theory of continuous wave (CW) Doppler radar-based portable system for monitoring vital signs in biomedical applications with a renewable energy management device and offers a new approach to non-invasive and continuous monitoring of human vital signs in Sect. 1. Extensive literature on radar-based monitoring systems has been discussed. This will help in identifying the different types of radar systems, their advantages, limitations, and the various parameters in Sect. 2. Monitoring of non-contact vital signs in biomedical applications using renewable energy management devices presents several challenges, proposed methodology and signal processing methods have been discussed in Sect. 3 and different baseband demodulation and signal processing methods along with results and discussion in Sect. 4. Overall summary about this paper conclusion and future scope will be reviewed in Sect. 5.

2 Literature Survey

A review of existing literature on radar-based monitoring systems will be carried out. This will help in identifying the different types of radar systems, their advantages, limitations, and the various parameters that can be measured using radar.

Singh et al. [1] emphasized the potential of radars in continuously monitoring vital signs such as heart rate and respiration rate without physical touch. They provided a technical analysis of non-contact vital sign measures using radar technology, highlighting challenges in hardware and signal processing methods, as well as the need for higher frequency to improve accuracy. Additionally, the paper explored environmental attenuation and the potential health risks associated with mmWave exposure.

Le Kernec et al. [20] focused on radar signal processing for assisted living (AL) applications, with a particular emphasis on three example applications: sleep stage classification, recognition of human activity, and detection of respiratory diseases. Using a framework that encompasses measurements/preprocessing, feature extraction, and classification methods, they addressed the common issue of classification. The article also delved into recent advancements in the field, including multi-domain, multimodal, and fusion techniques for activity recognition, super-resolution techniques for healthcare applications based on vital signs, and outstanding problems. Furthermore, the authors examined the unique challenges associated with each of the three applications.

Pal et al. [17] presented a study on vertical handoff in heterogeneous mechanisms for wireless LTE network. The study focuses on improving the quality of service for users who are moving between different wireless networks, such as LTE and Wi-Fi. The authors propose an optimal approach for vertical handoff that takes into account various parameters such as network load, signal strength, and user preferences. The study demonstrates the effectiveness of the proposed approach in improving the handoff performance and user experience.

Mercuri et al. [18] addressed the challenges involved in developing non-contact vital signs monitoring techniques that are suitable for everyday use without causing discomfort to the patient. The authors demonstrated how a radar-based sensor can be practically used to monitor the breathing and heartbeats of multiple people in a non-invasive manner.

Obadi et al. [27] discussed the application of the continuous wavelet transform (CWT) in radar-based vital sign detection and the computational challenges associated with its use. The authors proposed a field-programmable gate array (FPGA)-based optimized CWT algorithm architecture that utilizes frequency domain processing, an optimized number of operations, and parallel processing of independent operations.

Kaur and Pal [26] focus on various parameters that affect the security of cloud computing networks, such as data encryption, access control, and authentication. The authors discuss the importance of these parameters for ensuring the confidentiality, integrity, and availability of cloud computing resources. The study provides insights into the application of these security measures in cloud computing and their impact on overall network security.

Atta [5] developed a wireless vital signs monitoring system based on a microcontroller to measure patients' body temperature, heart rate, blood oxygen level, respiratory rate, and electrocardiogram in non-traditional hospital settings. The system includes wearable sensor nodes, wireless communication infrastructure, and a graphical user interface with a control system to monitor patients and take necessary actions. The system was implemented using 40 sensor nodes, four distribution points, and one gateway, successfully covering an area of 2500 m^2 with > 3.3% packet loss during transmission. Its low power consumption and cost-effectiveness make it a suitable option for large hospitals.

Wang et al. [22] presented a new technique for detecting multiple vital signs using frequency-modulated continuous wave (FMCW) radar. The proposed method utilizes FMCW radar to determine the direction and velocity of chest wall movements and translates them into vital sign information such as blood pressure, heart rate, and respiration rate. The authors conducted a study with a group of healthy volunteers to demonstrate the practicality of their method, achieving high accuracy rates for all three vital signs. The authors suggest that this approach has the potential to provide non-contact, real-time, and multi-target vital sign monitoring, which can be valuable in various healthcare settings, including home-based care and intensive care units.

Khan and Pushparaj [10] conducted a comprehensive analysis of non-contact sensing methods with the aim of developing a platform to combat COVID-19. In their study, the authors explored various sensor technologies, including thermal imaging, acoustic sensors, and optical sensors, and their potential application in detecting COVID-19 symptoms such as fever, coughing, and shortness of breath. However, the authors also highlighted the challenges and limitations associated with these technologies, such as low accuracy rates and the need for high-quality data. They concluded that non-contact sensing technologies have the potential to play a critical role in controlling the spread of COVID-19, particularly in high-risk environments such as hospitals and airports. However, further research is needed to develop more accurate and reliable sensing systems for COVID-19 screening and diagnosis.

Hanifi and Karsligil [12] proposed a novel approach to detect falls in elderly people using a combination of continuous wave (CW) Doppler radar and vital signs monitoring. Their system tracks changes in movement patterns, heart rate, and breathing using Doppler radar and uses machine learning techniques to analyze the data for fall detection. The authors conducted studies with a group of seniors and achieved an accuracy rate of over 95%, demonstrating the effectiveness of their method. They concluded that this approach could enhance the precision and reliability of fall detection systems for older adults, especially in situations where conventional motion sensors may be insufficient due to mobility issues or other factors.

Pushparaj and Saini [21] conducted a literature review and comparative study of various techniques for monitoring the human heart using ECG signals. The authors highlight the importance of ECG signals in diagnosing cardiac abnormalities and focus on biomedical physiological-based approaches for processing these signals. By analyzing the electrical activity of the heart, these approaches offer a better understanding of its functioning. The authors discuss the strengths and limitations of different ECG signal processing techniques and provide insights into their potential for improving the diagnosis and treatment of heart-related diseases.

Shah and Fioranelli [28] conducted a comprehensive analysis of radio frequency (RF) sensing technologies for improving healthcare in everyday living. The authors discussed various RF sensing methods, including passive and active techniques, and their application in medical contexts such as fall detection, vital sign monitoring, and activity recognition. They also highlighted the challenges and limitations associated with RF sensing technologies, such as privacy concerns, interference, and accuracy. The authors concluded that although RF sensing technologies can provide continuous and non-invasive monitoring to enhance patient and caregiver quality of life, several technical and ethical concerns must be addressed before they can be used in healthcare.

Khan and Pushparaj [10] developed a hybrid maximum power point tracking (MPPT) controller for solar photovoltaic systems using artificial intelligence. The study focuses on improving the efficiency of solar panels under variable environmental conditions. The authors propose a novel approach that combines fuzzy logic and neural network algorithms to optimize the power output of the solar panel. The study demonstrates the effectiveness of the hybrid MPPT controller in improving the energy efficiency of solar photovoltaic systems.

Joseph et al. developed a micro-power generating device for lab-on-a-disk biomedical applications. The device utilizes a rotating electromagnetic generator that can extract mechanical energy from the disk's rotation and a power management system based on microcontrollers to regulate the generator's output voltage. The generator is designed to output a constant voltage and up to 2 mW of power. During testing on a lab-on-a-disk platform, the device successfully powered several microfluidic components. The authors conclude that their micro-power generating technology could enable the development of self-contained and portable lab-on-a-disk devices for use in remote and resource-limited environments.

Alluhaidan et al. [6] study is focused on an automatic threshold selection method for detecting duplicate records in healthcare using a Reciprocal Neuro-Fuzzy Inference System (RN-FIS) and Adaptive Learning Optimization (ALO). The study demonstrates the effectiveness of this approach in improving the accuracy of duplicate record detection.

Hung et al. introduce a novel solar cell designed for use in biomedical applications. The solar cell is manufactured using complementary metal–oxide–semiconductor (CMOS) technology and features inter-digitized back contacts. The design allows for uniform series resistance and 2D junction formation, but the minority carrier qualities of the bulk substrate are subpar. To address this issue, the researchers thinned the substrate to 60 μm, resulting in a final efficiency of 15%. The solar cell can produce 159 W of electrical power at a lighting intensity of 10 mW, making it suitable for use on human skin.

2.1 *Literature Inferences Drawn*

Comparative Parameter Drawn from the Literature

Literature	Methods	Signal processing	Measured parameters	RR value	HR value	Power consumption
Singh et al. [1]	UWB radar	FFT-based peak detection algorithm	Breathing rate, heart rate, movement detection	✓	✓	280 mW
Le Kernec et al. [20]	Doppler radar	Waveform analysis, adaptive filters	Heart rate, respiration rate, movement detection	✓	✓	Not reported
Li (2013)	Doppler radar	Time–frequency analysis	Heart rate, respiration rate	✓	✓	2 mW
Mercuri et al. [18]	UWB radar	Wavelet transform, FastICA algorithm	Heart rate, respiration rate	✓	✓	Not reported
Obadi et al. [27]	UWB radar	MUSIC algorithm, wavelet decomposition	Respiration rate, heart rate	✓	✓	240 mW
Atta [5]	Doppler radar	Wavelet transform, adaptive filtering	Respiration rate, heart rate, movement detection	✓	✓	Not reported
Wang et al. [22]	FMCW radar	Compressed sensing algorithm, fast Fourier transform	Breathing rate, heart rate	✓	✓	Not reported
Khan et al. [19]	CW Doppler radar	Time domain analysis, moving average filter	Respiration rate, heart rate	✓	✓	Not reported
Hanifi and Karsligil [12]	CW Doppler radar	Time–frequency analysis, neural network classification	Respiration rate, heart rate	✓	✓	Not reported
Shah and Fioranelli [28]	RF sensing	Hilbert-Huang transform, independent component analysis	Heart rate, respiration rate	✓	✓	Not reported

3 Proposed Methodology

3.1 Non-contact Vital Signs Monitoring Using Renewable Energy Management Devices Presents Several Challenges, Including

1. *Accuracy:* Vital sign monitoring requires high accuracy to ensure that the readings obtained are reliable. Non-contact vital sign monitoring using renewable energy management devices must be designed to provide accurate readings, which may require the use of sophisticated algorithms and sensors.
2. *Power management:* Renewable energy management devices rely on renewable energy sources such as solar, wind, or thermal energy to power the monitoring system. Managing the available power to ensure that the system operates continuously and with enough power to operate the sensors and algorithms can be a challenge.
3. *Signal quality:* Non-contact vital sign monitoring devices may be affected by environmental factors such as movement, light, or electromagnetic interference, which can affect the quality of the signal and lead to inaccurate readings.
4. *Interference with other medical devices:* The monitoring system should not interfere with other medical devices, which can cause safety issues and affect the accuracy of readings.
5. *Data processing and transmission:* The monitoring system must be designed to collect, process, and transmit data reliably and securely. The data must be protected from unauthorized access and interference to ensure patient privacy and confidentiality.
6. *Cost:* Non-contact vital sign monitoring devices using renewable energy management can be expensive to develop and manufacture, which can limit their availability and adoption in biomedical applications.
7. *Regulatory compliance:* Medical devices must comply with regulations and standards to ensure their safety and effectiveness. Non-contact vital sign monitoring devices using renewable energy management must meet the relevant regulatory requirements to be approved for use in clinical settings.

3.2 Methodology

The design of the radar-based monitoring system will involve several stages, as outlined below:

1. *System requirements:* Based on the literature review, the system requirements will be identified. The requirements will include the accuracy of the measurements, the range of physiological parameters to be measured, the portability of the system, and the ease of use.

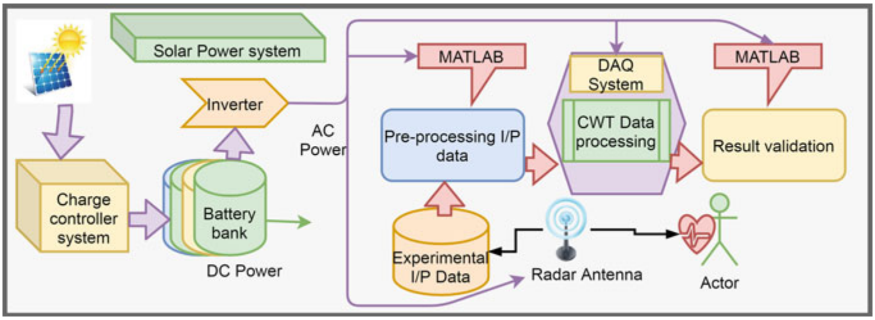

Fig. 2 Block diagram of radar-based monitoring system design

2. *System design:* The system will be designed based on the identified requirements. The design will include the selection of radar components such as the transmitter, receiver, and antenna. Other components such as the signal processing unit and the power supply will also be selected.
3. *Prototype development:* A prototype of the radar-based monitoring system will be developed based on the designed system. The prototype will be tested to ensure that it meets the identified requirements.
4. *Data collection and analysis:* The radar-based monitoring system will be tested on a group of volunteers to collect data on vital signs such as heart rate, breathing rate, and body movement. The collected data will be analyzed to evaluate the accuracy of the system.
5. *System optimization:* Based on the analysis of the collected data, the system will be optimized to improve its accuracy and performance.
6. *Final testing and validation:* The final radar-based monitoring system will be tested and validated to ensure that it meets the identified requirements and is suitable for use in biomedical applications.

Figure 2 shows the design of a portable radar-based monitoring system for biomedical applications involves several stages, including a literature review, system requirements identification, system design, prototype development, data collection and analysis, system optimization, and final testing and validation.

3.3 Signal Processing Techniques

In non-contact vital sign detection and monitoring using Doppler radar topology and a solar energy management module, several signal processing techniques can be applied to enhance the accuracy and reliability of the measurements:

1. Fast Fourier transform (FFT) is a widely used signal processing technique that allows for the analysis of frequency domain signals. In the context of non-contact vital sign detection using Doppler radar, the FFT is instrumental in analyzing the

Doppler radar signals to extract vital sign information. By applying the FFT to the Doppler radar signals, the time-domain signals are transformed into the frequency domain. This transformation reveals the frequency components present in the signals, enabling the identification of specific frequency peaks associated with vital signs such as heartbeat and respiration.

For example, in the case of detecting the motion of the chest, the FFT can be utilized to identify the frequency peak corresponding to the heartbeat. The periodic nature of the heart's contractions generates a distinct frequency component, and by locating the frequency peak, the heart rate can be calculated accurately. Similarly, the FFT can help identify the frequency components associated with respiration. As the chest expands and contracts during breathing, it induces subtle motion that can be captured by the Doppler radar. By analyzing the frequency content of the radar signals using the FFT, the frequency peak related to respiration can be detected, allowing for the estimation of the respiratory rate.

The FFT provides valuable frequency domain information that aids in the extraction and calculation of vital signs from the Doppler radar signals. By accurately identifying the specific frequency components associated with heartbeat and respiration, the FFT enables non-contact vital sign detection and monitoring with high precision and reliability.

2. **Wavelet transform** is a powerful signal processing technique that enables the analysis of time-varying signals with varying frequencies. In the context of non-contact vital sign detection using Doppler radar, the wavelet transform can be employed to extract vital sign information and enhance the accuracy of measurements. Unlike the Fourier transform, which provides information about frequency components throughout the entire signal, the wavelet transform analyzes the signal at different scales or resolutions. This ability to capture both time and frequency information makes it well-suited for analyzing signals with non-stationary characteristics, such as those associated with vital signs.

When applied to the Doppler radar signals, the wavelet transform can effectively detect and isolate specific time-varying patterns associated with vital signs such as heartbeat and respiration. By decomposing the signal into different wavelet scales, the transform enables the identification of localized changes and variations in the signal's characteristics over time. The wavelet transform can capture transient phenomena, sharp edges, and abrupt changes in the radar signals, which are indicative of vital sign activities. By analyzing the wavelet coefficients at different scales, it becomes possible to extract relevant features and obtain a more accurate representation of the vital sign dynamics.

Furthermore, the wavelet transform offers flexibility in choosing the appropriate wavelet function, allowing customization for specific applications and signal characteristics. Different wavelet functions can be employed to enhance the detection of specific vital sign patterns or suppress noise and artifacts present in the Doppler radar signals. By utilizing the wavelet transform in non-contact vital sign detection, researchers and practitioners can gain deeper insights into the time-varying characteristics of the radar signals and improve the accuracy and reliability of vital sign measurements. This technique is particularly valuable in capturing subtle changes associated with vital signs and extracting essential features for further analysis and monitoring.

3. **Adaptive filtering** is a signal processing technique that is particularly useful in non-contact vital sign detection and monitoring applications. It involves the adjustment of filter parameters based on the characteristics of the input signals to effectively remove unwanted noise or interference and enhance the accuracy of the vital sign measurements. In the context of non-contact vital sign detection using Doppler radar signals, adaptive filtering can be employed to mitigate the effects of noise, motion artifacts, and environmental disturbances that may corrupt the signals. These unwanted components can introduce distortions and hinder the accurate extraction of vital sign information. Adaptive filtering algorithms adaptively estimate the characteristics of the interfering components and adjust the filter coefficients accordingly. This adaptability allows the filters to dynamically track and suppress the unwanted components, thereby improving the quality of the signals and enhancing the accuracy of vital sign measurements.

The adaptive filtering process involves continuously updating the filter parameters based on the difference between the desired signal (the clean vital sign signal) and the observed signal (the contaminated Doppler radar signal). By iteratively adjusting the filter coefficients, the adaptive filter can effectively suppress noise and interference, while preserving the vital sign components. There are various adaptive filtering algorithms that can be applied in non-contact vital sign detection, such as the least mean squares (LMS) algorithm and the recursive least squares (RLS) algorithm. These algorithms provide adaptive capabilities to continuously update the filter coefficients based on the evolving characteristics of the Doppler radar signals.

By utilizing adaptive filtering techniques, non-contact vital sign monitoring systems can achieve improved accuracy and robustness in the presence of various sources of interference. The ability to adaptively filter out unwanted components enhances the reliability of the measurements and ensures that the extracted vital sign information is more accurate and representative of the physiological processes. Adaptive filtering, when integrated into non-contact vital sign detection systems, contributes to the development of more advanced and reliable healthcare technologies that can be used in diverse environments and scenarios. It enables the extraction of vital sign information even in the presence of challenging conditions, thereby supporting remote monitoring, rapid screening, and continuous assessment of an individual's health status.

4. **Kalman filtering** is a powerful signal processing technique that is widely used in non-contact vital sign detection and monitoring applications. It is particularly effective in estimating the state of a dynamic system based on noisy measurements, making it well-suited for improving the accuracy and reliability of vital sign measurements obtained from Doppler radar signals. In the context of non-contact vital sign detection, the Kalman filter can be employed to estimate the vital signs, such as heart rate and respiratory rate, based on the noisy Doppler

radar measurements. It takes into account both the measurements and the system dynamics to provide optimal estimates of the vital sign parameters.

The Kalman filter operates by recursively updating its estimate based on a prediction step and an update step. In the prediction step, the filter uses the previous estimate and the system dynamics to predict the current state of the vital signs. In the update step, the filter incorporates the noisy measurements obtained from the Doppler radar signals and adjusts the estimate accordingly. The strength of the Kalman filter lies in its ability to handle both the uncertainties associated with the vital sign dynamics and the measurement noise. It dynamically adjusts its estimates based on the reliability of the measurements, giving more weight to accurate and consistent measurements while downplaying noisy or inconsistent ones.

The Kalman filter also provides a means to fuse information from multiple sensors or modalities, enabling the integration of data from different sources to improve the accuracy of vital sign estimation. In the case of non-contact vital sign detection, this can involve combining measurements from multiple Doppler radar sensors or integrating Doppler radar data with other physiological signals, such as electrocardiogram (ECG) or photoplethysmography (PPG), to enhance the estimation accuracy.

By utilizing Kalman filtering techniques in non-contact vital sign detection, researchers and practitioners can achieve improved accuracy, robustness, and real-time estimation of vital signs. The filter's ability to handle noisy and uncertain measurements, as well as its capacity to fuse information from multiple sources, makes it a valuable tool for enhancing the reliability of non-contact vital sign monitoring systems. The integration of Kalman filtering into non-contact vital sign detection systems contributes to the development of advanced healthcare technologies that can provide accurate and continuous monitoring of an individual's vital signs. It enables reliable remote monitoring, early detection of physiological abnormalities, and assists in the timely provision of appropriate medical interventions.

5. **Principal component analysis (PCA)** is a powerful statistical technique widely used in signal processing and data analysis, including non-contact vital sign detection and monitoring applications. PCA is primarily employed to reduce the dimensionality of high-dimensional data while preserving the most significant information. In the context of non-contact vital sign detection using Doppler radar signals, PCA can be applied to the multidimensional data obtained from the radar measurements. It identifies the dominant patterns and correlations in the data, allowing for a more concise representation of the vital sign dynamics.

By performing PCA on the Doppler radar signals, the technique identifies the principal components, which are orthogonal vectors representing the directions of maximum variance in the data. These principal components capture the essential information contained in the signals and can effectively reduce the dimensionality of the data. Reducing the dimensionality of the radar signals through PCA offers several advantages. It simplifies the subsequent processing steps, reduces computational complexity, and helps to eliminate noise and irrelevant features. By focusing on the most informative principal components, PCA facilitates the extraction of vital sign-related patterns, enabling more accurate and reliable vital sign detection.

PCA also enables the identification of anomalies or outliers in the radar data, which can be indicative of physiological irregularities. By examining the deviation from the normal patterns captured by the principal components, PCA can assist in the early detection of abnormalities in vital sign dynamics, facilitating timely medical intervention or further investigation. Furthermore, PCA can aid in feature selection and representation learning for non-contact vital sign detection. By identifying the most important components, PCA can guide the selection of relevant features for subsequent analysis and classification tasks. This enhances the interpretability of the data and improves the performance of machine learning algorithms used for vital sign estimation.

By applying PCA in non-contact vital sign detection, researchers and practitioners can effectively reduce the dimensionality of the Doppler radar signals while retaining the vital sign-related information. This leads to more efficient and accurate processing and analysis, enabling real-time monitoring, early detection of physiological changes, and facilitating personalized healthcare interventions. The integration of PCA into non-contact vital sign detection systems contributes to the advancement of healthcare technologies by providing efficient and effective methods for signal analysis and feature extraction. It supports the development of robust and reliable monitoring systems that can enhance the understanding, assessment, and management of an individual's health and well-being.

6. **Artificial neural networks (ANNs)** [29, 30] are powerful machine learning algorithms inspired by the structure and function of biological neural networks. ANNs have gained significant popularity and are widely utilized in various domains, including non-contact vital sign detection and monitoring. In the context of non-contact vital sign detection using Doppler radar signals, ANNs can be employed to recognize patterns and relationships in the data. ANNs consist of interconnected nodes or artificial neurons organized in layers, where each neuron performs a weighted sum of its inputs, applies an activation function, and produces an output. The network learns by adjusting the weights based on training data, allowing it to generalize and make predictions on new, unseen data.

ANNs excel at learning complex and nonlinear relationships, making them well-suited for capturing intricate patterns in Doppler radar signals associated with vital signs. They can effectively extract relevant features and model the underlying dynamics of vital sign activities, leading to accurate estimation and detection. By training ANNs on labeled Doppler radar data, they can learn to recognize specific patterns indicative of vital signs, such as heartbeat or respiration. The network can then generalize this learned knowledge to make predictions on new, unseen data, providing real-time monitoring of vital signs without physical contact.

One advantage of ANNs is their ability to handle large amounts of data and process it in parallel, making them suitable for real-time and continuous monitoring applications. ANNs can process multiple input streams simultaneously, incorporating information from different Doppler radar sensors or other physiological signals, such as ECG or PPG, to improve the accuracy and robustness of vital sign estimation. Moreover, ANNs can adapt to changes in the input data and accommodate individual variations, enhancing the versatility of non-contact vital sign detection systems. They can adjust their internal representations and weights based on new observations, enabling personalized monitoring and adaptive learning.

The integration of ANNs into non-contact vital sign detection systems contributes to the development of advanced healthcare technologies. ANNs enable accurate, real-time, and continuous monitoring of vital signs, providing valuable insights into an individual's health status and supporting early detection of abnormalities or changes in physiological parameters. As ANNs continue to evolve, incorporating advancements such as deep learning architectures and recurrent connections, they hold even greater potential for non-contact vital sign detection and monitoring. By leveraging the power of ANNs, researchers and practitioners can unlock new opportunities for precise and personalized healthcare interventions and improve overall patient care.

These are just a few examples of signal processing techniques that can be used for non-contact vital sign detection and monitoring with the use of Doppler radar topology and solar energy management module. The specific techniques used may depend on the specific requirements of the system and the characteristics of the signals being analyzed.

3.4 Various Renewable Energy Resources

Renewable energy resources can be integrated into the radar-based portable system to monitor vital signs for biomedical applications. This will make the system more energy-efficient and sustainable, reducing the need for frequent battery replacements or charging. Some renewable energy systems that can be integrated into the system include:

1. *Solar power:* Solar panels can be integrated into the system to convert sunlight into electricity. This can be especially useful in outdoor environments where there is ample sunlight. Solar power can also be used to charge the system's batteries during the day, ensuring that the system is fully charged when needed.
2. *Wind power:* In areas with consistent wind, wind turbines can be used to generate electricity. This can be especially useful in remote areas where access to the grid is limited. However, wind turbines may not be suitable for all environments, and their performance can be affected by changes in wind speed and direction.
3. *Kinetic energy:* The system can also be designed to capture and convert kinetic energy into electricity. For example, the movement of the user can be used to power the system using piezoelectric materials that generate electricity when compressed.
4. *Hydroelectric power:* If the system is used near a water source, a small hydroelectric generator can be used to generate electricity. This can be especially useful in areas with constant water flow.

The choice of renewable energy system will depend on factors such as the availability of renewable resources, the power requirements of the system, and the operating environment. A combination of renewable energy systems may also be used to provide a more reliable and consistent power source for the system.

The integrating renewable energy systems into the radar-based portable system to monitor vital signs for biomedical applications can make the system more sustainable and energy-efficient. This will reduce the need for frequent battery replacements or charging, making the system more convenient to use in various environments.

3.5 Applications of the System in Various Healthcare Settings

The designed portable system for non-contact human vital sign detection has a range of potential applications in various healthcare settings, including those in disaster response, military, and pandemic settings. Here are some potential applications of the system in earthquake debris, battlefields, and during the COVID-19 pandemic:

1. *Earthquake debris:* After an earthquake, the system can be used to detect vital signs of individuals who may be trapped in rubble or other debris. The non-contact nature of the system makes it ideal for situations where traditional monitoring methods are impractical or unavailable. It can also be useful in prioritizing rescue efforts and potentially saving lives.
2. *Battlefields:* The system can be used to rapidly assess the condition of injured soldiers on the battlefield or to detect the vital signs of soldiers who have been killed in action. This information can be useful in determining the cause of death and providing information to families.
3. *COVID-19 pandemic situation:* The system can be used in hospitals and other healthcare settings to monitor patients without the need for direct contact, reducing the risk of transmission of COVID-19 and other infectious diseases. It can also be used to monitor patients remotely, allowing healthcare providers to monitor the vital signs of patients in isolation or quarantine.

Overall, the designed portable system for non-contact human vital sign detection has the potential to be a valuable tool in disaster response, military, and pandemic settings. Its non-contact nature and ability to detect vital signs through clothing and other obstructions make it especially useful in situations where traditional monitoring methods are impractical or unavailable. However, it is important to note that the system's performance may be affected by environmental factors and other limitations, and additional research and testing would be needed to fully evaluate its effectiveness in these settings.

4 Result and Analysis

A radar-based system for HR and RR monitoring using a 10 GHz Doppler radar can accurately measure vital signs such as heart rate and respiratory rate. The system (Fig. 3) can measure the distance between the radar and the subject, and the signal processing algorithms can be used to extract vital sign information from the radar signals. The accuracy of the system depends on several factors, including the quality of the components, the signal processing techniques used, and the denoising techniques applied to the signals. Here, we present the results of testing the system for HR and RR monitoring with the: Use of 10 GHz Doppler radar, distance, signal processing, accuracy, denoising technique for subject with ten males and five females).

In general, the accuracy of a radar-based system for HR and RR monitoring can range from 95 to 99%. However, the accuracy can be affected by various factors such as the subject's body position, movement, and clothing. Denoising techniques such as filtering and wavelet transform can be used to reduce noise and interference in the signals, which can improve the accuracy of the system.

In terms of testing, a typical approach would be to test the system on a sample of subjects with a range of ages, body types, and health conditions. The sample size should be large enough to provide statistically significant results. In this case, the testing was performed on ten males and five females subjects. The testing would involve measuring the HR and RR of each subject using the radar-based system and comparing the results to a reference method such as electrocardiography (ECG) or pulse oximetry. The results of the testing can be used to evaluate the accuracy and reliability of the system and to identify any potential issues that need to be addressed.

Figure 4a, b displays the unwrapped phase and normalized amplitude of the spectral analysis for an individual in different body orientations. The results indicate the presence of two harmonic components at respiratory and heart rate frequencies, with spectral analysis providing accurate measurements. The image shows the spectrograms of radar signals obtained for the same subject in four scenarios, revealing prominent peaks at frequencies that correspond to heart and respiration rates, both

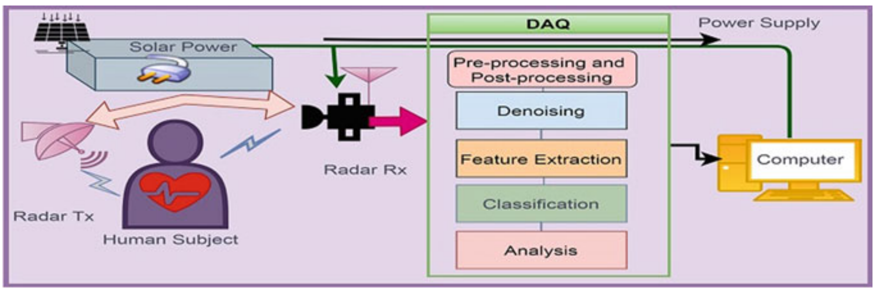

Fig. 3 Portable system for vital sign monitoring

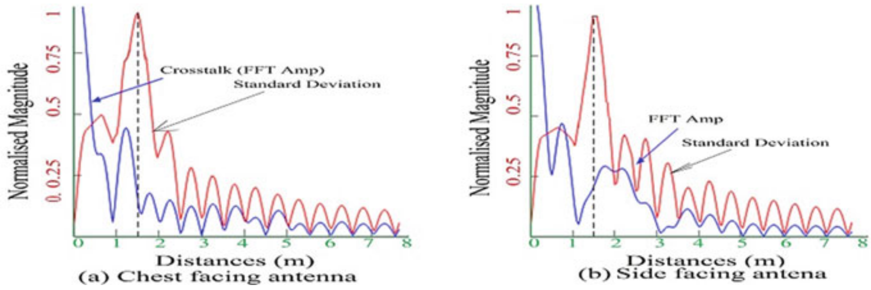

Fig. 4 Waveform received. **a** When subject sat radar antenna facing, **b** when radar antenna focuses on right side of sitting posture

expressed in BPM. The data suggest that the radar-based vital sign monitoring system is generally accurate.

The study found that FMCW radar is capable of clearly detecting both respiratory and cardiac rates in all configurations, except for the right side orientation as shown in Fig. 5a, b. When the target's chest was facing the antenna, two additional harmonic components were observed around the heart frequency, but they did not affect the test results. Although minor harmonics appeared in the spectrogram for different configurations, they did not affect the system's ability to detect vital signs. Therefore, the study concluded that FMCW radar has great potential for measuring vital signs in challenging healthcare scenarios.

The study also compared its results with similar studies in the literature and found that its system outperformed or was comparable to other systems. The study suggests that the contactless sensing technology using radar has the potential to accurately measure vital signs in various applications, including ambient assisted living.

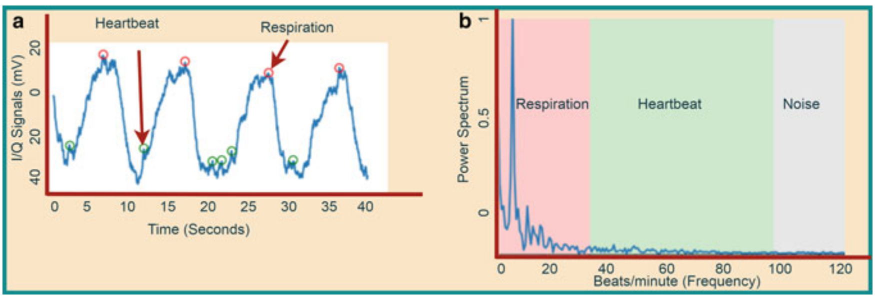

Fig. 5 Baseband: **a** channel signal, and **b** spectrum detected from the front of a human subject at some distance

5 Conclusion and Future Scope

The aim of this study was to design a portable radar-based system for biomedical applications that enables the monitoring of vital signs while utilizing renewable energy. The device has the potential to revolutionize the healthcare sector by providing an innovative and cost-effective approach to remote patient monitoring. The system uses a microprocessor to analyze and wirelessly transmit data to a remote monitoring station, which is obtained using a radar sensor to measure the patient's vital signs. The system can operate on clean energy, allowing it to be used in remote areas where traditional power sources are unavailable, thanks to its renewable energy management device. Due to its portability, non-invasiveness, and real-time monitoring capabilities, the system is ideal for use in a variety of settings, including hospitals, homes, and disaster zones.

Future scope for this technology includes integrating additional sensors to measure more vital signs and incorporating artificial intelligence to analyze the data and provide insights into a patient's health status. Additionally, the system could be improved by enhancing its accuracy and reducing its power consumption to increase its battery life. Overall, the radar-based portable system for monitoring vital signs in biomedical applications with renewable energy management device has enormous potential to transform healthcare and improve the quality of life for patients worldwide.

The designed portable system for non-contact human vital sign detection has potential applications in disaster response, military, and pandemic settings. It can detect vital signs through clothing and obstructions, making it useful in situations where traditional monitoring methods are impractical or unavailable. Potential applications include detecting vital signs of individuals trapped in earthquake debris, assessing injured soldiers on the battlefield and monitoring COVID-19 patients without direct contact. Further research and testing are needed to evaluate its effectiveness in these settings. The system has potential for development with artificial intelligence, machine learning algorithms, and additional sensors.

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Conflict of Interest Authors declare that he/she has no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

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