Precise indoor localisation technology based on TR-FMM

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Aiming to precisely locate a small mobile communication terminal in an indoor complex environment, a combination method, the time reversal-fast marching method (TR-FMM), is presented. The proposed method has been validated based on simulations in an indoor environment. The results demonstrate that it can build an excellent indoor channel model which is close to the actual environment. Localisation accuracy can be improved about 32.71 times than the regular TR method and the localisation error is 1.84 cm.

Introduction: With the increase of locating requirements, wireless indoor positioning technology has become more important in recent years. However, most existing indoor positioning systems have many limitations in positioning accuracy [1].

To achieve precise indoor localisation, a novel time reversal-fast marching method (TR-FMM) is therefore put forward. It involves two stages. In the first stage, an indoor channel model is predicted by the FMM [2, 3]. In the second stage, TR technology [4, 5] is employed to locate a small mobile communication terminal (SMCT) based on the predicted channel model. In the following, we introduce the main procedure of the TR-FMM, as shown in Fig. 1. It involves the following steps:

(a) Fix antennas around the room and collect TOF_c.
(b) Calculate the TOF_s at all detectors by the FMM based on the assumed field. Compute the propagation paths and the corresponding length L of each path.
(c) Calculate the difference between TOF_c and TOF_s, the correction factors as

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

TOF is the time of flight. TOF_c is the collected TOF and TOF_s is the simulated TOF. i represents the ith sensor.

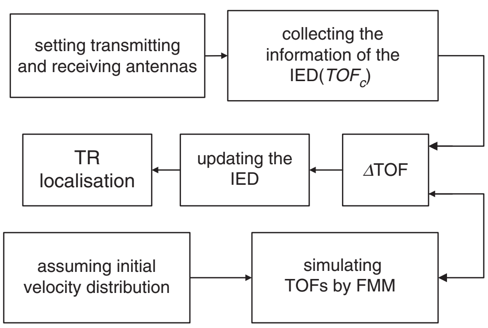

Fig. 1 *Localisation procedure by TR-FMM*

(d) Utilise the simultaneous algebraic reconstruction technique [6] to update the indoor environment distribution (IED) according to the ΔTOF along the paths described in step (c). The update method is

$$F^k(x, y) = dx/\left(dx/F^{k-1}(x, y) + \Delta TOF_i\right) \quad (2)$$

$F^k(x, y)$ is the velocity of pixel (x, y) in the kth iteration. dx is the size of one grid.
(e) Judge whether ΔTOF described in step (c) is smaller than a threshold or not. If ΔTOF is smaller than the threshold, then locate the SMCT using TR based on the indoor distribution in step (b). If not, repeat the process from steps (c) to (e) based on the latest updated IED in step (d).
(f) Transform velocity distribution in terms of

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

ε is the relative permittivity and u is the relative permeability. c denotes relative velocity.

(g) Locate the target by TR technology. The positioning principle is the reciprocity of the Green's function which can be expressed as

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

Here, x_s and x_r are the source point and the receiving point. t is the propagation time between x_r and x_s.
Simulation setting: In this simulation, we put up the assumed indoor channel model as shown in Fig. 2. The detailed parameter setting of the channel model is listed in Table 1. The five active sources are, respectively, fixed at (300, 300) (300, 425) (180, 250) (420, 250) to send pulse signal in turn.

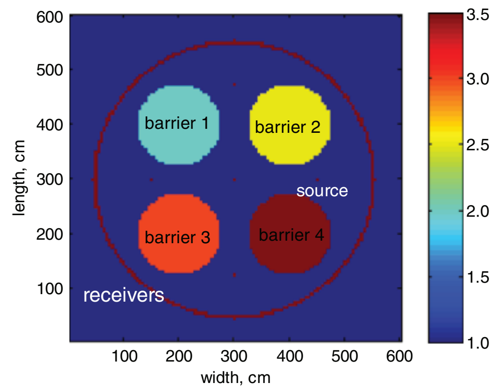

Fig. 2 *Assumed indoor channel model*

Table 1: Setting of indoor environment

	Centre coordinate	Radius	Relative permittivity	Relative permeability
Barrier 1	(180, 400)	70	2.0	1.0
Barrier 2	(420, 400)	70	2.5	1.0
Barrier 3	(180, 200)	70	3.0	1.0
Barrier 4	(420, 200)	70	3.5	1.0

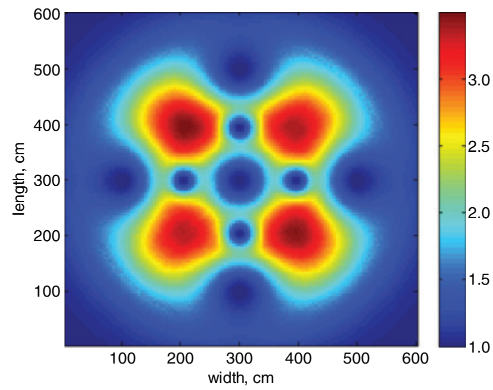

Fig. 3 *Estimated indoor channel model*

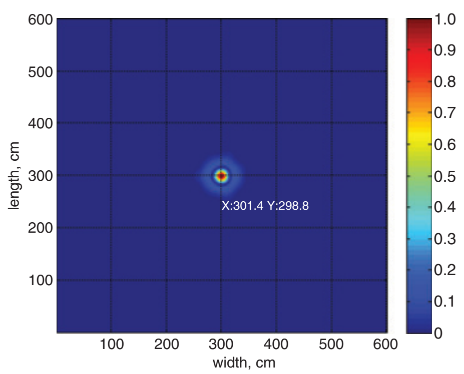

Fig. 4 *Localisation by TR-FMM based on estimated indoor channel model of Fig. 3*
Position is at (301.4, 298.8). Deviation is 1.84 cm

Simulation results: We simulated the channel model by the FMM and the results are shown in Fig. 3. There are four obvious rounds. They not only similar in shape but also on the data are proximate to Fig. 2. It was observed from Fig. 3, the novel method has excellently built an indoor channel propagation model.

An SMCT is fixed at (300, 300) which is the localisation target. In Figs. 4 and 5, we locate this target by the TR-FMM and only TR methods, respectively. Fig. 6 displays comparisons of three-dimensional (3D) imaging results.

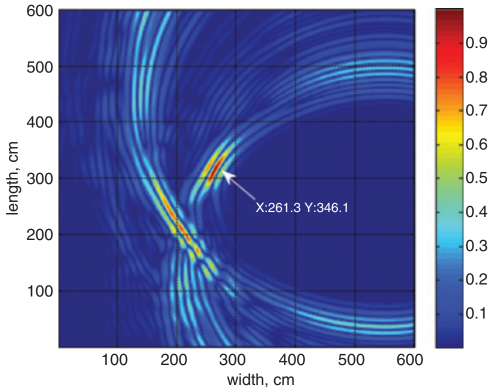

Fig. 5 *Localisation by regular TR based on unknown model*
Position is at (261.3, 346.1). Deviation is 60.19 cm

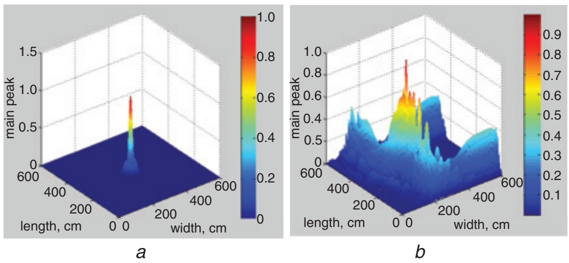

Fig. 6 *3D reconstruction results*
a By TR-FMM
Main peak is tall and slim. Energy is concentrated
b By regular TR method
Energy is relative scattered. Many other bulges which are stray waves surround it

Table 2: Comparison results by two methods

C	Localisation position (cm)	Remodelling waveform (dB)	PSF
M			
Only TR	(261.3, 346.1)	12.23	10.18
TR-FMM	(301.4, 298.8)	1.48	6.24
Improved times	32.71	8.26	1.63

To further analyse the results and validate the performance of the proposed method, a form is carried out in Table 2. C denotes comparison items and M represents methods. PSF is point spread function. To verify the stability of the proposed method, 10 times simulations are done as shown in Fig. 7. The results demonstrate that the proposed method is reliable for indoor target positioning.

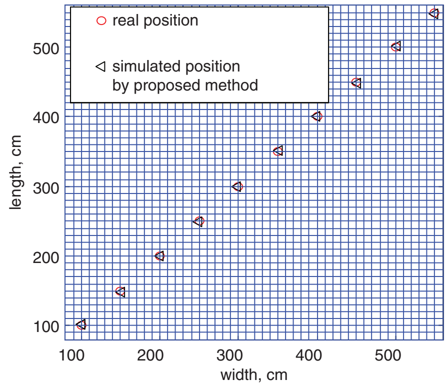

Fig. 7 *Many times results*

Conclusion: In this Letter, a new time reversal method, FMM, combining technology is proposed for indoor SMCT localisation. Simulation results show that the proposed method shows better performance than the regular TR method in localisation accuracy. Time consumption of one target localisation using the presented method is about 2.26 min. This procedure is performed by MATLAB 7.1 codes in a CoreII personal computer (PC) platform with a Windows 7 operating system, the PC having a dual-central processing unit running at 1.8 GHz, and a 2 GB memory configuration. More fast and accurate localisation can be expected when these codes are optimised in a special hardware platform. It has been demonstrated that the proposed TR-FMM combining method will be a useful technology in indoor positioning.

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One or more of the Figures in this Letter are available in colour online.

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References

1 Mautz, R.: 'Indoor positioning technologies' (Habil, ETH Zürich, 2012)
2 Sharifi, M., and Kelkar, M.: 'Novel permeability upscaling method using fast marching method', *Fuel*, 2014, **117**, pp. 568–578
3 Gómez, J.V., Álvarezm, D., Garrido, S., *et al.*: 'Improving sampling-based path planning methods with fast marching/ROBOT2013'. 1st Iberian Robotics Conf., Springer International Publishing, 2014, pp. 233–246
4 Borcea, L., Papanicolaou, G., and Tsogka, C.: 'Theory and applications of time reversal and interferometric imaging', *Inverse Probl.*, 2003, **19**, (6), p. S139
5 Paek, E.G., and Choe, J.Y.: 'Distributed time-reversal mirror array'. U.S. Patent, 8,350,750. 2013-1-8
6 Lin, Y., and Samei, E.: 'An efficient polyenergetic SART (pSART) reconstruction algorithm for quantitative myocardial CT perfusion', *Med. Phys.*, 2014, **41**, (2), p. 021911