Journal of Theoretical and Applied Information Technology
20th February 2013. Vol. 48 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

INDOOR AND OUTDOOR COOPERATIVE REAL-TIME POSITIONING SYSTEM

[1,2]JIANQI LIU, [3]QINRUO WANG, [4]JIANBIN XIONG, [5]WANGHUA HUANG [6]HUI PENG
[1, 3, 4, 5] Guangdong University of Technology, Guangzhou 510006, China
[2] College of Information Engineering, Guangdong Jidian Polytechnic Guangzhou, 510515, China
[6] Guangxi Vocational & Technical Institute of Industry, Nanning 530001, China
E-mail: [1]liujianqi@ieee.org, [3]wangqr2006@gdut.edu.cn, [4]276158903@qq.com, [5]147890672@qq.com, [6]ph2920116@sina.com

ABSTRACT

This paper proposes a cooperative real-time positioning system to solve both indoor and outdoor location tracking problem for disaster aid, we conduct a detailed overview of pre-existing indoor positioning systems, give architecture of cooperative positioning system, and introduce the least square method to improve accuracy of time difference of arrival (TDOA) positioning algorithm. Meanwhile, we address a method of coordinate transformation, which can transform rectangular coordinate to latitude and longitude. With these, the indoor location information and GPS information can be displayed on the maps. Finally, experiment shows the precision of cooperative positioning system, which can satisfy the disaster aid requirements.

Keywords: *Positioning System, Disaster Aid, 2D Positioning, GPS, TDOA*

1. INTRODUCTION

The need to locate people and objects as soon as possible has always been an important part of any organization or industry, such as cyber information system[1], mass casualty disaster aid[2, 3]. Natural disasters usually cause mass casualty incidents (MCI), such as earthquake, tsunami, volcanic eruption, fire hazard. For example, the Great Sichuan Earthquake has caused 69,180 known deaths and 374,176 injured according to Chinese official report. The same thing happened in Japan, according to the report of Japanese National Police Agency, there were 15,870 deaths, 6,114 injured in 2011 Tahoka earthquake and tsunami. These disasters have caused massive casualties, which involved varied types of rescuers or doctors. Unfortunately, traditional rescue operations are unable to know accurate location of patient, patients can move freely and often depart from the disaster scene without authorization from commander of emergency medical service (EMS). When patients contaminated with hazardous materials (e.g., cholera) depart before they are decontaminated, public facilities and receiving hospitals will run into risk for secondary exposure. If an incident commander could track the location of multiple rescuers and patients in-building or out-building from the command post, such capabilities would greatly improve rescue operations at the disaster scene. The patients' accurate position information may be critical or, at least, improve efficiency [4]. With the increasing sophistication of wireless technology, it is now possible to remotely locate patients or medical objects in indoor and outdoor environments. The rescuers or commander can track the patient or other objects conveniently on geographic information system (GIS) or map such as Google Maps.

An outdoor positioning system is to equip with global positioning system (GPS) receiver. GPS is a most widely used satellite-based positioning system, which offers maximum coverage, an accuracy of GPS can achieve about 3m [5]. But in the indoor environment, we should find other methods to acquire location information. We know that the communication between receivers and satellites is impossible in non-line-of-sight (NLOS) environment. There are various obstacles, for example, walls, human beings, which lead to multi-path effects [6, 7]. Some interference and noise from other wireless networks such as WIFI, or electrical radiating equipment such as microwave ovens, degrade the accuracy of localization. Irregular building geometry and the density of water vapor in the air leads to reflection, and

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

extreme path loss. The indoor positioning is more complex than the outdoor one. In order to design an appropriate positioning system for disaster aid, we should analyze the aid requirement. First, the number of patients is large, as the disaster often causes great casualties. Second, the scene is chaos; it is very difficult to seek a people or an object. Finally, positioning system must be easy to use with a low cost [8].

For the indoor positioning system, location information of target is relative to anchor nodes' location. It has its own rectangular coordinate system, which is different from geodetic coordinate system. Due to lack of latitude and longitude, there is a difficulty to display the tracking target on the map or GIS on the basis of the location acquired from indoor positioning system, which will influence target tracking. Target's location information should be transformed to latitude and longitude, whilst the indoor and outdoor location information should mix together harmoniously. So the cooperative positioning system that can cope with indoor and outdoor localization should be addressed immediately.

The remainder of this paper is organized as follows. An overview of indoor positioning system for disaster aid is conducted in Section 2. In Section 3 gives the architecture of cooperative positioning system and Section 4 discusses least square positioning algorithm and explains their principle in detail. Section 5 introduces coordinate transformation of indoor positioning. Finally, Section 6 makes a conclusion and presents the future work.

2. OVERVIEWS OF INDOOR POSITIONING SYSTEM

Many different approaches to solving the indoor positioning and navigation issues may be found in the literature. Some use pre-existing WLAN networks [9] while others use dedicated RFID tags and readers [10-12], infrared, ultrasonic, Bluetooth, UWB, or magnetic signals. The main advantage of using a pre-existing wireless communication infrastructure is low cost, coupled with the benefit of the availability of a robust and standardized communication channel that may also be used to support the positioning system [7]. The main drawback is often limited achievable accuracy, due to the fact that the systems are typically not designed for positioning. On the other hand, developing a system primarily aimed at positioning may require a lot of time and resources, but it can provide better control on specifications like accuracy, coverage and power consumption [13]. We conduct a survey of existing positioning system, which may be deployed in disaster aid system.

(a) MASCAL

MASCAL uses a prototype WiFi-based indoor geolocation system from Awarepoint Corporation in La Jolla, CA. This system utilizes existing wireless infrastructure and has three components: 802.11b RFID tags, fixed transceivers that measure ambient 802.11b signal strength and a central geolocation server that computes location [14]. This localization tags measure ambient 802.11b signal strength and periodically broadcast this data back to the location server. The localization algorithm compares tag data with the reference topology, effectively triangulating the location of the tag to within a theoretical resolution of 10 feet approximately. The performance of WiFi positioning has been gained from studies in indoor environments with a very high AP density [15].

(b) MoteTrack

MoteTrack is a robust, decentralized approach to Zigbee-based positioning system developed by Harvard University [16], which is chosen for CodeBlue and AID-N projects. Mote Track does not rely upon any back-end server or network infrastructure: the location of each mobile node is computed using a received radio signal strength signature from numerous beacon nodes to a database of signatures that is replicated across the beacon nodes themselves. This design allows the system to function despite significant failures of the radio beacon infrastructure. [17]. The accuracy of Mote Track can achieve 2-3 m in a building equipped with 20 beacon nodes distributed over one floor. When the denser node is deployed, the higher precision can be acquired, but the higher cost undertakes. The Zigbee-based positioning system can be disqualified from security applications [18] as attackers can easily alter the strength of received signals by either amplifying or attenuating a signal. Since the security is not guaranteed, this algorithm is ruled out in secure application.

(c) Nanotron Find

The Nanotron Find localization platform is high throughput Real Time Location Systems (RTLS) developed by Nanotron Technologies company. Its PHY employed the Chirp Spread Spectrum (CSS) technology based on the unlicensed 2.4 GHz ISM band, can void NLOS influence effectively, tolerate multipath effect to maintain 1 m localization

Journal of Theoretical and Applied Information Technology
20th February 2013. Vol. 48 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

precision [19]. It is a full function RTLS system equipped with nanoANQ or nanoANQ XT RTLS anchors, Nanotron’s Location Server (nanoLES) and nanoTAG that covers about 500 sqm indoors and 5,000 sqm outdoors. With the help of additional anchors or tags the system can be expanded. For example, the development toolbox provides 8 nanoANQ RTLS anchors that cover an area of 500 sqm or more. Twenty nanoTAG tags with configurable blink rate demonstrate system throughput of 200 location readings per second. The deployment of Nanotron Find RTLS in emergency environments, can track patients, staff, and assets, provide many benefits to both patients and responder. The find platform combines high throughput RTLS with wireless transmission of vital data utilizing the same hardware. But it's difficult to realize time synchronization of anchor nodes.

(d) Ubisense

Ubisense positioning system is an in-building UWB radio based tracking system developed by Ubisense company [20], which can determine the positions of people and objects to an accuracy of a few tens of centimeters, using small tags which are attached to objects and carried by personnel, and a network of receivers which are placed around buildings. According to the widely accepted definition, provided by the Federal Communications Commission Regulation, an UWB system is defined as any intentional radiator having a fractional bandwidth greater than 20% or an absolute bandwidth greater than 500 MHz [21]. UWB is well-suited to in-building of emergency field [22], because of its NLOS nature, resilience to multipath signal propagation, 3D-position, modest infrastructure requirements and high tracking accuracy [23]. A properly-architected UWB tracking system is low-power (thus low-maintenance), and the fundamental technology is simple and low-cost. The principle of operation of the UWB ranging system is based on the indirect measurement of the distance between transceivers, obtained by measuring the round-trip time (RTT) of an UWB pulse [24]. However, the price of this high performance positioning system is also high. An active research package includes five tags and four sensors costs about $16,875 [25]. And the problem of time synchronization of anchor node is the same as Nanotron Find.

Performance of indoor positioning system affects its availability directly. We evaluate their performance from the aspects of position accuracy, scalability, cost, and security. The evaluation and comparison results are shown in Table 1.

From the disaster aid aspect, the accuracy of positioning system should be within 2m, and the security should be guaranteed, a lower cost is better. As the increment of patients, the position system still has ability to manage, has a good scalability. From what have been discussed above, building a positioning system similar to Nanotron Find is more suitable than others for disaster aid, but the scalability and accuracy of the positioning algorithm should be improved.

Table 1: Summary Of Positioning System Comparison

System	Criterion					
	Radio	***Algorithm***	***Accuracy***	***Scalability***	***Cost***	***Security***
MASCAL	WIFI	RSSI	10m	Low	Low	No
MoteTrack	Zigbee	RSSI	3-10m	High	Low	No
Nanotron Find	CSS	TDOA	1m	Low	Medium	Yes
Ubisense	UWB	TDOA/ AOA	10-30cm	Mediu	High	Yes

3. ARCHITECTURE OF POSITIONING SYSTEM

In order to improve the efficiency of rescue operation, the incident commander tracks the location of rescuers and patients' in-building and out-building seamlessly.

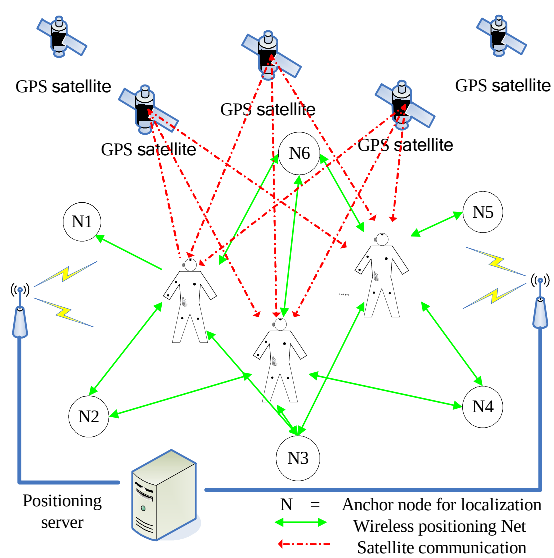

Figure 1: Architecture Of Cooperative Positioning System

The positioning system for disaster aid can be sub-categorized as: (1) the outdoor positioning; (2)

Journal of Theoretical and Applied Information Technology
20th February 2013. Vol. 48 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

the indoor positioning; (3) coordinate transformation for indoor location. The design of positioning system should take whole requirements into account. We propose a new cooperative positioning system as shown in Figure 1, which can accommodate to both indoor and outdoor environments.

For outdoor positioning, GPS consists of a network of 24 satellites in six different 12-hour orbital paths spaced so that at least five are in view from every point on the globe. GPS receiver employs SiRFstarIV GSD4t core chip. It is the first generation of the SiRFstarIV architecture. Optimized for size-constrained applications, it uses a host CPU to run the navigation libraries. The outdoor positioning module benefits from significant power consumption improvements, small package size, ease of integration and low-cost implementation.

Compared with outdoor positioning, the indoor positioning is more complex. In terms of security of positioning algorithm, the received signal strength indication (RSSI) is not suitable for disaster aid, but angle of arrival (AOA) , time of arrival (TOA), time difference of arrival (TDOA) [26], and time of flight (TOF) [27] are security. Because the number of positioning targets (patients, rescuers, and medicine objects) is large, the scalability of system is important, we select TDOA algorithm, and improve accuracy of TDOA by least square (LS) method. For physical layer, we employ CSS radio technology to overcome the NLOS nature and multi-path effect.

The positioning sever receives the difference in time of arriving at multiple anchor nodes, and determines the relative location of the patients or other targets. Meanwhile, the server transforms rectangular coordinate of indoor location to latitude and longitude. Finally, the server fuses the location data of outdoor and indoor, then display the latitude and longitude of targets on the map or GIS.

4. LEAST SQUARE METHOD BASED ON TDOA

The TDOA algorithm can be seen as the intersection of hyperbolas in 2D plane, if in 3D environment can be seen as the intersection of hyperboloids. Positioning systems that use the TDOA algorithm measure the difference in transmission times between signals received from each of the target (such as patient) to anchor nodes. TDOA requires the anchor nodes record any received signal. TDOA requires that each signal be transmitted synchronously, either at the same time or with some known delay occurring in signal transmissions.

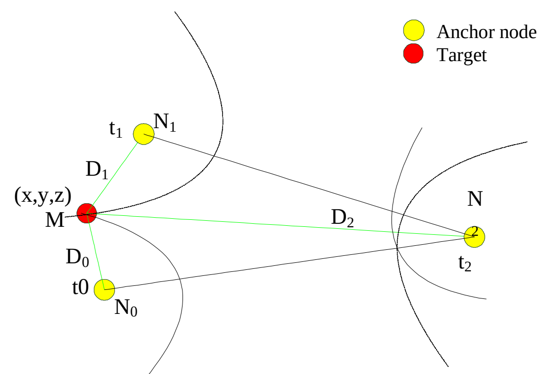

Figure 2: Positioning Based On TDOA Algorithm

For disaster aid, the tall buildings often are destroyed by disaster, the victims put up a tent on the floor. A 2-D positioning system can satisfy the requirement.

A 2-D target location can be estimated from the two intersections of two or more TDOA measurements. Three anchor nodes (N_0 , N_1 , and N_2) are required, whose location is pre-established.

Each of the anchor nodes receives a signal synchronously from the target and record when the signal is received. This information is forwarded to a positioning server which calculates the received signal's time difference between each of the anchor nodes. This difference is transformed through an algorithm to provide an estimated location of the target. Mathematically, the target node is located at the intersection of 3 hyperbolas in a 2D plane, while the target node is located at the intersection of 3 hyperboloids in 3D space. The location of a mobile transmitter in a 2D plane can be illustrated in Figure 2. The equation is given by

$$\begin{aligned} ct_{01} &= \sqrt{(x-x_0)^2+(y-y_0)^2} \\ &\quad -\sqrt{(x-x_1)^2+(y-y_1)^2} = D_0 - D_1 \\ ct_{02} &= \sqrt{(x-x_0)^2+(y-y_0)^2} \\ &\quad -\sqrt{(x-x_2)^2+(y-y_2)^2} = D_0 - D_2 \end{aligned} \tag{1}$$

where (x_0, y_0) , (x_1, y_1) , and (x_2, y_2) represent the coordinate of anchor nodes (N_0 , N_1 , and N_2) respectively, and (x, y) represents the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

mobile transmitter. t_{01} represents the difference of time arrive of N_0 and N_1 . According to simultaneous formulas, (x, y) can be deduced. But only depend on three anchor nodes, the precision of location can not be guaranteed. In order to increase the positioning accuracy, we introduce least square method into TDOA algorithm [28].

Assume the amount of all anchor nodes is n , for each anchor node i , $i \in [1, n]$, the distance d_{0i} relative to anchor node N_0 can be derived from following equation

$$d_{oi} = c t_{0i} = \sqrt{(x-x_0)^2 + (y-y_0)^2} - \sqrt{(x-x_i)^2 + (y-y_i)^2} = D_0 - D_i \quad (2)$$

where

$$\begin{aligned} D_0^2 - D_i^2 &= \|M - N_0\|^2 - \|M - N_i\|^2 \\ &= ((x - x_0)^2 + (y - y_0)^2) \\ &\quad - ((x - x_i)^2 + (y - y_i)^2) \\ &= x_0^2 - x_i^2 + 2x(x_i - x_0) + y_0^2 \\ &\quad - y_i^2 + 2y(y_i - y_0) \\ &= D_0^2 - (D_0 - d_{0i})^2 \\ &= 2D_0 d_{0i} - d_{0i}^2 \end{aligned} \quad (3)$$

Group all the known terms together and denote

$$b_i = \frac{1}{2}\left[x_0^2 - x_i^2 + y_0^2 - y_i^2 + d_{0i}^2\right] \quad (4)$$

which is a linear model for unknown parameters (x, y) and D_0 . Stacking the n nodes measurement, we have the linear system in matrix form

$$AX = b \quad (5)$$

where

$$A = \begin{bmatrix} x_0 - x_1 & y_0 - y_1 & d_{01} \\ x_0 - x_2 & y_0 - y_2 & d_{02} \\ \vdots & \vdots & \vdots \\ x_0 - x_n & y_0 - y_n & d_{0n} \end{bmatrix}$$

$$X = \begin{bmatrix} x \\ y \\ D_0 \end{bmatrix}, \quad b = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}$$

When the location of nodes can be precisely known and the TDOA measurements are noise-free, linear system is compatible. The solution is unique while the data matrix A is of full rank. Let e represents the error of observation value and ideal value.

$$\sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (b_i - b_{lsi})^2 \quad (6)$$
$$=> E^{\mathrm{T}}E = (b - AX)^{\mathrm{T}}(b - AX)$$

where

$$E = \begin{bmatrix} e_1 & e_2 & \cdots & e_n \end{bmatrix}^{\mathrm{T}}$$

According to least square principle, we conduct the derivative of equation (6). We have

$$\frac{\partial}{\partial X}(b - AX)^{\mathrm{T}}(b - AX) = 0 \quad (7)$$

Once a minimizing b_{ls} is found, then any X satisfying $AX = b_{ls}$ can be called an LS solution and $b - b_{ls}$ the corresponding LS correction. The unique LS solution can be obtained while the data matrix A is of full rank:

$$X_{1s} = \left(A^T A\right)^{-1} A^T b \quad (8)$$

Finally, the location (x, y) is deduced.

5. COORDINATE TRANSFORMATION

Due to the calculated location is relative to the anchor nodes, this rectangular coordinate location information can not display on the maps. We propose a scheme to transform the rectangular coordinate to latitude and longitude.

First, build a positioning model. Usually, we place the anchor nodes on rectangle like Figure 3, and set up initial coordinate of anchor nodes. Second, select the anchor nodes, which place on the rectangular four angles, as preference node, then measure their latitude and longitude. Finally, calculate latitude and longitude of other anchor nodes and targets, according to the latitude and longitude of four anchor nodes. Let La present latitude, Lo denote longitude. The equation is given by

$$\begin{aligned} La_{M_0} &= y_{M_0}(La_{N_3} - La_{N_0}) / (y_{N_3} - y_{N_0}) \\ Lo_{M_0} &= x_{M_0}(Lo_{N_1} - Lo_{N_0}) / (x_{N_1} - x_{N_0}) \end{aligned} \quad (9)$$

Journal of Theoretical and Applied Information Technology
20th February 2013. Vol. 48 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

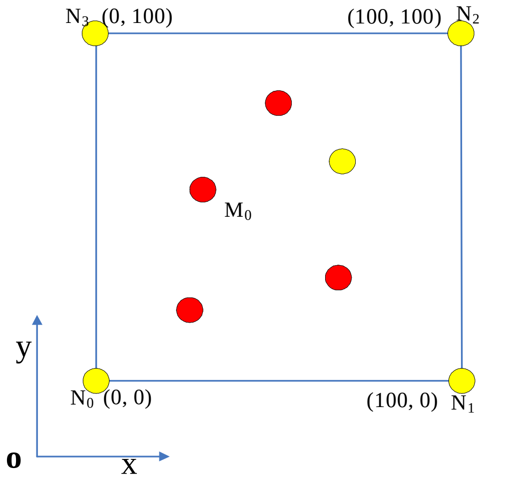

Figure 3: The Mode Of Coordinate Transformation

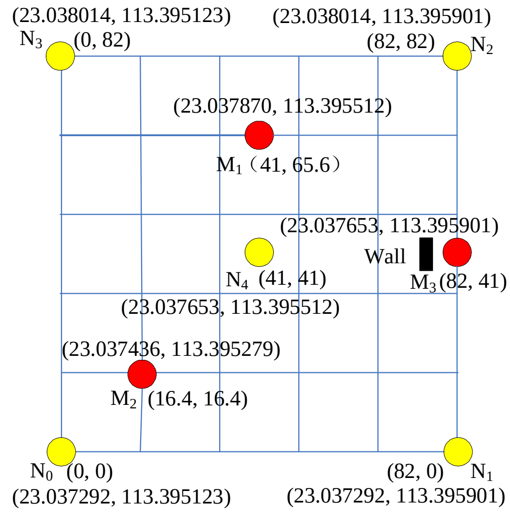

Figure 4: Specify Coordinate Manually

6. EXPERIMENT

After discussing the positioning algorithm, we test positioning system on the floor. The length and width is 82m respectively, we are not care the height in 2-D positioning experiment. We deploy four anchor nodes (N_0, N_1, N_2, and N_3) in corner of floor, and deploy one anchor node (N_4) in the middle. Meanwhile, the targets (M_1, M_2, and M_3) are deployed in designated location. At the beginning of the experiment, we should set up the rectangular coordinate system for positioning, and then establish the initial coordinate of anchor nodes. In order to compare ideal data with experimental data, we select three special locations for targets. The first location is for M_1, its coordinate is (41, 65.6), the second one (16.4, 16.4) is on the diagonal line of floor, the same line with N_0, N_2, and N_4, which is for M_2. The third location place on the floor beside the wall, the coordinate is (82, 41), where deploy M3. According to the Google Earth and GPS measurement, we specify the latitude and longitude of N_0, N_1, N_2, and N_3 as (23.037292, 113.395123), (23.037292, 113.395901), (23.038014, 113.395901), (23.038014, 113.395123). The latitude and longitude of other nodes are shown in Figure 4.

After run the algorithm mentioned above, the practical rectangular coordinates are calculated, then, the latitude and longitude are transformed from the rectangular coordinates. By comparing the practical value with the pre-established value, we can deduce the error of each mobile transmitter's location. The equation is given by

$$error = \sqrt{(x_{practical} - x)^2} + \sqrt{(y_{practical} - y)^2} \qquad (10)$$

By the same token, the error can also be calculated by using the latitude and longitude. However, as the numerical round-off in transform process, it is not as precise as that using rectangular coordinate.

Table 2: Test Result Of Mobile Target.

Coordinate	**Targets**		
	M1	***M2***	***M3***
(x, y)	(41, 65.6)	(16.4, 16.4)	(82, 41)
($x_{practical}$, $y_{practical}$)	(40.2, 65.1)	(15.6,17.2)	(80.9,42.5)
Latitude	23.037646	23.037429	23.038004
Longitude	113.395741	113.395286	113.395526
error	0.943398	1.131371	1.860108

The practical value, latitude, longitude and error are shown in Table 2. From analysis of experimental result, the precision satisfies the disaster aid requirement.

7. CONCLUSIONS

In this paper, we discuss the cooperative positioning system to cope with the problems that GPS can not position in indoor environment and indoor location information that can not be displayed on the maps or GIS. We introduce the LS method to improve the accuracy of positioning, and

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

give a method to transform indoor location information to latitude and longitude. These will help the commander or rescuer to track the patients or other objects, enhance the effect of rescue operation. But this system also has some problems such as the wall influences the positioning accuracy of M_3 , which should be improved in the future we should boost the robustness of positioning system.

ACKNOWLEDGEMENTS

The authors would like to thank the Natural Science Foundation of Guangdong Province, China (No.9151009001000021, S2011010001155), the Ministry of Education of Guangdong Province Special Fund Funded Projects through the Cooperative of China (No. 2009B090300341), the National Natural Science Foundation of China (No. 61262013), and the High-level Talent Project for Universities, Guangdong Province, China (No. 431, YueCaiJiao 2011) for their support in this research.

REFERENCES:

[1] J. Wan, H. Yan, H. Suo, *et al.*, "Advances in Cyber-Physical Systems Research," *KSII Transactions on Internet and Information Systems,* vol. 5, pp. 1891-1908, 2011.

[2] M. David, F. Thaddeus, W. Matt, *et al.*, "CodeBlue: An ad hoc sensor network infrastructure for emergency medical care," in *Proc. of Mobisys 2004 Workshop on Applications of Mobile Embedded Systems (WAMES 2004)*, pp. 12-14, 2004.

[3] G. Tia, T. Massey, L. Selavo, *et al.*, "The Advanced Health and Disaster Aid Network: A Light-Weight Wireless Medical System for Triage," *Biomedical Circuits and Systems, IEEE Transactions on,* vol. 1, pp. 203-216, 2007.

[4] M. Chen, S. Gonzalez, A. Vasilakos, *et al.*, "Body Area Networks: A Survey," *Mobile Networks and Applications,* vol. 16, pp. 171-193, 2011.

[5] B. Hofmann-Wellenhof, H. Lichtenegger, and J. Collins, *Global Positioning System : Theory and Practice* Viena, Austria : Springer, 2001.

[6] H. Suo, J. Wan, L. Huang, *et al.*, "Issues and Challenges of Wireless Sensor Networks Localization in Emerging Applications," in *Proc. of 2012 Int. Conf. on Computer Science and Electronics Engineering*, pp. 447-451, 2012.

[7] J. Wan, D. Li, Y. Tu, *et al.*, "Performance analysis model for real-time Ethernet-based computer numerical control system," *Journal of Central South University of Technology*, vol. 18, pp. 1545-1553, October 2011.

[8] M. Chen, J. Wan, and F. Li, "Machine-to-Machine Communications: architectures, standards, and applications," *KSII Transactions on Internet and Information Systems,* vol. 6, pp. 480-497, 2012.

[9] G. Sachin, "Infrastructure-based Location Estimation in WLAN Networks," in *Proc. of IEEE Wireless Communications and Networking Conf. (WCNC)*, pp. 465-470, 2004.

[10] M. Chen, S. Gonzalez, V. Leung, *et al.*, "A 2G-RFID-based e-healthcare system," *Wireless Communications, IEEE,* vol. 17, pp. 37-43, 2010.

[11] M. Chen, R. Huang, Y. Zhang, *et al.*, "A smart RFID system," pp. 1-2, 2010.

[12] M. Chen, S. González, Q. Zhang, *et al.*, "Code-centric RFID system based on software agent intelligence," *IEEE Intelligent Systems,* vol. 25, p. 12, 2010.

[13] A. De Angelis, J. Nilsson, I. Skog, *et al.*, "Indoor Positioning by Ultrawide Band Radio Aided Inertial Navigation," *Metrology and Measurement Systems,* vol. XII, pp. 447-460, 2010.

[14] E. A. Fry and L. A. Lenert, "MASCAL: RFID tracking of patients, staff and equipment to enhance hospital response to mass casualty events," *AMIA ... Annual Symposium proceedings / AMIA Symposium. AMIA Symposium*, pp. 261-265, 2005.

[15] P. A. Zandbergen, "Accuracy of iPhone Locations: A Comparison of Assisted GPS, WiFi and Cellular Positioning," *Transactions in GIS,* vol. 13, pp. 5-25, 2009.

[16] K. Lorincz and M. Welsh, "MoteTrack: A Robust, Decentralized Approach to RF-Based Location Tracking," in *Location- and Context-Awareness*. vol. 3479, T. Strang and C. Linnhoff-Popien, Eds., ed: Springer Berlin Heidelberg, 2005, pp. 63-82.

[17] B. Paramvir and N. P. Venkata, "RADAR: An In-Building RF-based User Location and Tracking System," in *Proc. of the19th Annual Joint Conf. of the IEEE Computer and Communictions Societies,* pp. 775-784, 2000.

[18] J. Clulow, G. Hancke, M. Kuhn, *et al.*, "So Near and Yet So Far: Distance-Bounding Attacks in Wireless Networks," in *Security and Privacy in Ad-Hoc and Sensor Networks*. vol. 4357, L. Buttyán, *et al.*, Eds., ed: Springer Berlin Heidelberg, 2006, pp. 83-97.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[19] *nanotron find*. Available at: http://www.nanotron.com/EN/PR_find.php

[20] *ubisense*. Available at: http://www.ubisense.net/

[21] *Federal Communications Commission (FCC). Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems*, 2002.

[22] R. Hill, J. Al-Muhtadi, R. Campbell, *et al.*, "A Middleware Architecture for Securing Ubiquitous Computing Cyber Infrastructures," *IEEE Distributed Systems Online,* vol. 5, p. 1, 2004.

[23] M. R. Mahfouz, C. zhang, B. C. Merkl, *et al.*, "Investigation of High-Accuracy Indoor 3-D Positioning Using UWB Technology," *IEEE Transactions on Microwave Theory and Techniques,* vol. 56, pp. 1316-1330, June 2008.

[24] R. J. Fontana, "Recent system applications of short-pulse ultra-wideband technology," *Microwave Theory and Techniques, IEEE Transactions on,* vol. 52, pp. 2087-2104, 2004.

[25] G. Yanying, A. Lo, and I. Niemegeers, "A survey of indoor positioning systems for wireless personal networks," *Communications Surveys & Tutorials, IEEE,* vol. 11, pp. 13-32, 2009.

[26] D. W. Lim, H. W. Kang, S. J. Lee, *et al.*, "Position DOP Analysis for Sensor Placement in the TDOA-based Localization System," *Journal of Electrical Engineering & Technology,* vol. 7, pp. 1009-1013, Nov 2012.

[27] S. Lanzisera, D. T. Lin, and K. S. J. Pister, *RF time of flight ranging for wireless sensor network localization*. New York: Ieee, 2006.

[28] "Total Least Squares Method for Robust Source Localization in Sensor Networks Using TDOA Measurements," *International Journal of Distributed Sensor Networks,* vol. 2011, 2011.