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Research on Indoor Multi-target Simultaneous and Precise Localization

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Abstract
Recent years, the research about indoor localization technology has entered a new epoch. However, most existing positioning systems only apply to single-target localization. For multiple targets, achieving simultaneous and precise localization is becoming a great difficulty in the indoor field. The main reason is inter symbol interference (ISI) which comes from multiple signals transmitted simultaneously. To solve this problem, we propose a novel method in this paper. By employing robust time reversal (TR), simultaneous and precise localization of multi-target can be achieved in the basis of indoor channel model predicted by fast marching method (FMM) and simultaneous algebraic reconstruction technique (SART). To verify the performance of the presented method, numerical simulations are carried out. The results show that FMM-SART can excellently predict indoor model which is close to real environment. Based on this predictive model, TR technology can simultaneously locate multi-target in the range of 2cm.

Keywords
Multi-target, Indoor Simultaneous Localization, Fast Marching Method, Time Reversal

I. Introduction

Recently, target positioning has attracted much attention. Many positioning systems have been studied, such as GPS of USA, GLONASS of European, BEIDOU of China [1-2]. Nevertheless, these systems are limited to outdoor environment due to satellite signals weak when it reaches ground. Currently, some indoor positioning technologies have been studied and applied to indoor environment.

At present, indoor positioning technologies commonly base on infrared, Bluetooth, ultrasonic, ultra wide band (UWB), Radio Frequency Identification (RFID), etc. Relative poor positioning precision of infrared-based positioning technology can be got due to Non-Line of Sight (NLOS) propagating and short transmission distance [3]. While Bluetooth-based system can locate targets easily by measuring Received Signal Strength Indicator (RSSI), the stability of Bluetooth system is very poor in indoor environment [4-5]. Ultrasound-based indoor positioning technology has integrally higher accuracy by delay signal it requires large investments of hardware facilities and the cost is too high [6]. RF-based location technology has great cost advantage and is suitable for NLOS condition. But its communication capability reduces due to the effect of short distance. Moreover, it is difficult to expand to other systems [7].

For above discussed methods, they are generally suitable for single target localization, and there are various defects in accuracy of positioning. Especially, for multiple targets positioning, these methods are not applicable.

To precisely and simultaneously locate multiple targets under indoor environment, we propose a novel method, which is a combination of FMM-SART method with TR technology. In this new method, FMM-SART method is applied to inverse evaluate channel model and TR technology is employed to achieve positioning of multi-target. FMM algorithm estimates channel model through the difference of TOF to calculate propagation path from source to receiver. SART method iteratively updates velocity distribution by changing emitters. TR technology locates multi-target by utilizing the reciprocity of transceiver [8]. The proposed method has been done on simulation demonstrations in indoor complicated environment. Simulation results show that the novel method can simultaneously locate multi-target with high accuracy.

II. Channel Model Prediction Method and Reconstruction Technology

This section mainly introduces proposed indoor positioning methods. It is divided into two phases as following. To predict indoor model, FMM-SART method will be discussed in the first part. Then, the second phase will describe reconstruction technology for indoor multi-target in detail.

A. Channel Model Prediction Method, FMM-SART

The FMM is a level set method, proposed by Osher and Sethian [9-10]. It is originated from the ray theory [11] and has been applied in electromagnetic field. And it is used to compute the time of flight (TOF) and the signal propagation path under the assumptive environment distribution. Then, SART is employed to update velocity distribution (VD) continually [12-13]. We utilize FMM-SART to predict indoor channel model. Its main procedures involve the following steps.

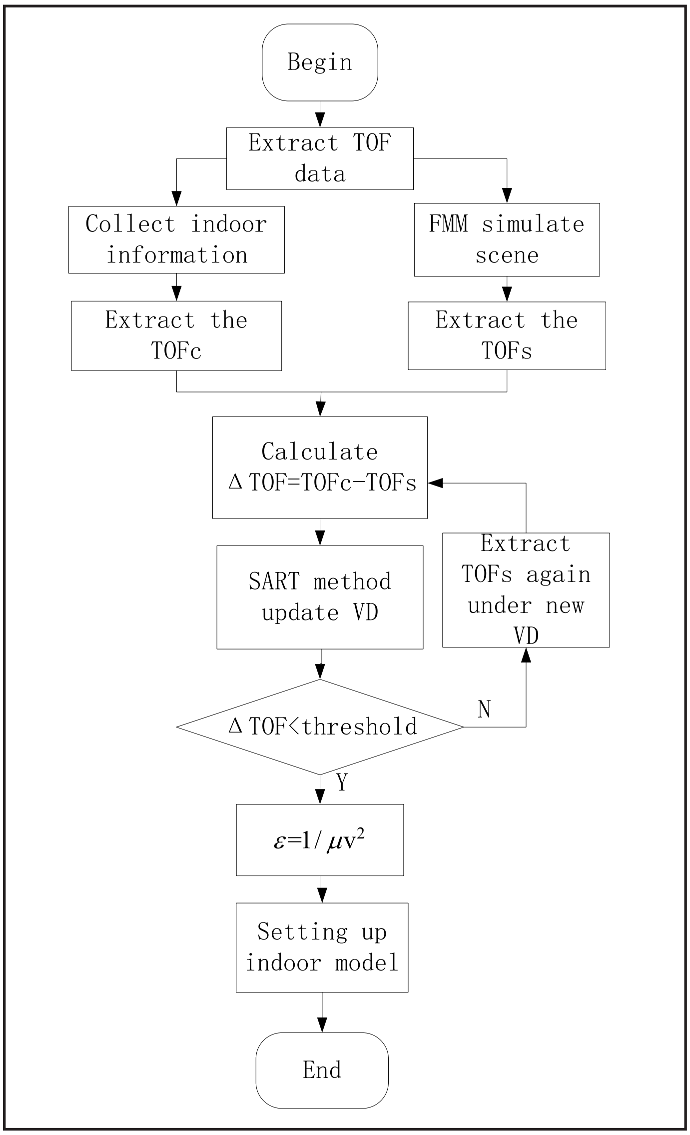

Fig.1: Channel Model Prediction Procedures

Extracting TOF data. TOF is the propagation time of signal possessing the largest amplitude. It contains the extract of $TOF_c(i)$ and $TOF_s(i)$. $TOF_c(i)$ is the TOF collected from the sensor of i. $TOF_s(i)$ is the TOF of the ith sensor computed by FMM in term of the assumptive homogeneous media.

- Calculating the difference of TOF byequation (1) :

$$\Delta TOF_i = (TOF_c(i) - TOF_s(i))/L \quad (1)$$

In which L is the length of the ray path from the seed point to the receiver of i.

- Utilizing SART method to update VD. SART attempts to iteratively update the initial assumed velocity distribution towards to the real distribution by different TOF. It updates a pixel (x,y) in iteration k according to the following equation:

$$v^{k+1} = dx/(dx/v^k + \sum_i^n \Delta TOF_i) \quad (2)$$

Where k is regarded as the iterative step, dx is called as the length of discrete point and n is the amount of rays by updating the given point.

- Judging whether ΔTOF_i is smaller than threshold. If it is "N", the TOFs will be extracted again under new VD until ΔTOF_i is smaller than threshold. If it is "Y", the permittivity distribution will be calculated by the formula:

$$\varepsilon = 1/\mu v^2 \quad (3)$$

- Here, ε represents permittivity value and μ denotes permeability value. After inputting velocity distribution, we can get the electromagnetic permittivity distribution.
- Setting up indoor channel model in terms of permittivity distribution in last step.

B. Multi-target Reconstruction Technology, TR

The application of TR to communication was suggested in recent years. However, it is scarce for indoor multi-target positioning. In this section, we will introduce the primary principle of TR for multi-target. Its main procedure can be illustrated as Fig. 2.

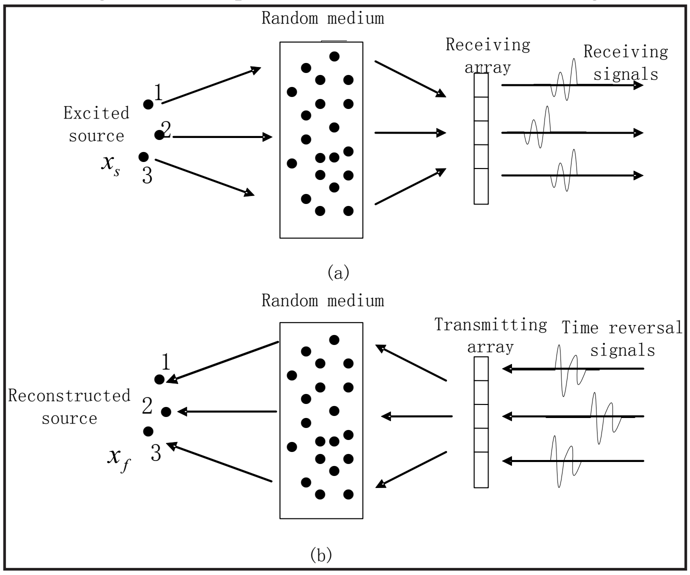

Fig.2: Multi-target Time Reversal Procedure Schematic. (a) is forward procedure of TR and (b) is reversed procedure of TR.

According to the reciprocity principle of the green's function existing [14]:

$$G(x_r, x_s, t) = G(x_s, x_r, t) \quad (4)$$

Where x_r is the position of receiving array and x_s is excited source location. It indicates that if propagation channel is invariable, it will take the same time between inversed procedure and forward process.

Assuming signal $x(t)$ is sent from source $c(m_0, n_0)$ and transfer function is $h(\tau, m_0, n_0)$, the signal of receiving array can be expressed as:

$$y(t) = x(t) * h(\tau, m_0, n_0) + n(t) \quad (5)$$

Here, $n(t)$ is noise which is only related to time. '*'denote convolution operation. We inverse $y(t)$ along time and make it go through the same channel function $h(\tau, m_0, n_0)$. Reconstructed signal at x_f will be described as:

$$\begin{aligned} z(t, m_i, n_i) &= y(-t) * h(\tau, m_i, n_i) \\ &= x(-t) * h(-\tau, m_0, n_0) * h(\tau, m_i, n_i) \\ &\quad + n(-t) * h(\tau, m_i, n_i) \\ &= x(-t) * R(\varepsilon, \rho, N) + n(-t) * h(\tau, m_i, n_i) \end{aligned} \quad (6)$$

In this equation, $R(\varepsilon,\rho,N)$ is the correlation function between $h(\tau,m_i,n_i)$ and $h(\tau,m_0,n_0)$, in which $\rho = m_0 - n_i$, $N = n_0 - n_i$. The signal component of $z(t,m_i,n_i)$ is convoluted twice due to it goes through channel twice. Only when satisfying $m_i = m_0$ and $n_i = n_0$, $R(\varepsilon,\rho,N)$ gains maximum value. It demonstrates time reversal focus procedure is coherent superposition while the noise is incoherent superposition. Therefore, the noise is weakened. Sequentially, TR method effectively improves signal to noise ratio (SNR).

III. Simulations and Discussions

In this section, we consider three targets and simultaneously locate them by general TR method and FMM-TR method under indoor environment.

A. Multi-target Indoor Positioning by General TR Method

In section A, we do simulations for three targets by conventional TR method.

A general indoor scene is schemed in Fig.3. When the signal propagates in the indoor environment, it will be reflected and diffracted by interior furnishings such as desk, computer and other scattering objects in the region of interest. To reduce the reflection from wall, PML absorbing boundary is employed. In this simulation, we consider a two-dimensional 600*600 cm indoor environment. Three active sources (Target 1, Target 2, Target3) are positioned at (250,180) (250,420) (300,300) in the room. The size of target is in the range of 10cm×5cm. Sensors are fixed equidistantly into a circle with radius of 240cm.

During the course of positioning, the forward process of time reversal is measured based on practical indoor environment. However, the reverse process is simulated based on unknown environment. Here, we assume indoor environment as uniform dielectric. Sequentially, the back propagation is simulated under homogeneous medium.

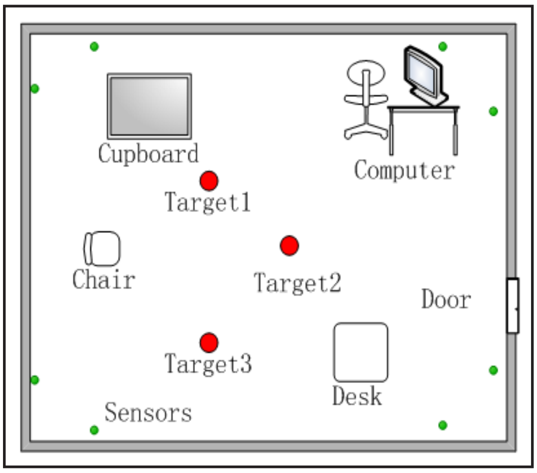

Fig. 3: Indoor Scene

As a result in Fig.4, three targets are located simultaneously by regular TR method. The positioning results show that reconstructed positions of three targets are Positioning1(162,200), Positioning2(176,448), Positioning3(269,205). As mentioned above, the actual coordinate positions are (250,180) (250,420) (300,300). The positioning errors respectively are 90.2cm, 79.1cm and 99.9cm. The average deviation is 89.7cm which is quite large.

To further display the reconstructed effect, we make three-dimensional image as shown in Fig. 5. It shows that there are many cluttered peaks in this domain. Three unobvious peaks are surrounded by some small side lobes. They are short and thick. According to above analysis, we can conclude that this conventional TR method can only judge general location of multiple sources. By this means, we can predict how many targets in indoor environment, yet their exact locations can't be calculated.

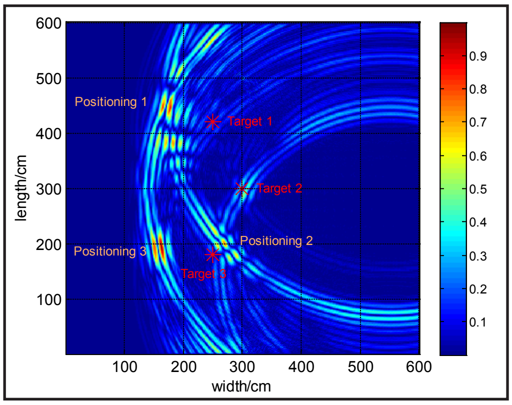

Fig. 4: Positioning Results for Three Targets by General TR Method under Homogeneous Medium. The real point represents reconstructed position by TR method. Positioning 1, Positioning 2 and Positioning 3 are reconstructed positions. The marker " " denotes actual position represented by Target 1, Target 2 and Target 3.

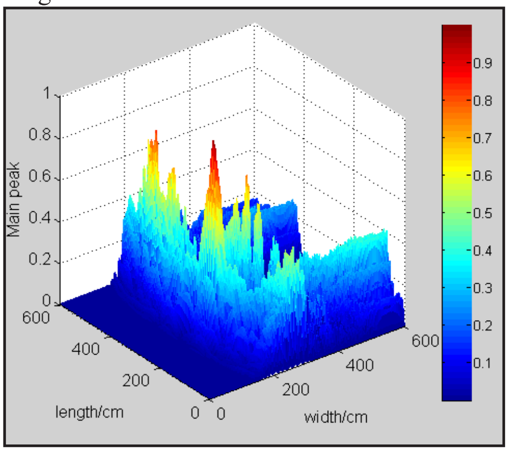

Fig. 5: Three-dimensional Image

B. Multi-target Indoor Positioning by FMM-SART Method

In section B, we do simulations for three targets by FMM-TR method. This procedure can be divided into two stages. In the first stage, we assume an indoor channel model and figure out it by FMM-SART method. In the second stage, we utilize this estimated model and combine TR technology to simultaneously locate three targets.

1. Channel Model Estimation

In this sub section, we assume a general indoor channel model and predict this model by FMM-SART method.

The top view of room is shown in Fig. 6. We simplify complex indoor model as four circular barriers. Their coordinates are (180,400) (420,400) (180,200) (420,200). The radius is 60cm. The relative permittivity is sited as 2.0, 2.5, 3.0 3.5. Five emitters are placed at (300,300) (300,420) (300,180) (160,300) (440,300). They can send short Gaussian pulse. The frequency is 2.45GHz.

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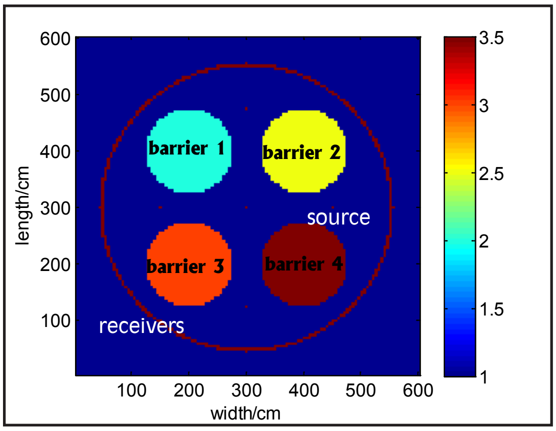

Fig. 6: Top View of Simplified Indoor Model

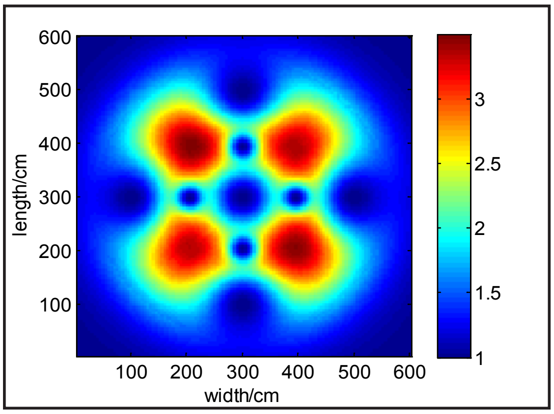

Fig. 7: Estimated Indoor Model

After filtering interferential signals derived from emitters and sensors, the optimal predicted model can be recovered in Fig. 7. It is obvious that estimated channel model approach to real situation which can be observed in Fig. 6. Four circular barriers demonstrate they have the same shape, value and electromagnetic distribution between predictive model and actual model. Thus, we have built an excellent indoor channel model which near to practical condition. To verify the performance of estimated model, we do simulations for multi-target based on this predicted model in section 2.

2. Indoor Positioning for Multi-target

In section 2, we do the same setup with section A to locate three targets based on estimated channel model in section 1.

We position three active sources together at (250,180), (250,420), (300,300). They are also above three targets (Target1, Target2, Target3) in section A. From Fig.8, three pulse signals are accepted successively in the receiver position. It indicates waveform trend received by one antenna. Signal amplitude is attenuate along the time axis. In Fig.9, we receive arrival of time (TOA) of all transducers receiving signals. Four nodes is scattered in every waveform. Every paragraph possesses special waveform which results from interference of four different degree barriers. For Fig.8, signals are reversed in time and then we can obtain the time reversal signals from Fig. 10. Comparing Fig.8 with Fig.10, they are exactly symmetrical on the time. Amplitude is consistent in accordance with time. According to multipath compensation principle, time reversal signals will be focused at initial point in time and space.

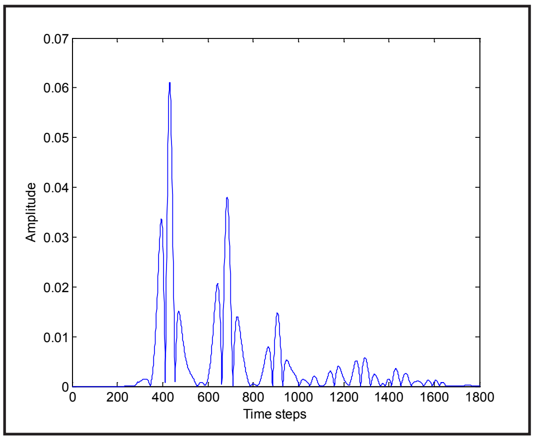

Fig. 8: Received Signals by One Antenna

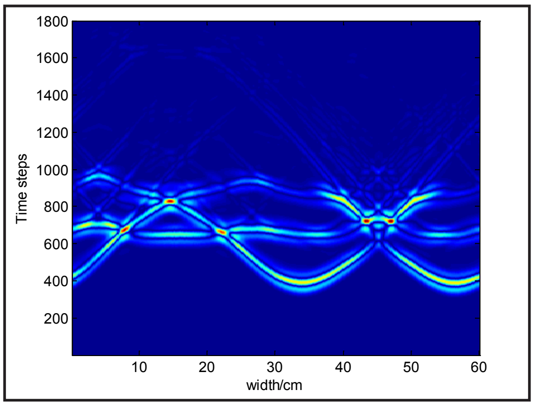

Fig. 9: Receiving Time of All Antennas

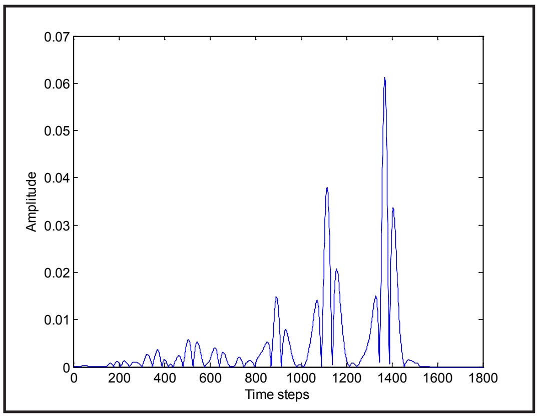

Fig. 10: Time Reversal Signals of Fig.8

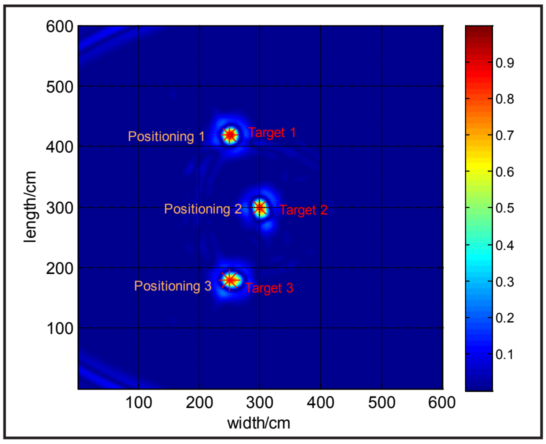

Fig. 11: Positioning Results for Three Targets by FMM-TR Method. The solid point represents reconstructed position by

FMM-TR method. The marker " " denotes actual position.

As seen on Fig.11, three bright spots clearly appear. The results show that three targets are well localized at (251.6,178.2), (248.3,178.8), (301.4,298.6). The accuracy of reconstructed sources is 2.41cm, 2.08cm, 1.98cm respectively. Reconstructed position by this method is an average of 2.16cm that is extremely close to real position. Their coordinates nearly overlap. In order to further validate the simulation results, we provide 3D image as shown in Fig. 12. It can be calculated that, the energy are diffused about 3cm away from the targets. The peak value of the proposed method is nearly 1.33 times larger than by general TR method.

The comparison between Fig. 4 and Fig.11 shows that the positioning accuracy of proposed method can increase 41.53 times effectively. The image contrast is greatly improved by the proposed iterative reconstruction method.

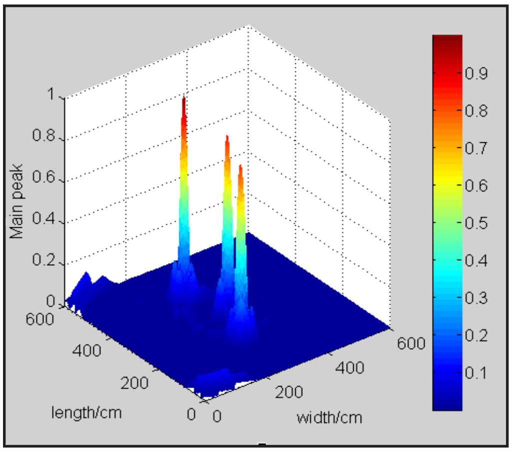

Fig. 12: Three-dimensional Image

IV. Conclusion

In this paper, the presented method has been used to estimate channel model and locate multi-target under indoor environment. Numerical simulation results show that new approach can excellently predict indoor model which is approach to real environment for indoor positioning. It proves that proposed method has better performance than the regular TR method in both the localization accuracy and image contrast for multiple-target positioning. The new method has relatively high efficiency and low complexity. It can be used to compute any indoor channel model directly, fast and in real time. As the high precision of this method, it will have great potential application for indoor multiple small mobile terminals positioning. Future research can be focused on applying it to the reality.

V. Acknowledgement

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References

[1] *Mautz R. Indoor positioning technologies[D]. Habil. ETH Zürich, 2012, 2012.*

[2] *Koyuncu H, Yang S H. A survey of indoor positioning and object locating systems[J]. IJCSNS International Journal of Computer Science and Network Security, 2010, 10(5): 121-128.*

[3] *Al Nuaimi K, Kamel H. A survey of indoor positioning systems and algorithms[C]//Innovations in Information Technology (IIT), 2011 International Conference on. IEEE, 2011: 185-190.*

[4] *Chen L, Pei L, Kuusniemi H, et al. Bayesian fusion for indoor positioning using bluetooth fingerprints[J]. Wireless personal communications, 2013, 70(4): 1735-1745.*

[5] *Wang Y, Yang X, Zhao Y, et al. Bluetooth positioning using RSSI and triangulation methods[C]//Consumer Communications and Networking Conference (CCNC), 2013 IEEE. IEEE, 2013: 837-842.*

[6] *Runge A, Baunach M, Kolla R. Precise self-calibration of ultrasound based indoor localization systems[C]//Indoor Positioning and Indoor Navigation (IPIN), 2011 International Conference on. IEEE, 2011: 1-8.*

[7] *Zeng H, Zhang J, Dai G, et al. Security Visiting: RFID-Based Smartphone Indoor Guiding System[J]. International Journal of Distributed Sensor Networks, 2014, 2014.*

[8] *Paek E G, Choe J Y. Distributed time-reversal mirror array: U.S. Patent 8,350,750[P]. 2013-1-8.*

[9] *Sharifi M, Kelkar M. Novel permeability upscaling method using Fast Marching Method[J]. Fuel, 2014, 117: 568-578.*

[10] *Valero-Gomez A, Gomez J V, Garrido S, et al. Fast Marching Methods in Path Planning[J]. IEEE Robotics and Automation Magazine, no, 2013.*

[11] *Chen G, Wang W, Zeng H, et al. Combining Time Reversal and Fast Marching Method in Wireless Indoor Positioning[J]. International Journal of Information Technology & Computer Science, 2013, 5(12).*

[12] *Lin Y, Samei E. An efficient polyenergetic SART (pSART) reconstruction algorithm for quantitative myocardial CT perfusion[J]. Medical Physics, 2014, 41(2): 021911.*