



Real-Time Contactless Breathing Monitoring System Using Radar with Web Server

Alcides Bernardo Tello^{1,2,3(✉)}, Shuyuan Yang¹, Yonel Chocano Figueroa³,
and Anderson Daniel Torres Bernardo⁴

¹ School of Artificial Intelligence, Xidian University, Xian 710071, China
abernardo@udh.edu.pe

² Universidad de Huanuco, Huanuco 10001, Peru

³ Universidad Nacional Hermilio Valdizan, Huanuco 10001, Peru

⁴ Ming Chuan University, Taoyuan 333, Taiwan

Abstract. As an innovative monitoring system, methods for non-contact human vital signs detection have been on the rise recently. Although different technologies use different principles, the chief purpose is physical health assessment. Nevertheless, in practice, the position and angle of an individual are not always in an ideal condition for the current vital signs monitoring programs to obtain reliable information. Therefore, this study proposed a method of automatic gain of low-frequency signals used to track the monitoring signals of the human **vital** signs dynamically. This study also designed a web system that processes and stores millimetre-wave radar technology data to detect the patient's heartbeat and breathing rate with a touch-free approach. Additionally, this system proved to be helpful for non-sensory perception and information gathering in daily life. Afterwards, the algorithm that monitors the vital signs analyses the breathing pattern, heart rate, and their variations after the human signs enter a static state. The reference design was a customised respiratory and heart rate signal extraction based on the STM32F401 chip and 24G Doppler radar sensor. Our method has successfully detected the presence of apnea events and has thus alerted the corresponding individual accordingly. Ultimately, the contactless method is particularly suitable for the pandemic as it is the best way to prevent the transmission of infectious illnesses; furthermore, it provides a steady stream of data to be stored in the server for further use and analysis.

Keywords: Radar · Millimetre radar · Vital signs · Heartbeat rate · Breathing rate · Web server

1 Introduction

Monitoring breathing rate is crucial to a health examination, even more so if we store a steady stream of data in a web server, and an example of this is recording heart rate and

The original version of this chapter was revised: the affiliations of the author and co-authors presented incorrectly. This was corrected. The correction to this chapter is available at https://doi.org/10.1007/978-3-031-25191-7_59

breathing. Fortunately, breathing has a recognisable periodic pattern with variations in period and amplitude [1], which can be used for further health analyses.

There are two main types of methods for measuring breathing and heart rate [2]: contact methods such as nasal pressure transducer sensors and non-contact methods such as thermal and optical sensors. Touch-free methods are equivalent to keeping physical distancing. In this regard, this contactless method is suitable for the pandemic as it is the best way to prevent the transmission of infectious illnesses such as COVID-19. Therefore, this study focused on contactless respiration monitoring as a vital sign in various medical situations.

A radar detects the distance and location of an object from a given point in space based on echoes; furthermore, it even captures the shape and size of the target; which has been in use for a long time [3]. Still, its applications can be fresh and unique at any time. Particularly, in recent decades, its application has emerged in the healthcare sector [4–6], rendering it a relevant subject of study for researchers and students in computer science, biomedical and electronic engineering.

In a non-hospital setting, vital signs include respiration, pupils, pulse, skin and blood pressure [7, 8]. Therefore, healthcare providers must develop devices to examine these vital signs safely and efficiently. This study designed a web system that processes and stores millimetre-wave radar technology data to detect and analyse the patient's heartbeat and breathing rate with a contactless approach.

Research demonstrates that breathing detection helps predict patients at risk of cardiac arrest and other diseases [9, 10], as the body maintains oxygen delivery to the tissues; thus, this study focused on breathing monitoring. Our contribution included radar-specific signal processing and algorithms applied to radar data.

Besides developing the web server, the chief contribution is solving the existing signal loss when there is motion in the field of vital sign detections.

Regarding the organisation of the rest of this article, the second section provides the hardware components in the system. The third section presents the validation of this project, followed by the discussion section. Finally, it offers a conclusion and provides prompts for future works.

2 The System Design

The system comprises hardware and software as follows:

2.1 Hardware Components

Figure 1 shows the overall picture of the system. The system comprises four parts, the first three of which are hardware devices for vital sign detection. These parts collect and analyse speed signals in their jurisdictional space using sensors. Then, these signals are forwarded as data to a web server, which stores the dataset for further processing.

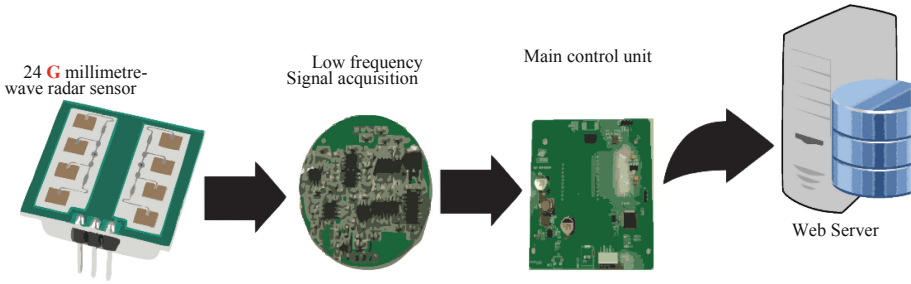


Fig. 1. Hardware block diagram for the vital sign detection.

24G Millimetre Wave Radar Sensor. Figure 2 shows the front side and backside view of the 24G millimetre wave radar sensor. It is a low-cost 24Ghz ISM band single-channel radar transceiver with a planar microstrip antenna structure, independent transmitting and receiving channels, and a single intermediate frequency signal output. The primary usage of this radar sensor is for the fast detection of information from close-range targets. Its size is 25 mm in length, 25 mm in width and 7 mm in height. **Front view Back view.**

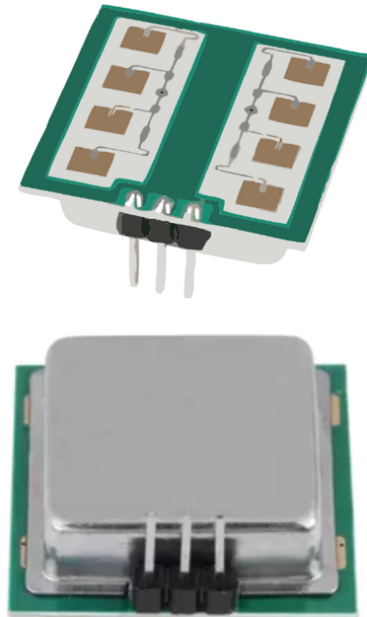


Fig. 2. Millimetre wave radar sensor.

The Low-Frequency Signal Acquisition Module. Figure 3 depicts the low-frequency signal acquisition module, ranging from 0.6–3Hz within the monitoring realm of the radar. The primary function of this module is the extraction of the radar intermediate

frequency signal of the sensor and low-frequency signals such as respiration and heart rate extracted from the space surrounding the radar’s signal. Then, depending on the distance of the moving target in the area, it automatically amplifies the low-frequency signal.

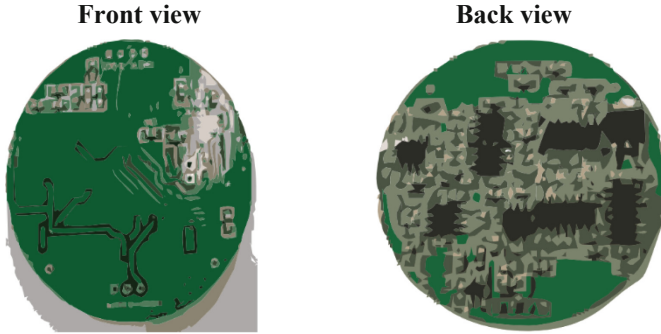


Fig. 3. Low-frequency signal acquisition module.

Figure 4 displays the circuit design of the low-frequency signal acquisition module, which uses NE5532 as the front-end signal amplification and fidelity. STC12C5204AD serves as automatic signal amplification to ensure output amplitude to the STM32 chip, thus helping it solve the respiration and heart rate algorithm.

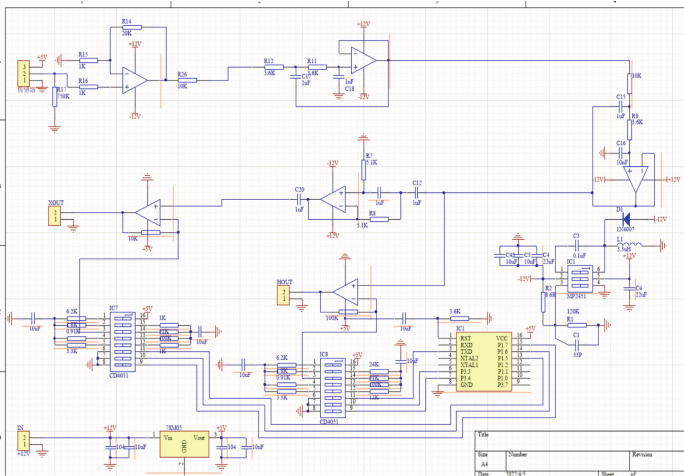


Fig. 4. Circuit design of low-frequency signal acquisition module.

Main Control Unit. Figure 5 shows the master MCU, which reads ADC analogue signals through GPIO. This module converts the analogue signal of the low-frequency signal acquisition module into a digital signal.



Fig. 5. The main control.

The Enclosure. Figure 6 shows the shell design of the product. This enclosure contains the primary control circuit that can adjust the angle to reach the target. This end-product is ready to measure the fluctuation of the chest cavity and the change in the heartbeat speed when the sensor is pointed at the chest cavity.



Fig. 6. The product enclosure.

2.2 The Server and Software

Figure 7 presents the system's architecture from data acquisition to storage in a database. First and foremost, there is a computer housing the database server. This structure belongs to the client-server architecture, with a centralised server. The server also performs the required processing and returns the data in the format required.

Heart and Respiratory Rate Extraction. Since GPIO is used to connect the low-frequency signal processing module and the master chip, the chip uses the ADC function to convert the analogue signal of the pin port into a digital signal. The program uses a timer to obtain the IO port number. The purpose of using this program is to get digital

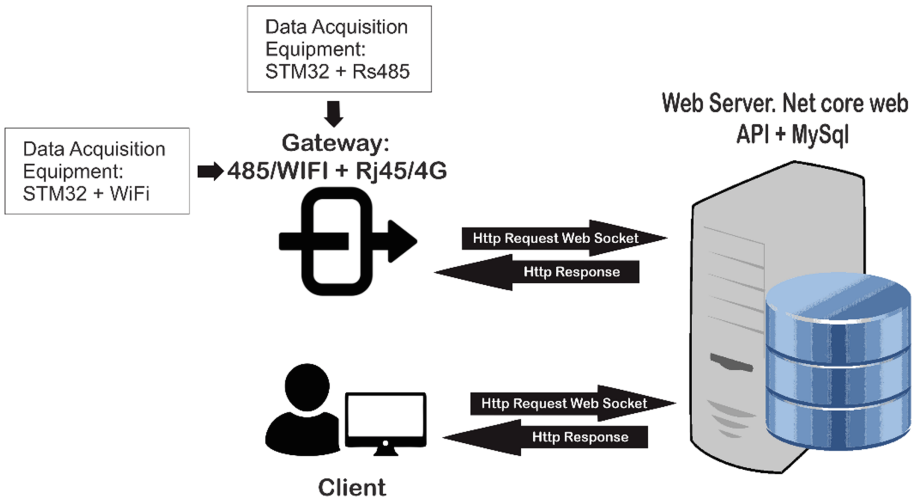


Fig. 7. Structure of the system for data acquisition, storage and processing

quantity every 20 ms. Data calculation is performed after continuous collection of 1000 data. Figure 8 shows the heart rate signal after filtering. Since the breathing rate is lower, we can detect it using this characteristic.

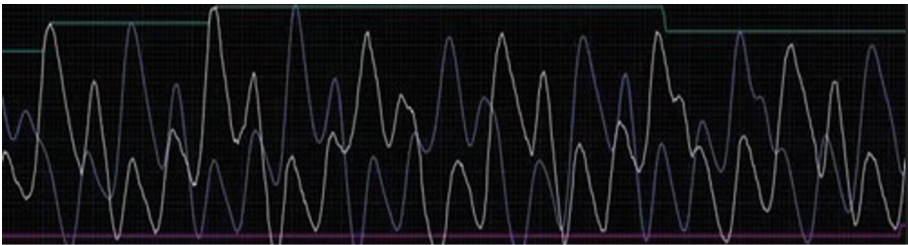


Fig. 8. AD signal processing

The signal changes during AD signal processing, and a superposition of the respiration and the heart rate signals occurs. The heart rate is the higher frequency; each crest represents the heart rate. The signal is a superposition of breathing and heart rate signals, and it is found by filtering out high-frequency components higher than the heart rate signal. Therefore, the algorithm that searches for peaks finds the heart rate signal. This algorithm also performs a Fast Fourier transform on the original signal to get a signal with a lower frequency than the heart rate. The high-frequency component of the original signal increases when the person is in motion. On the other hand, the signal gets jumbled when the individual is in motion. When no one is in the surroundings, the signal appears in a straight line with no noticeable change. In the circuit design, the chip collected two signals, with one port for respiratory signal and one port for heart rate signal.

3 Validation

This study chose adults with apnea to monitor their sleep during the night for data acquisition in a non-medical environment. The distance between the participants and the radar was one and a half metres. The radar signals allow continuous data collection, even in the darkness. Then, the dataset was used to extract the breathing rate and determine the breathing patterns.

Normal breathing presents a periodic pattern within a specific range [11], exhibiting a certain number of respiratory cycles in one minute with harmonic components. Figure 9 shows the respiratory signal after filtering, demonstrating the combined program and the parsed signal. The processed value of the breathing is named the filtered-breathing signal, and it displays the signal from a normal breath, followed by that obtained from snoring and apnea. In the first step, the original signal of breathing is obtained in the program. Next, it is read through the computer serial port. The value of the raw breath signal is named the unfiltered-breath signal.

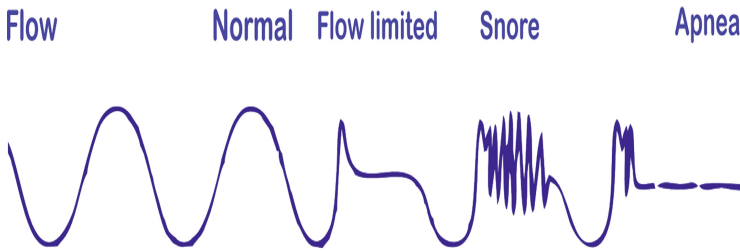


Fig. 9. Respiration signal after filtering.

As shown in Fig. 9, FFT can carry out Fourier transform to get the frequency distribution and obtain the specific respiration value. The collected respiratory signal for a time interval also judges the peak and provides the particular respiratory signal value. Additionally, the ripple of the signal can tell us about the human body's motion. Therefore, in this program, the variance of numerical changes within a few seconds determines whether the person is moving since the original signal changes dramatically due to the person's motion; thus, using variance was the quickest solution.

Based on this signal, the breathing value is obtained. If the breathing is stable for a long time, then the person is in a sleep state. Such a result also highlights the time of inhalation and exhalation. By analysing the variability of respiration, it is possible to obtain more information about the health of the lungs.

4 Discussion and Results

Ultimately, the study confirms the feasibility of monitoring breathing rates using a radar. It also affirms that signal processing methods help extract the breathing rate from the dataset collected by the radar and stored in the architecture provided in Fig. 7.

Non-contact monitoring juxtaposed with sensor-based monitoring reveals numerous advantages, regardless of the darkness, time and place.

Measuring breathing has evolved from placing the hand close to the nose to placing a thermistor in a nostril to detect exhalation. However, in critical times similar to the COVID-19 pandemic, physical contact [12, 13] with patients poses jeopardy to health, and the elderly might need assistance from a distance. Therefore, it is necessary to enhance non-invasive methods. Furthermore, invasive techniques cause distress, which in turn yields inaccurate measurements. In this sense, various technologies have successfully proved the efficacy of non-contact in-home monitoring techniques; for example, the pyroelectric Infra-Red Detector is used to detect when the elderly are in motion [13].

Advances in computing technology have led to even better breathing monitoring. However, it has not yet reached maturity for a safe healthcare environment. Thus, there are opportunities for boosting breathing measurements as studies are still progressing to develop more effective breathing monitoring methods.

Senescence is increasingly becoming a major societal challenge. In this study, we found that recording vital signs can help to monitor medical problems and even forecast many diseases. However, capturing such information is a challenging task. Therefore, industry and academia have proposed diverse approaches, including the miniaturisation of wearable devices [14, 15]. Notwithstanding those advances, wearable sensors, which are prominent currently, are not suitable for everyone. Moreover, like the elderly or infants, some patient groups might feel uncomfortable with wearable devices. Therefore, non-wearable devices may be a suitable solution for them.

5 Conclusion

In light of the study's findings, traditional non-continuous measurements using sensors have encumbered the progress of vital signs monitoring systems. Thus, when appropriately used, radar can provide a solution to this hindrance. Additionally, it offers an unobtrusive method of breathing detection, which is a practical approach for the elderly and infants. Moreover, the contactless method designed in this study befits the distancing requirement during pandemics as the best way to prevent the transmission of infectious illnesses; furthermore, a steady stream of data is stored in the server for further use and analysis.

Due to ongoing restrictions on public settings such as hospitals, no contact is suitable for healthcare systems. Accordingly, families can install the system designed in this study; then, the algorithm can determine the individual's sleeping pattern during the night; in return, this can indicate if there is, for example, apnea or any other cessation of breathing.

6 Future Work

Further tests and applications include detecting home-based activities that are not restricted to heart and respiratory rate. Hence, there are extensive opportunities to improve other non-contact methods for measuring and monitoring activities for healthcare benefits. Additionally, recording and storing data is key to future research in the field, mainly when it is a touch-free approach.

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