A review of millimeter-wave radar research

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Summary: With the rapid development of scientific research and the maturity of technology, millimeter-wave radar has become the focus of research in industrial production, national defense construction and other fields because of its high precision and high applicability. This paper introduces the application fields and algorithm development of millimeter wave radar, expounds the common application scenarios of millimeter wave radar, and gradually elaborates the development and update of radar detection algorithm, on this basis, the new research direction of millimeter wave radar and the improved algorithm idea of FMCW millimeter wave radar detection algorithm are proposed.

Keywords: millimeter wave radar; radar algorithm; Radar research

1. Introduction

In recent years, millimeter wave radar has become a hot research topic, often used in the industrial field to complete speed measurement and ranging, in some extreme environment non-contact measurement, millimeter wave radar also has high system stability, digital signal processing efficient and reliable and many other advantages. Millimeter-wave radar can be divided into pulse radar and continuous wave radar.Among them, frequency-modulated continuous wave radar (FMCW) has the advantages of no distance dead zone, high measurement accuracy, small transmission power and low energy consumption, which is the focus of current radar research.Simple FMCW signal waveforms include sine waves, triangle waves, and sawtooth waves, and relatively complex waveforms include a combination of modulated waveforms in multiple ways, each waveform has its own unique advantages and scope of application, and plays a key role in different fields. Different FMCW millimeter wave radar signals correspond to different signal processing methods, after years of research and development, several waveform systems commonly used include sawtooth wave system, triangle wave system, frequency shift keying system and multi-frequency shift keying system.

2. Millimeter wave radar application

2.1 Common application fields of millimeter wave radar

Due to the late start of the development of millimeter wave radar in China, the research institute and related universities were mainly responsible for the pre-research of the prototype at the earliest.For example, CLP 14, 38, Shanghai Microsystem Research Institute, etc. have previously studied millimeter-wave radar components, complete systems and digital signal processing algorithms, and have obtained some results.Due to the low level of domestic semiconductor technology and insufficient hardware circuit module development capabilities, most of the projects are still in the experimental simulation stage, and the more advanced ones are also in the prototype research and development stage, and it is still too early to put into large-scale commercial use.

The research on millimeter-wave radar focuses on the application of millimeter-wave radar in intelligent driving cars.During the driving process of the car, millimeter waves are emitted outward through the radar antenna, receiving the target reflection signal, and after background processing, the physical information of the vehicle's surrounding environment is quickly and accurately obtained, such as: the relative distance between the vehicle and the detected object, the relative speed, the direction of movement, and the angle.After obtaining physical information, the detection target is tracked and recognized and classified, and at the same time, the data is fused with the vehicle's own dynamic information, and finally intelligently processed by the central processing unit (ECU).The vehicle will inform or warn the driver in a variety of ways such as sound, light, and touch after reasonable decision-making, or actively intervene in the vehicle in time, so as to ensure the safety of the driving process and reduce the accident rate .

Together, the automatic acquisition and processing of bridge detection was realized through the secondary development of millimeter-wave radar applications, and the millimeter-wave vibration detection test of high-speed railway bridges of Beijing-Shanghai high-speed railway lines was carried out.Secondly, the analysis results of bridge deflection response theory are compared with the measurement results of millimeter-wave radar dynamic deflection, on this basis, the dynamic deflection and span-torsion ratio are statistically analyzed, and the modern time-frequency analysis of the non-stationary signal of the dynamic deflection response of high-speed rail bridges is carried out to reveal the three-dimensional change process and characteristics of bridge dynamic deflection time-frequency-amplitude, and realize the combination of millimeter-wave radar and engineering applications.

The use of millimeter wave radar for heat source detection, the use of direct detection millimeter wave radiometer, direct detection millimeter wave radiometer belongs to passive millimeter wave detection system, mainly composed of receiver and antenna, with high concealment, strong anti-interference ability characteristics, the basic function of the receiver is to measure the radiation power of the heat source received by the antenna.Passive millimeter wave detection system is different from active millimeter wave detection system, active millimeter wave detection is a millimeter wave source emitting millimeter wave, and then receiving the target reflected back millimeter wave, this detection resolution and radiation measurement ability are very high, but there will be angular flicker of the target, and passive millimeter wave detection can overcome this shortcoming, it only receives millimeter wave energy emitted or scattered from the target and the background, this detection is closely related to the characteristics of the target.Passive millimeter wave detection and identification systems use the difference in millimeter wave radiation between the target and the background to detect and identify targets.The antenna irradiates the target area, the target and the surrounding scene will emit millimeter wave beams and be received by the antenna, and the signal is extremely weak after the millimeter wave radiation energy enters the receiver.First of all, the low-noise amplifier section is converted into a voltage signal, the amplified voltage signal also contains a lot of interference clutter signal, the corresponding attenuation adjustment into the detector, the detector because of its high sensitivity, can distinguish the low-frequency voltage signal and interference signal into the video amplifier, into the video amplifier for voltage signal amplification, output millimeter wave signal, can be collected and processed by this signal.Finally, in the real environment in the field, a large number of detection tests are carried out for moving targets on land, and the characteristic value information of many moving targets is collected, the target detection is completed, and the target recognition and positioning of the target recognition and detection system is realized.

2.2 mm wave radar other applications

In addition to millimeter wave radar for ranging and speed measurement, there is very little research on the application of millimeter wave radar in human attitude imaging, and only sporadic research results have been made abroad, so the use of millimeter wave radar to observe the various states of people can become the next topic to be studied.Through the radar transceiver equipment and information processing, a more intuitive image presentation of the human movement trajectory can be realized, and a more detailed and clear image presentation of the human movement posture and human body contour can be realized, so that the research on millimeter wave radar is more perfect.

3. FMCW millimeter wave radar algorithm

3.1 Radar detection principle

The basic principle of radar measurement can be expressed as: the RF front end transmits chirp signal to detect the target, and the echo signal reflected by the target and the transmitted signal are mixed in the receiver to obtain a beat signal containing target distance information.The beat signal itself can be thought of as a single-frequency signal. Using DFT (Discrete Fourier Transform) to estimate the signal frequency and initial phase, the distance feature of the target can be extracted.The application of this ranging principle can be traced back to Manterestam and Barbareksi in the former Soviet Union, who first applied frequency modulation to radio altimeters to achieve target height measurement. Since then, chirp measurement technology has developed rapidly. The development of chirp ranging technology can be carried out from estimation theory and practical applications.

3.2 Development history of radar algorithm

From the theoretical measurement point of view, because the beat signal itself is a single-frequency signal, the essence of ranging is the process of spectral estimation of single-frequency signals. The more accurate the frequency and initial phase (phase) measurements, the higher the ranging accuracy.Most of the earliest studies were based on classical spectral estimation methods to study beat signals.In 1958, R. Blackman and J. Tukey proposed the BT method to calculate the signal power spectrum. Later, with the wide application of FFT (Fast Fourier Transform) technology, the periodic diagram method has gradually received people's attention. M.S. Bartlett improved the periodic graph method and proposed the average periodic graph method to achieve power spectrum estimation of signals.Both methods belong to the classical spectral estimation method, although the frequency of the target can be identified, but the measurement performance is directly affected by the number of sampling points, the frequency resolution and accuracy are very low, and the phase information is ignored.In order to improve the parameter estimation accuracy of spectral estimation and improve the problem of classical spectral estimation, modern spectral estimation methods have gradually begun to develop. The first to be applied was the maximum likelihood estimation method. In 1974, D.C. Rife and R.R. Boorstyn used the maximum likelihood estimation method to derive the theoretical estimation of amplitude, frequency, and phase of single-frequency sinusoidal signals.The Cramer-Rao Lower Bound, where these unbiased estimators of variance are obtained,The consistency of DFT estimation and maximum likelihood estimation methods in principle is derived, and it is theoretically proved that the DFT method has the ability to achieve the lower bound accuracy of Cramero.Since then, great progress has been made in achieving accurate frequency estimation using DFT, resulting in methods such as DFT interpolation, Chirp-Z transformation, phase difference estimation, etc.P. T. Nguyen proposed the method of interpolating DFT to realize the estimation of frequency and amplitude of multi-frequency signals and improve the accuracy of spectral estimation.Steffen Scherr uses the Chirp-Z transform to achieve accurate frequency measurements and distance estimation.South China University of Technology Kang Ding The phase difference method and discrete FT (Fourier Transform) are used to achieve the overall estimation of sinusoidal signals.So far, the estimation method of single-frequency signal parameters has matured.

After being able to use DFT for accurate parameter estimation, FMCW radar ranging theory can be developed around the application of parameter estimation.P. T. Nguyen proposed a method to improve frequency resolution based on DFT interpolation, and used X-band radar to achieve distance measurement within 1m to 4.5m with an error of 3mm.In order to further improve the ranging accuracy by using phase information, G. S. Woods proposed a method based on FMCW and CW radar working together to achieve accurate target ranging.The maximum error measured with X-band radar does not exceed 1mm.Dalian Maritime Universityof Guoqing Qi Based on the phase difference estimation after FFT zeroing, the ranging algorithm combining frequency and phase is realized.The phase information of the DFT adjusts the discrete measurement value of the DFT according to the linear relationship between the phase on the DFT peak and the frequency of the

DFT, which greatly improves the measurement accuracy of the DFT.Wuhan University of Science and Technology Peng Zhong In 2014, a method combining FFT and Chirp-Z transform was proposed, which effectively improved the ranging accuracy of FMCW radar.North University of China Xingchen He In 2015, an EMD noise reduction technology based on autocoherent function was proposed to reduce the noise interference of the bad beat signal. Using the energy center of gravity correction theory and combining with Chirp-Z transform, a new algorithm for FFT+Chirp-Z transform is proposed.

3.3 Algorithm improvements

So far, relevant experts at home and abroad have conducted a lot of research on the monocular ranging method of FMCW radar, so that the ranging accuracy of a single target can reach the millimeter level.With the continuous development of phase measurement technology, its excellent performance has gradually been reflected in practice.Therefore, a high-precision ranging algorithm combining frequency ranging and phase ranging is proposed. Based on the accuracy and accuracy of phase measurement, the theoretical measurement accuracy of the algorithm can reach the submillimeter or even micrometer level.

4. Summary

This paper elaborates on the application of millimeter wave radar in different fields such as automobiles, bridges, and detection, and introduces the development and improvement process of millimeter wave radar algorithms.In practical life applications, there are few studies on the use of millimeter-wave radar for human body monitoring, and there are cases where the detection accuracy is not enough. Through continuous improvement of algorithms or the combination of several algorithms, better radar detection and monitoring effects can be obtained, but there are still shortcomings.Through the integration of traditional digital signal processing methods and machine learning ideas, the use of digital signal processing methods to preprocess radar signals and other work to achieve the purpose of further accurate detection of radar targets, so that the combined algorithm may become the mainstream direction of millimeter wave radar research in the future era of artificial intelligence.

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