Study on the detection method of the number of people passing through the wall based on IR-UWB

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Abstract. The purpose of this study is to realize the detection of the through wall personal based on IR-UWB radar. The through wall detection system sends IR-UWB signal to the detection area, which can penetrate the wall and radiate to the detection area behind the wall. When transmitting or receiving IR-UWB signal, antenna array with a certain aperture is needed to achieve azimuth resolution. After receiving the echo signal, the IR-UWB through wall detection system stores or directly transmits the echo signal containing the target information to the signal processing platform for subsequent detection processing. This study can achieve the number of obstacle crossing and detection based on BP neural network, and can detect different numbers and different obstacles through two detection methods. The final experimental results show that compared with the traditional probability method based on maximum likelihood estimation, the probability of this method has been greatly improved, and the judgment effect has also been significantly enhanced. The achievements of this project can be extended to the fields of human and animal recognition, human health detection, intelligent medical treatment, intelligent home and so on, based on the protection of privacy.

1 Introduction

1.1   The wall-penetrating performance of electromagnetic wave

Wall blocking is a main feature of wall - penetrating detection. When the electromagnetic wave penetrates the wall, it will produce serious attenuation, its penetration characteristics directly affect the selection of detection signal. Different walls have different penetration characteristics, and the same wall has different attenuation and phase offset for electromagnetic wave signals of different frequency bands [1], which is more prominent for broadband signals. The Hughes advanced electromagnetic technology center has measured the penetration characteristics of electromagnetic wave in a variety of media, and drawn the relationship diagram between the attenuation and frequency of electromagnetic wave in a variety of media, and the corresponding relationship diagram of some wall media is shown in Figure 1. As can be seen from Figure 1, electromagnetic wave attenuation is the most serious when it penetrates concrete wall (6 inches) compared with other media. Among them, the attenuation of low-frequency electromagnetic wave at 1-10ghz is relatively small. With the decrease of frequency, the attenuation also decreases. The attenuation is about 10dB at 8GHz and below 5dB at 3GHz. When the frequency is more than 10 GHz, the attenuation of electromagnetic wave in concrete wall increases rapidly. The attenuation of electromagnetic wave through dry wall is relatively small, but through brick and concrete wall is relatively large. If the wall thickness increases, the attenuation of electromagnetic wave through the wall will also increase. In the actual building, there will be reinforcement in the wall. The cutoff of reinforcement mesh to low frequency and the shielding effect of waveguide will cause the attenuation of low

frequency signal through the wall to be greater than high frequency signal [2]. A large number of practical measurement results show that if the actual convenient frequency of signal penetrating concrete wall is about 3GHz, the available frequency is not more than 10GHz [3], the electromagnetic wave with the frequency spectrum of 250MHz ~ 3GHz can effectively penetrate most of building materials, and the higher frequency electromagnetic wave attenuates more seriously in the process of penetration [4]. Therefore, when designing IR-UWB signal for wall - penetrating detection, the main spectrum energy should be concentrated in this frequency band. At the same time, in order to achieve high resolution, the frequency bandwidth of IR-UWB should be maximized as much as possible.
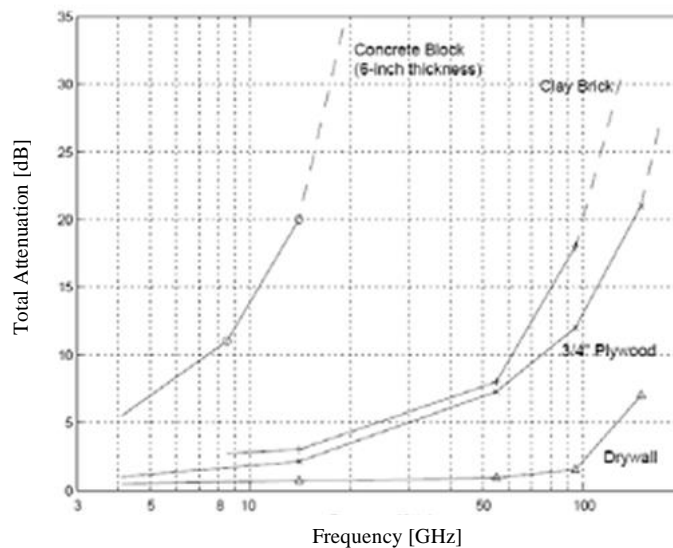

Fig. 1. One way attenuation of electromagnetic signal through various walls.

1.2 Advantages of IR-UWB signal in wall-penetrating detection

IR-UWB signal uses extremely narrow pulse to realize ultra wide band, which not only has a high range resolution but also has a strong penetration characteristic [5], and some studies have proved that the loss of using pulse signal is smaller than that of continuous wave signal in the process of wall - penetrating [6], so it is very suitable for wall - penetrating detection. At the same time, IR-UWB has many other attractive characteristics and advantages in detection [7], mainly including:

(1) Strong target recognition ability. Because of the high range resolution of IR-UWB signal, it is easy to separate the echo of each scattering center of the target, reflecting the fine structure of the target, which has the potential advantage of target recognition.

(2) High resolution of multipath. It is easy to filter and receive the multipath signal correctly by using the appropriate time window, so that it can provide accurate detection ability in the dim environment such as indoor.

(3) Strong anti-interference ability. Because of its short duration in time domain, it is easy to suppress the interference signal in time window by using a narrow time window. The scattering cross section of the interference source corresponding to the IR-UWB pulse is relatively small, which makes the IR-UWB system less affected by the passive interference source.

(4) The ability to detect stationary targets. This is because the detection of IR-UWB signal can be independent of Doppler shift detection.

(5) The detection blind area is small. This feature makes it easy to detect and detect close range targets. These characteristics make the wall - penetrating detection system based on IR-UWB have advantages that other types of wall - penetrating detection system can not compare. In recent years, IR-UWB has been widely used in wall - penetrating detection, and also in ground penetrating radar, medical detection and other detection systems that need to be penetrated.

1.3 Research status of IR-UWB wall-penetrating detection resolution
At present, there are many definitions of resolution in the detection system. The commonly used reso-lution criterion is Rayleigh criterion [8], that is, when the peak value of the signal from the first target falls at the first minimum value of the second target signal, it is considered that two point targets with the same size can be resolved, and the distance between the two targets is Rayleigh resolution. Rayleigh resolution criterion is based on the human vision system assumed resolution ability, which is simple and widely used. However, Rayleigh resolution is only a representation of resolution, which does not mean that when the distance or angle of two point targets with the same scattering intensity is larger than Rayleigh resolution, two distinguishable peaks can be obtained from the received echo signal (or image). Literature [9] has made a detailed analysis and Research on this. It is pointed out that when the azimuth distance of two targets is equal to twice the-3dB beam width, two peaks can be clearly seen under all possible phase differences, and the deviation between the two peaks and the actual target position is eliminated. This means that for two ideal point targets with the same intensity, to distinguish them and accurately measure their positions, the distance between the two targets must be greater than or equal to two times of - 3dB beam width. In addition, according to the long-term use experience, it is pointed out in reference [12] that the angular resolution of the radar antenna with the combination of reception and reception to the targets located in different spatial positions is generally equal to the- 3dB width of the main lobe of the antenna one-way pattern. Therefore, another definition of radar angular resolution is the-3dB width of the main lobe of the radar antenna's one-way beam pattern, which actually corresponds to the- 6dB width of the main lobe of the two-way beam pattern. Similarly, the time resolution corre-sponding to the distance resolution is defined as the-6dB width of the pulse waveform [10]. There are also some references, which discuss resolution specially, regard the case that the depression between two target peaks is greater than - 3dB as correct resolution.

The resolution of IR-UWB wall-penetrating detection system mainly depends on the design of sys-tem parameters. Accordingly, the calculation of resolution is of great significance for the design of sys-tem parameters. For two-dimensional detection system, the resolution can be divided into range (longi-tudinal) resolution and azimuth (transverse) resolution. For example, when the conventional radar works in narrow band and far field, the range resolution is only related to the bandwidth and propagation speed of the detection signal:

$$\Delta R = \frac{v}{2B} = \frac{c}{2B\sqrt{\varepsilon_r}}$$

(1)

Where V is the propagation speed of the signal in the medium, $v = \frac{c}{\sqrt{\varepsilon_r}}$, ε_r is the relative permit-

tivity of the medium, B is the bandwidth of the signal. The azimuth resolution corresponds to the angular resolution of the antenna (array) beam, which is approximately the product of the angular resolution of the antenna (array) beam and the target distance.

$$\Delta CR = \frac{\lambda_0 R}{L}$$

(2)

Where λ_0 is the wavelength corresponding to the signal carrier frequency, R is the distance from the antenna to the target, and L is the effective aperture of the antenna array. Azimuth resolution is not only related to signal frequency, but also to antenna array aperture and target distance.

2 Design scheme

2.1 Detection of number of people
In the detection of human reflection waveform, the BP neural network method is used to classify the number of people with and without obstacles from one to five. The training steps of BP neural network

are as follows: first, the number of input layer nodes, hidden layer nodes, output layer nodes, initialization input layer, connection weight between hidden layer and output layer neurons, initialization hidden layer threshold, output layer threshold, given learning rate and neuron excitation function, then the hidden layer output is calculated according to the input direction. Quantity, connection weight between input layer and hidden layer, and threshold value of hidden layer, calculate output of hidden layer, then output calculation of output layer, according to output of hidden layer, connection weight and threshold value, calculate BP neural network prediction output, then error calculation, according to network prediction output and expected output, calculate network prediction error, update network connection weight according to network prediction error And the network node threshold, and finally determine whether the iteration is over, if not, continue the cycle. After the BP neural network has trained the model, it can put the sample data into the judgment. The final output result is five probabilities, which represent the probabilities of zero to five people respectively. The maximum value of the probabilities is the human value.
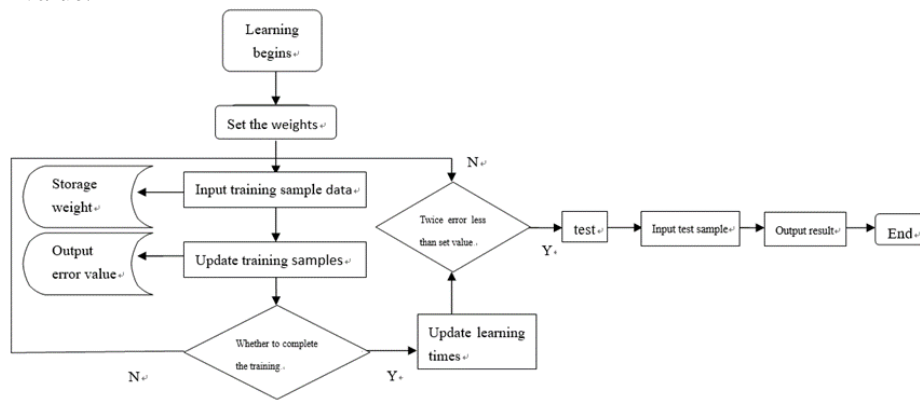

Fig. 2. Flow chart of number detection.

2.2 Basic principle of IR-UWB wall - penetrating detection

The whole process of wall - penetrating detection involves three spaces: target space, data space and image space, as shown in Figure 4. The target space is the actual space of the object. The data space is composed of echo signals recorded by different antennas. The image space is the space where the final image is generated. It is a simple reconstruction of the target space.
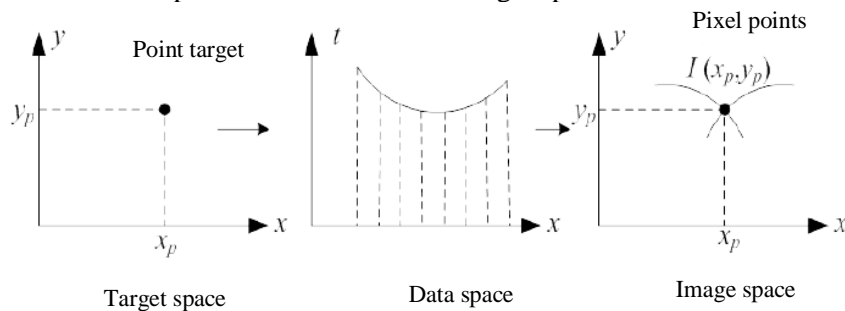

Fig. 3. Description space of detection system

As shown in the figure, we suppose $f(x,y)$ is the target space, $d(x,t)$ is the data space, $I(x,y)$ is the image space, where x is the azimuth, y is the distance and t is the time. Through transmitting IR-UWB signal and receiving echo signal, IR-UWB wall - penetrating detection system realizes the mapping from target space $f(x,y)$ to data space $d(x,t)$. After that, the mapping from data space $d(x,t)$ to image space $I(x,y)$ is realized by BP detection algorithm. It is assumed that there is a scattering point with a reflection / scattering coefficient of $x_p = (x_p, y_p)$ in the target space σ_p behind the wall, which is

recorded as $f(x_p, y_p)$. The purpose of IR-UWB wall - penetrating detection is to make $I(x_p, y_p)$ in image space accurately reflect the position and scattering intensity of $f(x_p, y_p)$ in target space. For the large-scale target behind the wall, if the location and scattering intensity of some main points can be accurately reflected in the image space, then the contour detection of the target behind the wall is realized. According to the above basic principle of wall - penetrating detection, IR-UWB wall - penetrating detection system is mainly composed of detection and detection. The detection part includes specific detection environment (such as wall characteristics) and detection method (mainly including IR-UWB signal and receiving antenna array). The detection part is mainly composed of wall - penetrating detection algorithm (such as BP algorithm) and other signal processing methods.

2.3 Number detection of 0-5 people when there is no obstacle

When there is no one: environment and output detected by radar.

Because the experimental environment is 7m long, there will be a peak value at 7m in the figure, indicating that it has detected the wall. Environment and output detected by radar.
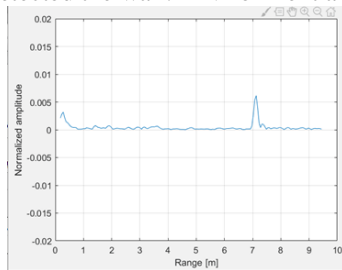

Fig. 4. Environmental conditions and output conditions when no one is available
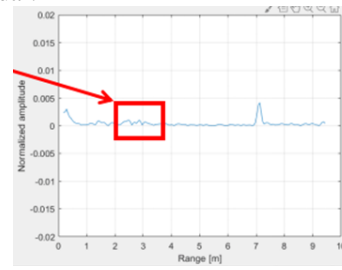

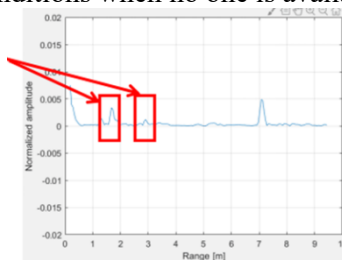Fig. 5. Environment and output of 1 person

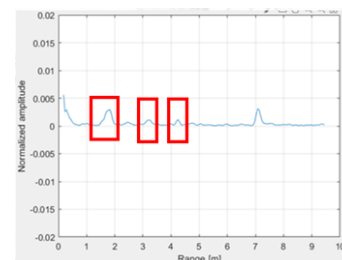Fig. 6. Environment and output of 2 persons

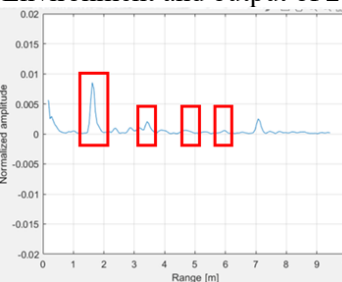Fig. 7. Environment and output of 3 persons

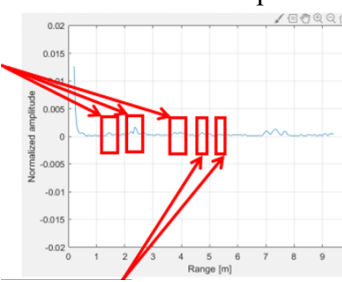Fig. 8. Environment and output of 4 people

Fig. 9. Environment and output of 5 people

Table 1. Table captions should be placed above the tables.

Number of people,	Probability				
	0 people	1 people	2people	3 people	4 people
0	97.2278	5.3298	5.9998	1.0604	1.3479
1	3.5346	91.2145	13.6598	4.2644	2.7391
2	0.96711	3.0617	89.0159	8.1853	5.4183
3	0.52619	0.19084	5.7454	88.7304	37.3087

4	0.14505	0.85575	0.23488	6.6452	87.819
5	0.12912	0.28213	0.10038	0.47095	50.6108

2.4 Detection of the number of people passing through the plywood with a thickness of about 0.05m

Table 2. Number detection and accuracy.

	0	1	2	3	4	5
0	100%	6.9%	0.7%	0.0%	0.0%	0.0%
1	0.0%	55.9%	23.3%	0.2%	0.0%	0.0%
2	0.0%	24.0%	68.9%	23.4%	3.1%	0.0%
3	0.0%	11.2%	6.3%	52.4%	17.4%	5.6%
4	0.0%	5.9%	0.9%	24.1%	50.8%	17.3%
5	0.0%	0.0%	0.0%	0.0%	28.1%	33.2%
6	0.0%	0.0%	0.0%	0.0%	0.6%	43.9%

3 Conclusion

This project uses the number of people based on bp neural network for classification and waveform-based respiration detection. Compared with the traditional probability method based on maximum likelihood estimation, the probability of this method has been improved, and the accuracy can be improved by about five percentage points.

Another advantage of this project is that it can combine the number detection and breath detection to judge the number and position, which is much better than the single method.

The future application scenario of this project is combined with smart home and smart medical treatment. For example, in the field of smart air conditioning, using this research can protect privacy and identify the number of people to adjust the power of air conditioning.

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