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Research on Uwb Technology and Uwb Radar

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Abstract. Ultra-Wideband (UWB) technology signifies a significant leap forward in wireless communication techniques. This state-of-the-art method utilizes the direct modulation of impulse signals with rapid rise and fall times, achieving a signal bandwidth that can extend into several gigahertz (GHz). The origins of UWB technology can be traced back to pulse communication methods developed in the 1960s, which provided the foundational principles for its evolution. UWB technology utilizes ultra-wideband pulses that exhibit an exceptionally wide frequency spectrum, enabling efficient communication across a range of applications. Consequently, it is often classified as either wireless carrier communication technology or baseband communication technology. UWB finds its primary application in military radar systems, high-precision positioning solutions, and communication systems designed for minimal interception and detection, highlighting its essential function in both defense and civilian sectors.

Keywords: Ultra-Wideband (UWB), Pulse Communication, High-Precision Positioning

1. Introduction

In February 2002, the Federal Communications Commission of the United States released initial regulations concerning the utilization of spectrum and power for civilian ultra-wideband (UWB) devices. According to these regulations, communication systems with a relative bandwidth greater than 0.2 MHz or a bandwidth greater than 500MHz at any moment during transmission are referred to as UWB systems, and the UWB technology is approved for use in commercial products. Subsequently, Japan opened up ultra-wideband frequency bands in August 2006. With its remarkable data transmission rates reaching up to 1 Gbit/s, strong resistance to multipath interference, low power consumption, cost efficiency, superior penetration capabilities, reduced vulnerability to interception, and compatibility with current wireless communication systems, UWB technology has become the favored option for Wireless Personal Area Network (WPAN) communications [1]. In contemporary society, UWB technology is increasingly prevalent, with UWB radar gradually being integrated into everyday life and emerging as a significant tool.

2. Uwb brief introduction

UWB represents a technique for uncarried spectrum spreading that employs low-duty-cycle impulse pulses as carriers of information. This method entails the direct modulation of impulsive pulses

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characterized by exceptionally rapid rise and fall times. A standard UWB system produces a sequence of impulsive pulses that are directly transmitted, thereby deviating from conventional definitions of medium frequency and radio frequency. Consequently, the transmitted signal may be perceived as either a baseband signal, in traditional radio terminology, or as a radio frequency signal when considering the spectral components of the transmitted signal.

3. The Uwb operation process

Single-period Gaussian pulses, known as impulsive pulses, map one bit of information to hundreds of such pulses. These pulses, which span nanoseconds in width, display a wide spectrum. Ultra-wideband (UWB) technology has established a wireless channel capable of gigahertz transmission. At the transmitter clock, CDMA-based UWB pulse radio transceivers produce periodic pulse sequences. These sequences are modulated with user information alongside a pseudo-random code that signifies the user's address. The pulse generation circuit is driven by the modulated sequences to produce specific pulse shapes, which are then amplified and transmitted through the UWB antenna. Upon reaching the receiver, the UWB antenna captures the incoming signal, which is subsequently amplified by a low-noise amplifier before being directed to a correlator. This correlator utilizes a locally generated pulse sequence that is synchronized with the transmitter and modulated according to the user's pseudo-random code. Through a correlation process that includes multiplication, integration, and sample-and-hold operations, the transmitted information from the user is extracted from the signal and subsequently demodulated.

4. Applications of UWB

Ultra-Wideband (UWB) is a radio communication technology that facilitates rapid and dependable data transfer over limited distances. This paper explores the application of UWB in indoor localization systems tailored for emergency response operations. A persistent challenge during emergency rescues is the loss of communication and tracking capabilities for responders within a building, making it impossible for those outside to pinpoint their exact locations. This project aspires to develop a device that could track indoor locations using a microcontroller and the DWM 1000. This system will be designed to track and collect data from on-scene situations such as collapsed buildings, landslides, and other natural disasters. The system is built based on exact measurements of the transmitted time of arrival (ToA) and time difference of arrival (TDoA). While TDoA merely deals with relative time for all receivers, ToA requires accurate knowledge of the synchronizing and transmitting times between the transmitter and receiver. Aside from that, measurements will be used to evaluate the performance of the DWM 1000 UWB parameters. Beyond its utility in emergency response, the system empowers precise control and localization of first responders using UWB technology. It provides fast, accurate, real-time object tracking and tracing for indoor applications. The system's versatility extends to assisting visually impaired individuals in navigating unfamiliar spaces, aiding emergency evacuations in smoke-filled environments, and enhancing child safety in crowded venues [2]. Ultra-Wideband (UWB) is a wireless communication technology that operates within frequency bands exceeding 1 GHz, distinguished by its use of non-sinusoidal narrow pulses at the nanosecond scale, thereby enabling significant utilization of the spectrum. It achieves data transmission rates of several hundred megabits per second over wide bandwidths, as mandated by the FCC, which requires a bandwidth exceeding 500 MHz in the 3.1–10.6 GHz range. UWB is characterized by its short pulse, absence of a carrier, time-domain operation, non-sinusoidal waveforms, and extensive relative bandwidth. These unique technical features enable UWB pulse

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communication to cater to a growing range of applications, including wireless multimedia, radar, precision positioning, wall-penetrating detection, imaging, and measurement. The primary specifications of UWB are as follows: Frequency range: 3.1GHz to 10.6GHz; System power consumption: 1mW to 4mW; Pulse width: 0.2ns to 1.5ns; Repetition cycle: 25ns to 1ms; Emission power: -41.3 dB m/MHz; Data rate: ranging from tens to hundreds of Mb/s; Decomposed multi-path delay: ≤1ns; Multipath attenuation: ≤5dB; System capacity: significantly greater than that of 3G systems; Space capacity: 1000kb/m [3].

The UWB has many performance features. First, it has an anti-jamming performance.. UWB signals transmit weak radio pulses across a broad frequency band, with output power often lower than typical equipment noise. Upon reception, signal energy is restored, and spread spectrum gain is achieved during deexpansion, resulting in high transmission efficiency. UWB data rates can reach tens to hundreds of megabits per second, significantly surpassing Bluetooth by a factor of 100. Its extremely wide bandwidth, exceeding 1GHz and reaching several GHz, allows simultaneous operation with narrowband systems without interference. The absence of a positive carrier signal enables direct transmission of the shock sequence, contributing to UWB's wide spectrum and low average power, which enhances coexistence with other systems and improves spectrum utilization, thereby increasing system capacity. Additionally, UWB offers strong confidentiality through the use of time-hopping spread spectrum techniques. The transmitted data can be removed only when the receiver knows the spread spectrum code of the sending end. The transmission power density of the system is extremely low, which can not be received by traditional receivers.The establishment of the system structure is comparatively straightforward. In contemporary wireless communication technology, continuous electromagnetic waves serve as the communication carrier, with both the frequency and power of the carrier fluctuating within a specific range to convey information through the carrier's state changes. In contrast, UWB technology operates without carriers, transmitting data signals by emitting narrow pulses of non-sinusoidal waves at the nanosecond scale. Within UWB systems, pulse miniature excitation antennas are employed directly by transmitters, thereby obviating the need for the upconversion typically necessary in conventional transceivers and consequently eliminating the requirement for functional amplifiers and mixers. Furthermore, UWB systems facilitate the utilization of very low-cost broadband transmitters.

Simultaneously, the receivers utilized in UWB systems are distinct from those in traditional systems, as they eliminate the need for intermediate frequency processing, thereby simplifying the implementation of the UWB system architecture. Additionally, UWB positioning boasts remarkable accuracy, with impulsive pulses contributing to high positioning precision. The integration of positioning with communication is straightforward when employing UWB technology, a feat that proves challenging with conventional radio systems. UWB technology exhibits robust penetration capabilities, enabling precise positioning in indoor and underground environments, whereas GPS (Global Positioning System) functions solely within the visible range of its positioning satellites. Unlike GPS, which offers absolute geographical location, ultra-wideband radio locators facilitate relative positioning, achieving centimeter-level accuracy while also being more cost-effective. Furthermore, UWB engineering is both simple and economical; in terms of engineering implementation, UWB technology is significantly less complex than other wireless technologies and can be entirely digitized. The process involves mathematically generating and modulating nanosecond-level non-sinusoidal narrow pulses, which can be integrated onto a single chip, significantly reducing device costs. The UWB system eliminates sinusoidal carriers, allowing direct modulation and enabling the receiver to perform signal detection using correlation devices. This approach negates the need for complex carrier frequency modulation, demodulation circuits, and

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filters in the transceiver, requiring only a digital method for pulse generation. Therefore, adopting UWB technology can significantly reduce system complexity, reduce the size of transceivers, lower their power consumption, and facilitate digitization and the use of software-defined radio technology [1]. The last feature is portable. This technology uses baseband transmission and does not require RF modulation and demodulation, so its devices consume less power, cost less, and are flexible.

5. Uwb radar’s history, characteristic and applications

UWB radar (Ultra-Wideband radar) is utilized in cardiology, respiratory, and vocal function monitoring, particularly for detecting vocal cord activity through remote observation of silent vibrations. DARPA's "Advanced Speech Coding" project aims to replace traditional microphones with sensors that interpret speech via neural and muscular movements. MIT's Radar Stethoscope project, initiated in 1995, highlighted UWB radar's biomedical applications, including a specialized microwave radar developed by LLNL, capable of detecting breathing and heartbeat signals while minimizing environmental interference through distance gating technology. The McEwan research project secured U.S. patents for devices converting physiological signals into sound, enhancing indoor monitoring capabilities. Since 1999, advancements in UWB radar have led to significant progress in various biomedical fields, including cardiology, obstetrics, pediatrics, respiratory medicine, and neurosurgery, owing to its compact size, low power consumption, and high spatial resolution.

After the FCC in the United States allowed the technology to be commercialized in February 2002, many companies began investing human, material, and financial resources to develop and research ultra-wideband radar in related fields.Compared with laser, infrared detection, and acoustic detection technologies, using ultra-wideband radar to detect human vital signals is unaffected by environmental temperature and thermal objects, can effectively penetrate media, and better addresses the severe temperature effects on laser and infrared detection, which are prone to failure when encountering objects or leading to false alarms. It also overcomes the issues of ultrasonic detection being affected by environmental clutter reflections, water, ice, and material obstructions. Ultra-wideband radar can be widely applied in both wartime and peacetime scenarios, such as post-war casualty search, personnel search after earthquakes or collapses, and infectious diseases. To the UWB radar, it also has many features and advantages. The system exhibits three primary characteristics. Firstly, it boasts exceptional resolution. The pulse duration in the time domain for ultra-wideband radar is notably brief, typically in the nanosecond range, enabling it to deliver superior temporal resolution, which facilitates high-resolution target detection and measurement. Secondly, it demonstrates high precision. Ultra-wideband radar employs high-energy, short-pulse-width signals, allowing for precise determination of target position and velocity while maintaining high resolution, thus enhancing measurement accuracy. Lastly, it possesses robust resistance to multipath interference. By utilizing wideband signals, ultra-wideband radar effectively mitigates interference and multipath effects, outperforming conventional radar systems in outdoor environments and yielding more accurate target information. The advantages are as follow. Ultra-wideband radar can accurately measure the distance, speed, angle, and other information of the target, and will not be interfered by obstacles in front of the target. UWB radar can effectively identify stealth targets has strong anti-stealth performance. Ultra-wideband radar can achieve high-resolution detection and measurement under high dynamic range. Compared with traditional radar, ultra-wideband radar has the characteristics of low power, energy-saving and better battery life. UWB radar can work in complex environments such as ground, air and ocean fields. The differences between UWB radar and millimeter wave radar can be seen in four aspects. First, UWB radar uses ultra-wideband technology, and the transmitted signal bandwidth is greater than 20%, and the signal has the characteristics of short pulse broadband, high repetition frequency and low peak-to-average ratio have certain anti-interference and resolution advantages against multipath effects in the environment; millimeter wave radar uses electromagnetic waves in the millimeter wave band for measurement. UWB radar excels in short-range ranging, target detection, and identification, while millimeter wave radar is primarily utilized for long-distance obstacle detection, search and rescue, and robot navigation. UWB radar features short pulse width, high repetition frequency, and low peak-to-average ratio, providing resistance to interference and multipath effects. In contrast, millimeter wave radar offers narrow bandwidth, high power, direct radiation, and a high signal-to-noise ratio, ensuring robust detection sensitivity in complex environments.

The last difference is antenna design. UWB radar usually uses dipole, monopole, circular pole and other antennas to meet the needs of low profile and multi-angle detection in complex scenarios; millimeter wave radar usually uses horn antenna, microstrip antenna and other structures to achieve high directivity detection and positioning. There are also many applications about the UWB radar. UWB radar can accurately locate and track moving targets and can also achieve effective target detection in harsh environments. To address the shortcomings of traditional positioning technologies, a UWB high-precision positioning system has been designed. The positioning system mainly includes the design of hardware and software for communication interface circuits such as the electronic mobile tag system and UWB antenna tag system. The hardware design primarily involves the main control DWM-1000 chip, DWM-1000 base station antenna chip, and wireless communication interface circuits. The software system mainly includes the basic software logic and the electronic sticky note P-coordinate parsing algorithm software flow design, achieving the transmission, reception, data calculation and analysis, and precise positioning of electromagnetic wave signals. Test results show that the system positioning error range is less than 10 cm, reducing non-line-of-sight errors and noise interference, meeting the requirements for high precision, strong stability, and low power consumption in positioning systems [4].

6. Application of Uwb in coal mining industry and detect breathing and heartbeat signals

Research into the utilization of UWB echnology for precise positioning and energy efficiency management within coal mining operations is advancing significantly. This section delineates the foundational principles of UWB technology and its inherent advantages in the context of coal mine environments, examining specific applications such as personnel positioning, equipment tracking, and auxiliary transportation systems. The integration of UWB technology has markedly enhanced safety management protocols in coal mines, streamlined production processes, and facilitated reductions in workforce while simultaneously boosting operational efficiency. Furthermore, the precise management capabilities afforded by UWB technology have led to substantial decreases in energy consumption, thereby fostering energy conservation and emissions reduction. An exploration of the implementation challenges and potential solutions associated with UWB technology in coal mines offers both a theoretical framework and practical insights for the intelligent transformation of the coal mining sector. [5]. It can also achieve non-contact ranging and precise imaging, providing a variety of applications for high-precision measurement methods. UWB radar, due to its simple structure, low transmission power, strong penetration capability, high resolution, and fast transmission speed, has gradually become a widely used life information detection technology and equipment in various detection scenarios. The essential method for accurately detecting life information involves the utilization of radar echo processing technology to extract signals related to breathing and heartbeat from UWB radar echoes. This process is vital for identifying life

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information, acquiring location data, monitoring and preventing illnesses, and ensuring the safety of individuals across various scenarios [6].

7. Conclusion

Ultra-wideband radar represents a significant technological advancement, offering unparalleled precision and versatility across various sectors. As research continues to evolve, the potential applications of UWB radar are set to expand dramatically, revolutionizing industries and improving daily life. This technology not only enhances situational awareness in fields such as automotive safety and healthcare but also paves the way for innovations in smart cities and the Internet of Things (IoT). By enabling real-time data collection and analysis, UWB radar can facilitate more efficient resource management and contribute to the development of autonomous systems, ultimately leading to safer and more connected environments.

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