The Application of FMCW Radar Technology in Human Heartbeat Respiration Monitoring

Weichen Tang*

Department of College of Electronic Science & Engineering, Jilin University, Changchun, China

*Corresponding author: tangweichen@ldy.edu.rs

Abstract. In recent years, FMCW radar technology has become a research hotspot in the field of non-contact monitoring of vital signs. Compared with traditional contact sensors, FMCW radar-based monitoring devices can detect vital signals such as respiration and heartbeat without direct contact, providing a more convenient detection experience, and are expected to become the leading vital sign monitoring technology. This technology has a wide range of applications in anti-terrorism detection, medical monitoring, disaster rescue and autonomous driving. FMCW radar has the advantages of non-contact, long-range detection capability, anti-jamming capability, multi-parameter monitoring, and real-time performance, which makes it widely used in the fields of healthcare, security and intelligent transportation, providing a better guarantee for people's lives and health. This study explores the application of FM wave radar technology in human heartbeat respiration detection and finds that its signal processing process is complex, involving steps such as false alarm judgment, signal processing and frequency extraction, which requires precise signal processing and algorithm design to obtain accurate life information. Current technical challenges include optimising signal processing algorithms, miniaturising devices and reducing costs. Future research will focus on improving the accuracy and reliability of monitoring, expanding the application scenarios, and promoting the commercialisation and diffusion of the technology.

Keywords: FMCW radar; heartbeat monitoring; respiratory monitoring; non-contact monitoring; vital signs.

1. Introduction

With the rapid development of modern technology, there is a growing demand for health monitoring technologies, especially in non-invasive and remote monitoring technologies. Traditional methods of vital signs monitoring, such as ECG and respiratory belts, are highly accurate but limited by the size of the equipment, the environment in which it is used, and the comfort of the patient. In recent years, FMCW radar technology has been widely used in heartbeat and respiratory rate monitoring due to its non-contact monitoring characteristics.

FMCW radar technology uses the transmission and reception of radio waves to monitor the vital signs of a target by analysing the characteristics of the reflected waves. The technology is suited for a wide range of environmental circumstances, including adverse weather and illumination conditions, and can penetrate clothing and other impediments to enable high-frequency monitoring of minute body motions. In addition, the applications of FMCW radar technology are not limited to healthcare, but extend to other areas such as security monitoring, sports science, sleep analysis and car driver monitoring [1].

However, despite the fact that FMCW radar shows great potential for non-contact monitoring, its technology still faces a number of challenges, including the optimisation of signal processing algorithms, suppression of multipath interference, miniaturisation and cost-effectiveness of devices [2]. In order to encourage more research and application of FMCW radar in the field of vital sign monitoring, this paper reviews the current state of the technology's application in the monitoring of human respiration and heartbeat, analyzes its key technologies and the major obstacles it faces, and projects its future development trend.

2. Relevant Theory

2.1. Principle of Operation of FMCW Radar

Frequency Modulated Continuous Wave (FMCW) radar works by transmitting radio waves whose frequency varies linearly with time and receiving an echo signal that is reflected back from the target. The transmitted signal is mixed with the received echo signal in a mixer to produce a differential beat signal whose frequency is proportional to the distance to the target. By analysing this differential beat signal, the distance and speed of the target can be accurately calculated [3]. FMCW radar has significant advantages in close-range measurements due to its high resolution, low power requirements and simple signal processing, and with technological advances. Its cost has been reduced and its size has been reduced, which has led to the expansion of its application areas into a wide range of fields, such as medical monitoring, automotive safety, and sports science.

2.2. Signal Processing for FMCW Radar

Traditional FMCW radar structure **is** shown in Figure 1, the radar contains a transmitter, receiver, mixer and analog-to-digital converter and other parts of the signal generator to generate FMCW waveforms, all the targets by the radar transmit beam irradiation will reflect radar waves, radar receivers to receive the reflected echoes, first of all, through the mixing de-skewing operation, the RF signal is converted to the baseband frequency signals, that is, often referred to as the difference between the beat signal, the differential beat signal contains all the information about the target, such as distance and speed and angle. The differential beat signal contains all the information of the target, such as distance, speed, and angle, through the processing of the differential beat signal, the required information can be obtained [3].

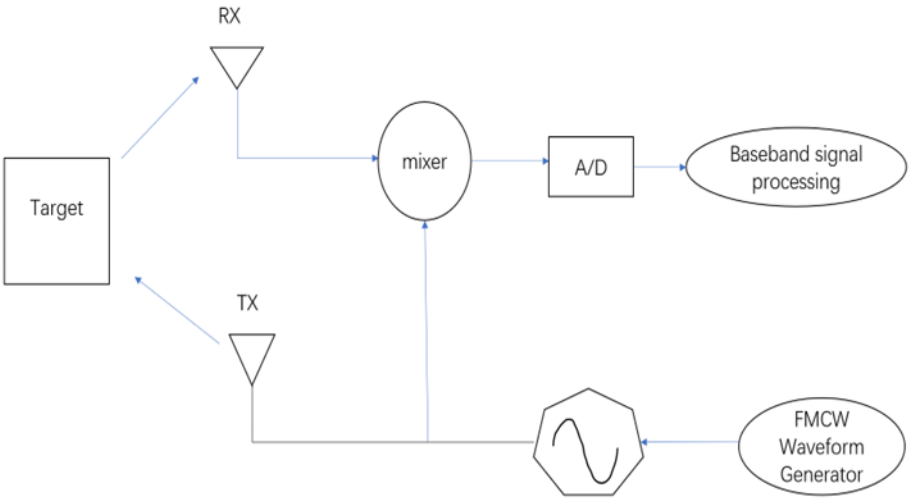


Figure. 1 Traditional FMCW radar structure.

3. FMCW Radar Application

3.1. Practical Applications

There have been many practical examples of the use of frequency-modulated continuous wave (FMCW) radar in heartbeat and respiration monitoring. Texas Instruments (TI) has developed a millimeter-wave radar system based on the IWR6843ISK and DCA1000EVM for extracting vital sign signals from the human body. The system extracts respiratory and heartbeat signals by transmitting frequency-modulated radio waves and receiving the signals reflected back, which are then processed by algorithms. It includes steps such as pre-processing, rough human positioning, phase extraction and unwinding, phase differencing, noise removal, and band-pass filter output of

respiration and heartbeat signals. The instrument is widely used in medical health monitoring, sleep analysis, and cardiopulmonary function assessment, and has the advantage of non-contact monitoring.

Certainly, some automotive manufacturers have begun to use FMCW radar technology to monitor drivers' vital signs to ensure driving safety. Usually including the IWR1642EVM evaluation module and corresponding signal processing algorithms, data processing through tools such as MATLAB, and constantly detecting the driver's heart rate and respiratory rate, the early warning system can remind the driver to take a rest or take emergency measures in time to reduce the occurrence of traffic accidents. For example, on 3 January 2024, Aeva announced that it has become the preferred LiDAR supplier to the world's top automakers. This success marks Aeva's position as a trusted Tier 1 supplier to the automotive industry and is a significant milestone in the transition to FMCW technology in the automotive manufacturing industry.

In addition, the smart home sector is beginning to introduce FMCW radar technology for the health monitoring of family members. The development trend of the smart home is from passive to active, and radar sensing, especially millimetre wave radar sensing in the smart home applications are highly respected, in the light of the exhibition: Yunfan Ruida, easy to explore, spaced out, and several other leading radar sensing solution providers are all out to show their products and solutions, and the other millimetre wave radar in the smart home in the field of lighting, recreation and health care, security and other areas will be widely used [4]. These devices can monitor the health of family members around the clock without interfering with daily life. Through the built-in small FMCW radar module, the vital signs data are collected and analysed in real-time, and the respiratory and heartbeat signals are separated by a specially designed band-pass filter. It is suitable for health monitoring of the elderly, children, and family members who need special care, detecting abnormalities and providing early warnings promptly.

In hospital environments, FMCW radar is used to monitor the vital signs of critically ill patients in real time. This type of monitoring not only reduces the workload of medical staff but also improves the accuracy and real-time monitoring. Due to its non-contact nature, the FMCW radar is particularly suitable for sterile environments, such as intensive care units (ICUs), and also avoids causing discomfort to patients. By monitoring the patient's heartbeat and respiratory rate in real-time, the system can automatically record vital signs data and generate reports to help doctors make timely diagnoses and adjust treatment plans.

3.2. Experimental Research and Performance Analysis

Among many experiments, Yang Tianhong, Qu Lele establishment an experimental model [5], for multi-target vital signs detection as an application scenario, using the MIMO FMCW mm-wave radar platform to design multi-target vital signs detection experimental case, through the setup of the radar system and the return data acquisition, the target distance angle estimation, the digital beam formation and the detection of vital signs and other content, to achieve the complete process from radar return data acquisition to signal processing. to the complete process of signal processing, the experiment can give readers a perceptual understanding of the radar system, but lacks high precision and low computational complexity, and did not achieve a low-cost radar chip for millimetre-wave radar health monitoring into the life scene to provide the possibility.

The main problem lies in the vital signs detection, the electronic noise in the radar system and the stationary target in the surrounding environment The side flap signal will introduce a DC offset in the slow time-dimensional signal B(m), and the DC offset component will affect the accuracy of the phase signal extraction, so the DC offset correction must be carried out before extracting the phase signal. After DC offset correction, in order to avoid phase winding, the phase signal is obtained using an improved differential cross-multiplication algorithm. According to the linear relationship between the phase signal and the human thoracic microdisplacement signal, the thoracic displacement signal can be obtained [6].

4. Challenge

4.1. Signal Processing Complexity

The signal processing algorithm of FMCW radar is relatively complex and requires multiple processing of the raw data to extract accurate vital sign information. This includes multiple steps such as phase extraction, noise removal, and bandpass filter design. Due to the small changes in the vital sign signals, the accuracy of the algorithm is very demanding, and any small errors may affect the accuracy of the final results.

4.2. Environmental Interference Suppression

Interference sources like signals from other electronic devices and metal reflections in the actual application environment can affect the FMCW radar. These interferences can seriously affect the quality of the radar signal, making it difficult to accurately extract vital signs signals. How to effectively suppress these interferences and improve the robustness of the system is an important challenge currently faced [7].

4.3. Hardware Equipment Limitations

Hardware devices for FMCW radar, especially high-frequency radar modules, are still large and costly. This limits its application in portable and consumer devices. The power consumption and heat dissipation problems of the devices are also key constraints to their prolonged operation [8].

4.4. Multi-target Monitoring Problem

When there are multiple targets in the monitoring scene, the FMCW radar needs to be able to accurately distinguish and track the vital sign signals of each target. This puts higher requirements on the signal processing algorithm. It is a technical challenge to avoid signal confusion and improve the accuracy of monitoring in multi-target situations [9].

4.5. Limitations of Non-contact Monitoring

Although non-contact monitoring brings a lot of convenience, there are some limitations, such as the limitation of monitoring distance and the limitation of penetration ability. The monitoring results may be affected by factors such as target motion and attitude changes, which need to be compensated accordingly in the algorithm [10].

5. Conclusion

This paper reviews the current status and progress of the application of FMCW radar technology in heartbeat and respiration monitoring, analyses its working principle, key technologies, and challenges, and discusses the future development trend. It is shown that FMCW radar can effectively penetrate obstacles such as clothing and achieve real-time monitoring of heartbeat and respiration rates, which is of great significance in the fields of healthcare and safety monitoring, etc. FMCW radar shows great potential in heartbeat and respiration monitoring applications, but challenges still need to be overcome and the technology continuously optimised and improved to achieve widespread and mature applications. Future research will focus on improving the accuracy and reliability of monitoring, expanding application scenarios, and facilitating the commercialisation and diffusion of the technology.

References

[1] Kui Zheng Li. Research on Non-contact Respiration and Heart Rate Monitoring Algorithm Based on 77G FMCW Radar. 2022 2nd International Conference on Consumer Electronics and Computer Engineering (ICCECE), 2022.

[2] Yuan Deren. Research on human life signal detection technology based on millimetre wave radar. Ganan Teachers University, 2022.

[3] Qu Lele, Liu Shujie, Yang Tianhong, Sun Yanpeng. Multi-channel based life signal extraction from FMCW radar. Journal of Electronics & Information Technology, 2022, 4: 1318-09.

[4] AIOT Xingtu Research Institute. 2022 Millimetre Wave Radar Industry Analysis Report. 2022.

[5] Yang Tianhong, Qu Le. Experimental design of human vital signs detection based on FMCW millimetre wave radar. RESEARCH AND EXPLORATION IN LABORATORY, 2024, 6.

[6] Suisbiyanto Prasetya, Aloysius Adya, Pramudita Yuyu Wahyu. Effect of Angle Detection on Respiration Vital Sign Measurement Using FMCW Radar. ISAP, 2023.

[7] Zhipeng Gao, Yuhao Wang, Senior Member, IEEE, Xiaodong Liu, Student Member, IEEE, Fuhui Zhou, Member, IEEE, Kai-Kit Wong, Fellow, IEEE. FFDNet-Based Channel Estimation for Massive MIMO Visible Light Communication Systems. arXiv, 2022.

[8] Zhang Rongtao. Research on key technologies of cellular structure and 5G wireless communication network. INFORMATION & COMMUNICATIONS, 2020, 2: 213-02.

[9] Jiang Liu, Yuming Liu, Yunxuan Wang, Yating Chen, Tianxiang Zhou, Yan Huang. Deep Learning Approach for Gesture Recognition on Millimeter-Wave Radar. 2022 International Conference on Microwave and Millimeter Wave Technology (ICMMT), 2022.

[10] Yan Huang, Lvhongkang Lan, Yang Yang, Jiang Liu, Kun Deng, Yuming Liu, Kaihang Zheng. Automotive Millimeter Wave Radar Imaging Techniques. 2023 International Conference on Microwave and Millimeter Wave Technology (ICMMT), 2023