A Method of Localization with Multi-Channels UWB Bio-Radar in Application of Through-Wall Detection

Ziqi Zhang, Fugui Qi, Yang Zhang, Hao Lv, Zhao Li, Miao Liu and Jianqi Wang*
Department of Electronics, School of Biomedical Engineering, the Fourth Military Medical University, Xi'an 710032, China.
Email: wangjq@fmmu.edu.cn

Keywords: Bbio-radar, multi-channels, localization, through-wall

Abstract: Recently, technology of ultra-wide band (UWB) bio-radar develops rapidly which becomes a very helpful method of rescuing for post-disaster like earthquake and also useful surveillance medium for security fields like anti-terrorists. There are two main aspects of UWB technology that researchers concern namely technology of targets recognition and technology of targets localization. Most methods about targets localization based on intersecting of multi arcs cannot determine the location of the targets effectively because those arcs could not always intersect into one point. In this paper, we proposed a novel method based on hyperbolic model using multi-channels bio-radar for two dimensional localization. Free-space and through-wall experiments results indicated that the proposed method could determine the location of targets accurately and effectively with an average error around 10cm between detection results and real positions.

1 INTRODUCTION

Ultra-wide Band (UWB) bio-radar is a novel kind of radar combining radar technology and biomedical engineering technology, and regards organism like human bodies as the main detection targets, which is one of the most effective technical methods to search survivors that applied in some post-disaster search and rescue operations like the earthquake, the mine disaster, the debris flow and so on (Qi et al., 2016; Lv et al., 2016; Liang et al., 2016). Bio-radar could determine whether there is a life target and its location within the detection area quickly, which could provide guidance for professional rescue to improve accuracy and efficiency of the rescue. The detection results of bio-radar always contains two aspects: targets recognition (whether there is a life target and classification of target types), and targets location. Actually, targets location technology is eagerly needed in rescue operations, while it is still a difficult problem to be solved at the moment (Nguyen and Pyun, 2015; Monica and Ferrari, 2015). If the actual position of the trapped target can be accurately estimated, the limited search and rescue resources will be better concentrated and the efficiency of rescue will be greatly improved. Currently, algorithm of multi arcs intersecting is commonly used in two-dimensional positioning, which can easily lead to a circumstance that different arcs intersect into different points resulting in failing to locate the life targets. Therefore, this paper proposed a location method based on hyperbolic model with multi-channels portable bio-radar platform, and the experimental results of single target location indicated that this method could determine the two-dimensional coordinates of the target more accurately. The location of multi-targets is the most challengeable topic in location technology for the absence of shadowing effect (Kocur et al., 2011), research in this paper also lays the foundation for solving the difficult problem of multi-targets location.

This paper is organized as follow. In Section 2, the multi-channels UWB bio-radar and antennas array setup are introduced. Section 3 introduces the new kind of two dimensional detection method for life targets based on hyperbolic model and analyses feasibility of it theoretically. The experimental results are discussed in Section 4. The conclusion is given in Section 5 finally.

Zhang, Z., Qi, F., Zhang, Y., Lv, H., Li, Z., Liu, M. and Wang, J.
A Method of Localization with Multi-Channels UWB Bio-Radar in Application of Through-Wall Detection.
In *Proceedings of the International Workshop on Environment and Geoscience (IWEG 2018)*, pages 501-506
ISBN: 978-989-758-342-1

2 MULTI-CHANNELS UWB BIO-RADAR SYSTEM AND EXPERIMENTAL SETUP

2.1 Multi-Channels UWB Bio-Radar System

As Figure 1 shows, The multi-channels portable UWB bio-radar system we adopt consists of UWB bio-radar antennas with 1 transmitting antenna and 4 receiving antennas, a portable multi degree of freedom foldable support and a touch-sensitive wireless processor. Its operating central frequency of the UWB radar is 400MHz with a band width of 400MHz. The pulse repetition rate is 128 KHz, and the AD sampling frequency for each channel is 64 Hz, which is sufficient to capture the instantaneous change of human motion.

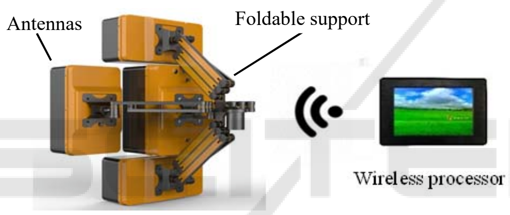

Figure 1: Multi-channels UWB bio-radar system.

2.2 Antennas Array and Experiment Setup

According to previous research (Zhang et al., 2006), it needs at least 3 channels to avoid "ghost" if the two dimensional location for a target should be determined. As Figure 2 shows, an antenna combination of one transmitting antenna and three receiving antennas (receiving antennas are marked as R_0, R_1, R_2 and T for transmitting antenna) is adopted in this paper. The transmitting antenna is placed in the middle of the array together with the receiving antenna R_1 on the top of it, another two receiving antennas are on the two sides of antenna T with a distance of 1.08m (the folding arms of the R_0 and R_2 are extended to the longest) repectively to ensure the angle resolution when targets locate at a relatively long distance. Therefore, they show a linear array as Figure 2. Thereinto, the box T contains not only transmitting antenna but host which controls wifi module connects with wireless peocessor and coordinate the linear antenna array smoothly.

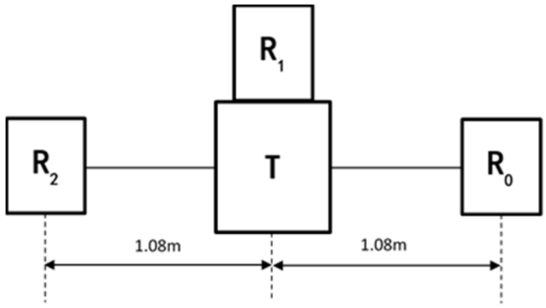

Figure 2: A schematic diagram of a linear antenna array.

In this paper, we intend to verify the effectiveness of the new location method via two different experimental scenarios, namely free-space and through-wall. Firstly we conduct the free-space experiment to verify the principle and then carry out the through-wall detection experiment, so as to gradually verify the rationality and correctness of the novel location method. The two experimental scenes are illustrated by Figure 3 to Figure 6.

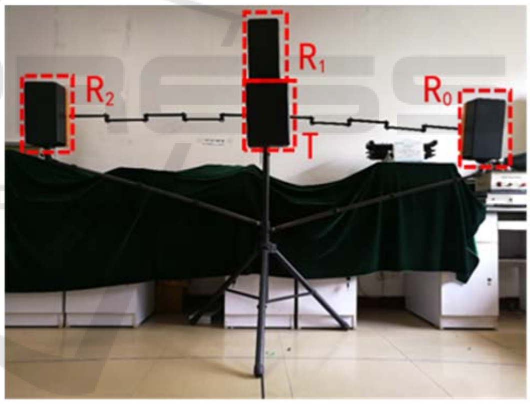

Figure 3: Antenna deployment in free-space scenario.

Figure 4: Experimental scene in free-space scenario.

Figure 5: Antenna deployment in through-wall scenario.

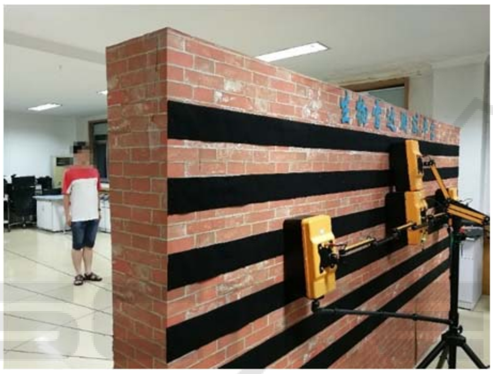

Figure 6: Experimental scene in through-wall scenario.

3 TWO DIMENSIONAL LOCALIZATION METHOD WITH MULTI-CHANNELS BIO-RADAR

The principle of the localization method is shown in Figure 7, the antennas array seems like a line from high angle, the receiver R_1 and transmitter T are approximately treated as the same point. In Figure 7, the traveling time of microwave from T to target P is denoted as τ_p, while τ_0,τ_1 and τ_2 denote the traveling time of reflected microwave from target P to R_0, R_1, and R_2 respectively.

Then, some distances are calculated by

$$\left|\overrightarrow{TP}\right| = \tau_p \cdot \mathrm{c} \tag{1}$$

$$\left|\overrightarrow{PR_0}\right| = \tau_0 \cdot \mathrm{c} \tag{2}$$

$$\left|\overrightarrow{PR_1}\right| = \tau_1 \cdot \mathrm{c} \tag{3}$$

$$\left|\overrightarrow{PR_2}\right| = \tau_2 \cdot \mathrm{c} \tag{4}$$

where c is the speed of light.

The distance of microwaves that sent from the transmitter then reflected by the target P to receiving antennas R_0, R_1, and R_2 are L_0, L_1, and L_2 respectively, then we can get

$$\begin{aligned} \left|L_0 - L_2\right| &= \left(\left|\overrightarrow{TP}\right| + \left|\overrightarrow{PR_0}\right|\right) - \left(\left|\overrightarrow{TP}\right| + \left|\overrightarrow{PR_2}\right|\right) \\ &= \left|\left|\overrightarrow{PR_0}\right| - \left|\overrightarrow{PR_2}\right|\right| \end{aligned} \tag{5}$$

Therefore, the absolute value of difference between $\left|\overrightarrow{PR_0}\right|$ 与 $\left|\overrightarrow{PR_2}\right|$ is equal to that between L_0 and L_2 which could be acquired by bio-radar easily. According to the knowledge of analytic geometry, if the absolute value of the distance difference between the point P and another two points on the plane is fixed, then the point P is located on one branch of the hyperbola with the focus of R_0 and R_2.

Mathematically,

$$c_{\mathrm{h}} = \overline{R_2T} = \overline{TR_0} \tag{6}$$

$$2a = \left|L_0 - L_2\right| = \left|\left|\overrightarrow{PR_0}\right| - \left|\overrightarrow{PR_2}\right|\right| \tag{7}$$

Among them, c_h is a half focal length of hyperbola, a indicates the real half axis of hyperbola, so the imaginary half axis of hyperbola is calculated by $b = \sqrt{c_h^{\,2} - a^2}$. Taking a set of data in the experiment (whose actual coordinates are (-1,-5)) for an example, then the hyperbola determined by R_0, R_2 and T is acquired as Figure 8 shows. If $L_0>L_2$, the target is in the left branch of the hyperbola in the third quadrant of Cartesian coordinates; If $L_0<L_2$, the target is in the right branch of the hyperbola in the fourth quadrant of Cartesian coordinates. While, it is not adequately to calculate on which specific point of that branch the target locates. Besides, we treat T and R_1 as the same point, so we can suppose that $\tau_p=\tau_1$, namely $\left|\overrightarrow{TP}\right| = \left|\overrightarrow{PR_1}\right|$. Then target P is also on the circle with the radium of r as shown in Figure 9.

$$r = \frac{L_1}{2} = \frac{\left|\overrightarrow{TP}\right| + \left|\overrightarrow{PR_1}\right|}{2} \tag{8}$$

If we plot that hyperbola and arc described above in the same Cartesian coordinate system, they will intersect at two points as shown in Figure 10. For this sample of data, due to the $L_0 > L_2$, we get (-1.056, -5.077) by tracking the intersection of the two curves in the third quadrant. Thus, we accomplished the two-dimensional positioning of the target P. In addition, the positioning result have little error compared with actual position of target namely (-1, -5). The absolute error is less than 8cm in this example.

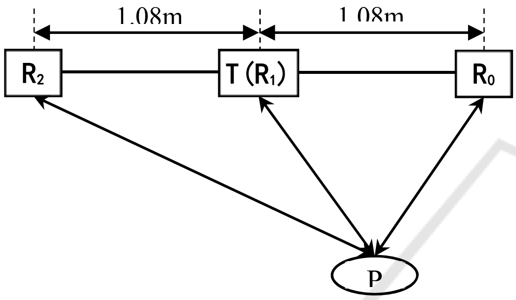

Figure 7: The principle of the localization method.

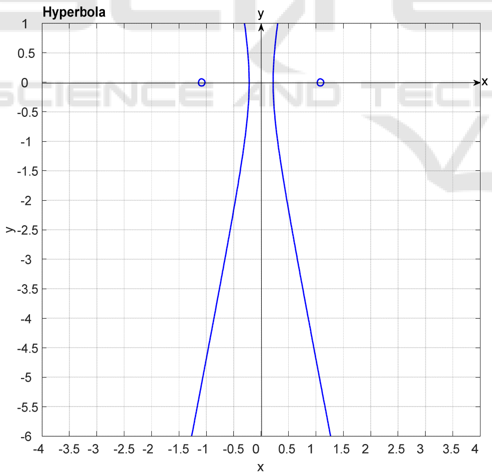

Figure 8: Hyperbola determined by R_0, R_2 and T.

(8)

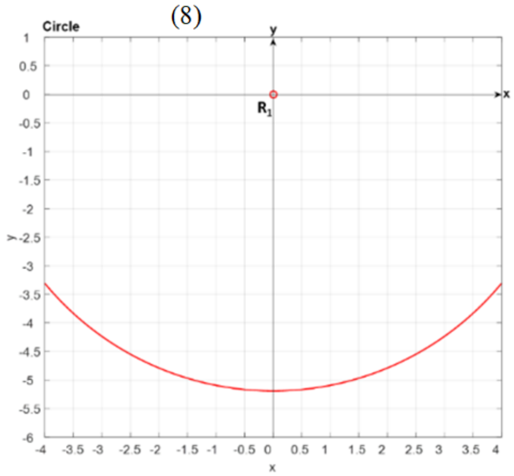

Figure 9: Circle determined by R_1 and T.

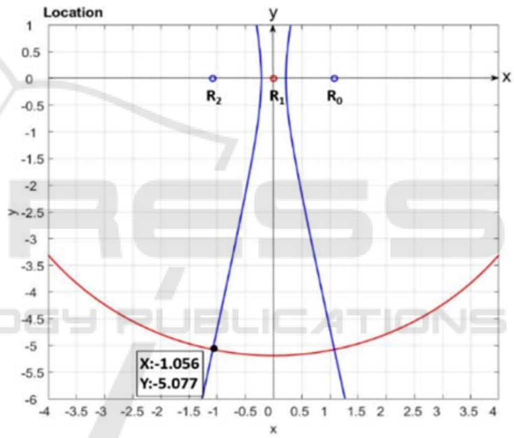

Figure 10: The method of the ensure the specific coordinates of the target.

4 EXPERIMENT RESULTS AND DISCUSSION

In order to describe the position of the target more easily, we have set up a Cartesian coordinate system on the ground of the laboratory as Figure 11 and Figure 12 show. The target positions were divided into 25 different points and marked with corresponding number. The position of the host of bio-radar is set as the origin of coordinates, both receiving antennas R_0 and R_2 are lied in horizontal axis. In free-space experiment, most coordinates of position are integer value except for positions on right sides of the coordinate system because of the limitation of the experimental site. In through-wall experiment, we let the bio-radar system turn around and carried out the experiment in opposite direction, so positions on left sides of the coordinate system is not integer value as shown in figures below.

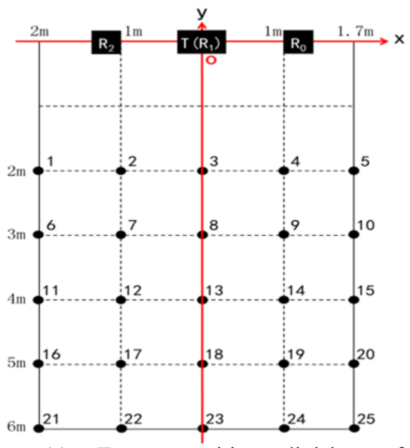

Figure 11: Target position division of free-space experiment.

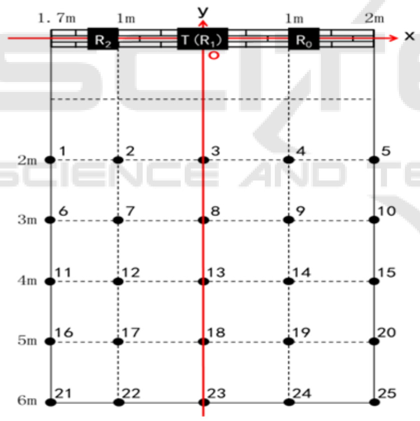

Figure 12: Target position division of through-wall experiment.

We calculate the errors between detection results and real positions. As for the example referred above, the detection results is (-1.056,-5.077) and the real coordinates of the positions is (-1,-5), so the distance between (-1.056,-5.077) and (-1,-5) namely error is 0.095m. To cooperate with the Cartesian coordinate system set above, experimental results are listed in Table1 and Table 2 in the form of matrix below. Among them, color red indicates a lager error but color green means a smaller error. What's more, we drew data of both the two scenarios into one line diagram as Figure 13 shows.

Table 1: Errors between detection results and real positions of free-space [a].

Ordinate	Abscissa				
	-2	-1	0	1	1.7
-2	0.122	0.014	0.090	0.143	0.098
-3	0.071	0.082	0.090	0.020	0.152
-4	0.134	0.130	0.060	0.158	0.092
-5	0.161	0.095	0.100	0.161	0.122
-6	0.192	0.221	0.050	0.142	0.067

[a] Unit of data in the table: m

Table 2: Errors between detection results and real positions of through-wall [a].

Ordinate	Abscissa				
	-1.7	-1	0	1	2
-2	0.175	0.277	0.210	0.036	0.121
-3	0.054	0.071	0.140	0.102	0.194
-4	0.153	0.100	0.160	0.140	0.028
-5	0.122	0.114	0.120	0.126	0.100
-6	0.291	0.110	0.130	0.014	0.106

[a] Unit of data in the table: m

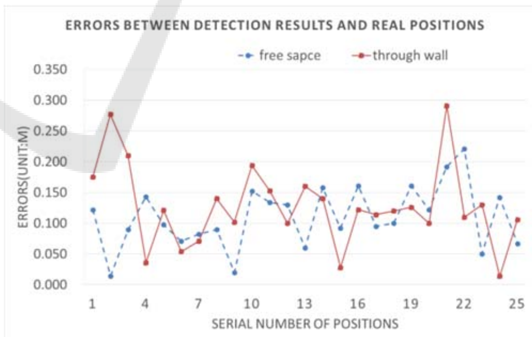

Figure 13: Errors between detection results and real positions of two scenarios.

5 CONCLUSIONS

This paper proposed a novel two-dimensional localization method for life target detection using multi-channels bio-radar based on hyperbolic model. Actual experimental results show that the proposed method could avoid the circumstance that different arcs fail to intersect into one point. Moreover, it could accurately determine the coordinates of a life target no matter in application of free-space or trough-wall scenarios.

ACKNOWLEDGMENTS

Research in this paper was supported by National Natural Science Foundation of China (Grant No. 61327805), Shaanxi Technology Committee (Grant No. 2016KJXX-03) and National Natural Science Foundation of China (Grant No. 31600796).

REFERENCES

Kocur D, J Rovňáková and D Urdzík 2011 Mutual shadowing effect of people tracked by the short-range UWB radar *International Conference on Telecommunications and Signal Processing*

Liang F, et al. 2016 Detection of Multiple Stationary Humans Using UWB MIMO Radar *Sensors* **16(11)** 1922

Lv H, et al. 2016 Improved Detection of Human Respiration Using Data Fusion Based on a Multistatic UWB Radar *Remote Sensing* **8(9)** 773

Monica S and G Ferrari 2015 UWB-based localization in large indoor scenarios: optimized placement of anchor nodes *IEEE Transactions on Aerospace & Electronic Systems* **51(2)** 987-999

Nguyen V H and J Y Pyun 2015 Location Detection and Tracking of Moving Targets by a 2D IR-UWB Radar System Sensors **15(3)** 6740-6762

Qi F, et al. 2016 Detection and Classification of Finer-Grained Human Activities Based on Stepped-Frequency Continuous-Wave Through-Wall Radar *Sensors* **16(6)** 885

Zhang Y, et al. 2006 Secure localization and authentication in ultra-wideband sensor networks *IEEE Journal on Selected Areas in Communications* **24(4)** 829-835