Characteristics and Realization of Pulse Ultra-wideband Signals

Yan ZHANG
Intelligent Science & Information Engineering College, Xi'an Peihua University, Xi'an, China
410325568@qq.com

Keywords: Ultra-wideband (UWB); Wireless sensor.

Abstract. Among the basic positioning methods commonly used in UWB, because the location method based on field intensity measurement is sensitive to environmental changes and the positioning accuracy is not high under the condition of multi-path fading channel, this method has not been widely valued and applied. This paper will study the technology and application of infinite sensor based on ultra-wideband, and use TOA positioning method to locate UWB wireless sensor networks. It is suitable for UWB wireless sensor networks with limited computing power. It has a wide range of applications and has good application prospects.

Introduction

Ultra-wideband wireless transmission technology is a new wireless communication technology with significant differences from conventional wireless communication technology, including narrowband communication, conventional spread spectrum communication and OFDM technology.

Definition of Ultra Wideband Signal

The definition of UWB was first given by the Federal Communications Commission (FCC) of the United States. It stipulates that the relative bandwidth of -10dB is more than 25%, or that the absolute bandwidth of -10dB is more than 1.5GHZ. Later, the FCC revised the bandwidth value to 500GHZ. Formula for FCC (1)

$$B = \frac{2(\text{f}_h - \text{f}_l)}{(\text{f}_h + \text{f}_l)}$$

(1)

Compute relative bandwidth. Calculating Absolute Bandwidth by Formula (2)

$$B_a = \text{f}_h - \text{f}_l$$

(2)

The formula for calculating the center frequency is formula (3)

$$f_0 = \frac{\text{f}_h + \text{f}_l}{2}$$

(3)

Among them, \(\text{f}_h\) denotes the high frequency point of -10dB scattering and \(\text{f}_l\) denotes the low frequency point of -10dB scattering.

In February 2002, the FCC stipulated that UWB technology should be allowed to enter the civil field, but it formulated very conservative rules: under the condition that the transmitting power is lower than the prescribed value of US radiation noise -41.3dB/MHZ, the frequency band of 3.1GHZ~10.6GHZ can be used for imaging system scanning underground and partition objects, automobile collision avoidance radar, ranging and wireless data communication between household electrical terminals and portable terminals. Specific constraints are shown in Table 1.

The traditional UWB signal is in the form of pulse radio, namely IR-UWB. As a carrier-free communication technology, it uses picosecond to nanosecond non-sinusoidal narrow pulse to transmit data, which has a very wide bandwidth and a very low power spectral density. Using IR-UWB to transmit, the pulse does not need carrier modulation, and the baseband signal can be radiated directly through the broadband antenna. According to the definition of FCC, UWB signals can be generated in many ways. At present, IR-UWB and orthogonal frequency division multiplexing ultra-wideband OFDM are more concerned. In this paper, wireless sensor networks based on pulse ultra-wideband IR-UWB technology are studied.
Table 1. FCC Radiation Limitations for Indoor and Outdoor UWB Applications.

| Frequency (MHz) | Indoor | Outdoor |
|----------------|--------|---------|
| 960~1610       | -75.3  | -75.3   |
| 1610~1990      | -53.3  | -63.3   |
| 1990~3100      | -51.3  | -61.3   |
| 3100~10600     | -41.3  | -41.3   |
| Above 10600    | -51.3  | -61.3   |

Ultra Wideband Pulse Realization

UWB communication system can be divided into baseband pulse mode and carrier modulation mode. The former is the traditional UWB communication mode, and the latter is proposed in the process of UWB wireless communication standardization after the FCC stipulates the spectrum usage range and power limitation of UWB communication. UWB communication system with carrier modulation can be divided into two forms: single-band and multi-band. This paper focuses on the form of pulse radio based on the former and takes the commonly used Gauss pulse as an example. Other forms are not described here.

The expression of time domain waveform function of Gauss pulse is shown in formula (4):

$$ f(t) = \pm \frac{1}{\sqrt{2\pi}\delta} e^{-\frac{t^2}{2\delta^2}} $$  \hspace{1cm} (4)

Among them, \( f(t) \) is the time domain function of the Gauss pulse, and the value of the function is dimensionless. \( \delta \) is the mean square deviation of the Gauss function and \( t \) is the time constant.

If \( \delta^2 = \frac{\alpha^2}{4\pi} \) Then formula (4) can be changed into formula (5):

$$ f(t) = \pm \frac{\sqrt{\delta}}{\alpha} e^{-\frac{t^2}{\alpha^2}} $$  \hspace{1cm} (5)

When the time parameter is selected properly, it can become a suitable pulse, which affects the width and amplitude of the pulse. In this case, it is called the forming factor of the pulse waveform. When the pulse amplitude increases, the pulse amplitude decreases and the pulse width becomes wider.

Fig. 1 shows the pulse waveform and the corresponding energy spectral density (ESD) of \( f(t) \) when the shaping factor \( \alpha \) is 0.5ns, 1.142ns and 2.5ns, respectively, and the energy density formula (5) is negative as shown in Fig. 2.

Figure 1. The Waveforms of \( f(t) \) When the Shaping Factor \( \alpha \) is 0.5ns/1.142ns and 2.5ns, respectively.
According to the previous discussion, the basic Gauss pulse waveform can be defined as formula (6):

\[ P(t) = A_p e^{-\frac{2\pi^2}{\alpha^2}} \]  

Calculate its energy by differential equation (7):

\[ E_p = \int \int \int p(t) \, dt = A_p \int \int \int A_c e^{-\frac{2\pi^2}{\alpha^2}} \, dt = \frac{A_p}{\alpha} \]  

In formula (7), \( E_p \) is the energy expression of Gauss pulse waveform and \( \alpha \) is the pulse shaping factor. It can be seen that when \( p(t) \) has unit energy, the condition is formula (2.8):

\[ A_p = \sqrt{\frac{2}{\alpha}} \]  

However, in order to radiate effectively, the generation of pulses should have a basic condition: no DC component. On the premise of satisfying this condition, a variety of pulse waveforms can be considered. All the waveforms represented by the derivatives of the Gauss function satisfy the above conditions. In practice, the most commonly used pulse waveform is the second derivative of Gauss function. The specific expression is shown in formula (9):

\[ \frac{d^2 p(t)}{dt^2} = (1 - 4\pi \frac{t^2}{\alpha^2}) e^{-\frac{2\pi^2}{\alpha^2}} \]  

In the formula, flat \( p(t) \) represents the pulse function and \( \alpha \) is the shaping factor. This is the second derivative derived from the differential of Gauss function. As shown in Fig. 3, the energy of the pulse is 3a/8V2S.
Comparing the energy spectral density of the first order $f(t)$ when the shaping factor $\alpha$ is 0.5ns and that of the second order $f(t)$ when the shaping factor $\alpha$ is 0.5ns, we can see that the pulse is differentiated. With the increase of the order of the Gauss derivative, the peak frequency increases correspondingly, and the energy can be moved to a higher frequency band.

Ultra Wideband Multipath Channel Model

The environment of UWB communication is wireless multipath channel, which corresponds to wireless multipath channel. This section mainly analyses two multipath channel models. Turin model, UWB channel model recommended by IEEE802.15.3a, namely S-V improved model, focuses on the analysis of standard channel model recommended by IEEE802.15.3.

Turin Model

Turin model was proposed by Turin in 1956. Turin model assumes that all the parameters representing the channel are random variables subject to a specific distribution, and the characteristics of these parameters can be obtained by statistics at the receiving end. In a wireless multipath channel, because there are multiple propagation paths between the transmitter and the receiver, the transmitted signal will produce multiple signals with time delay and attenuation. The received signal can be expressed as follows: Formula (10):

$$r(t) = \sum_{n=1}^{N(t)} a_n(t) s(t - \tau_n(t)) + n(t)$$  (10)

In formula $a_n(t)$ and $\tau_n(t)$ are channel gain and delay of path $n$ at delay time $t$, respectively. $N(t)$ is the number of paths observed at time $t$, and $n(t)$ is the additive noise at the receiver.

If the impulse response of the channel is $h(t)$, then the received signal should be shown in formula:

$$r(t) = h(t) * s(t) + n(t)$$  (11)

By comparing formula (10) and formula (11), the impulse response $h(t)$ expression of the channel can be obtained as formula (12):

$$h(t) = \sum_{n=1}^{N(t)} a_n(t) \delta(t - \tau_n(t))$$  (12)

In Formula (11), the channel impulse response is time-varying, considering the change of propagation environment caused by the movement of transmitter or receiver. However, in general, the change rate of the channel is very slow relative to the pulse rate. Therefore, it is assumed that the channel is stable during the observation time. So the impulse response of the channel can be expressed as formula (13):
From Turin model, three parameters representing wireless multipath channel can be derived: total multipath gain $D$, root mean square delay spread $\tau_{rms}$, power delay profile PDP, as shown in formula (14) (15) and Fig. 5, respectively.

$$h(t) = \sum_{n=1}^{N} a_n \delta(t - \tau_n)$$

$$G = \sum_{N'=1}^{N} |a_n|^2$$

$$\tau_{rms} = \left( \frac{\sum_{n=1}^{N} \tau_n^2 |a_n|^2}{G} - \left( \frac{\sum_{n=1}^{N} \tau_n^2 |a_n|^2}{G} \right)^2 \right)^{1/2}$$

The power delay profile (PDP) of multipath channel can be represented by Fig. 5, whose coordinate components are different arrival time and corresponding receiving power.

Figure 5. Power Delay Profile of Multipath Channel.

The Channel Model Recommended by IEEE 802.15.3a

In July 2003, the channel model Sub-Committee of the IEEE802.15.3a research group released the final report of the UWB indoor multipath channel model [IEEE802.15.SG3a, 2003], using this model to evaluate the performance of various physical layers submitted to the IEEE802.15.3 task group. The recommended model takes into account the contributions of various aspects in this field:

A. Statistical path loss model of UWB signal proposed by Ghassemzadeh et al.
B. Channel measurement and modeling described by Pendergrass and Beeler et al.
C. Intel recommendation model;
D. Measurement results completed by Hovinen, University of Oulu
E. Kunisch and Pamp's wireless communication channel model obtained through channel detection experiments in office environment
F. Ghassemzadeh and Tarokh obtained a statistical path loss model by analyzing over 300,000 frequency responses of 23 rooms and 712 locations
G. Mitsubishi obtains the channel model through measurement experiments in office buildings;
H. [Cramer et al. 2002b] UWB propagation channel analysis using CLEAN algorithm
I. Siaia's research.

Specifically, the sub-committee of IEEE Channel Model finally decided to adopt the UWB Channel Model of Fig. 6.
Acknowledgment

This work was supported by the special topic of Ideological and political education reform in 2019 in Xi’an Peihua University is "Integration and innovation of curriculum ideological and political education in basic computer teaching" (PHKCSZ201916).

References

[1] Manjeshwar, A. and Grawal, D.P. TEEN: A protocol for enhanced efficiency in wireless sensor networks. In: Proc. of the 15th Parallel and Distributed Processing Symp., San Francisco: IEEE Computer Society, 2001, 2009–2015.

[2] W. Heinzelman, A. Murphy, H. Carvalho and M. Perillo. Middleware to support sensor network applications. IEEE Network, 2014, 18 (1): 6-14.

[3] Perrig, A., R. Szewczyk and V. Wen. SPINS: Security Protocols for sensor networks Wireless Networks, 2012, 8 (5): 521-534.

[4] G. Anastasi, A. Passarella, etc. Performance Measurements of Motes Sensor Networks. MSWIM, 04, New York, USA, 2014: 174-181.

[5] W. Heinzelman, A. Chandrakasan and H. Balakrishnan. An application-specific protocol architecture for wireless micro-sensor networks Wireless Communications [J]. IEEE Transactions, 2002, 1(4): 660-670.

[6] H. Chan and A. Perrig. ACE: An emergent algorithm for highly uniform cluster formation. Proc. of the 1st European Workshop on Wireless Sensor Networks. LNCS 2920, Berlin: Springer-Verlag, 2004, 154–171

[7] A. Manjeshwar and D.P. Grawal. TEEN: A protocol for enhanced efficiency in wireless sensor networks. Proc. of the 15th Parallel and Distributed Processing Symp. San Francisco: IEEE Computer Society, 2001, 2009–2015.