Construction Process Control Based on Indoor Positioning Techniques

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Abstract
Indoor positioning technology has been widely applied in engineering with the development of automation in construction, and it is necessary to master the information of the high-accuracy location of the equipment and workers. Compared with the other techniques currently used, UWB has advantages of high-accuracy in pseudo-range measurement and excellent ability of anti-multipath. However, there is always in wide area in construction, while UWB can only cover the local area. Furthermore, Traditional construction process control depends on the scheduling and field management to a large extent, meanwhile lacks the on-time feedback in the construction process. The high-accuracy real-time location information of the target (workers or equipment) benefits the construction process in many aspects, such as: serving basic data for the arrangement of the targets in construction or as the reference for future work, preventing valuable equipment and facilities from being stolen, enriching the backup data in the engineering model such as BIM. This paper proposes a framework in combination with the indoor positioning technology UWB and RFID, providing a greater insight into the process management in construction, especially in real-time feedback and control regarding the robust construction environment.

Keywords: Construction process, indoor positioning, UWB, RFID

1 Introduction

Construction site activities is the matter of mutual concern to participants, include owners, contractors, architects, engineers, suppliers, etc. Because of the large volume of materials and the number of personnel in a construction project, knowing the location of people, equipment, and materials is of great value for various construction activities, for example, safety management, material supply and logistics planning etc. Accurate, reliable and frequent location information is necessary for on-site process control.

Recently, an increasing number of innovative information techniques and tools have been applied to the field of Architecture, Engineering, Construction and Facilities Management (AEC/FM). In the localization area, many of these technologies pertain to location in outdoor environments, such as Global Positioning Systems (GPS), laser scanning and Unmanned Aerial Vehicle (UAV). Although different techniques for indoor localization in construction have been proposed, how to obtain and to obtain what kind of indoor location information are needed to be discussed more for the on-site construction management.

In practice, the demand of indoor positioning information is in accordance with the requirements of specific construction project and the objectives of the project management. For example, the super high-rise buildings have a great number of inner spaces with relative smaller area of construction site which need more accurate positioning information in indoor

working environment. And the special-shaped buildings have complex structure and capricious inner environment, which lead to great difficulty in construction. Real-time and high-accuracy indoor positioning can solve the problems confronted in such situation: orient the team to the physical building; tag a location with task status information; compare model to physical construction; understand what is behind a wall; personnel tracking etc., which can enhance daily operations as well as rescue capabilities in an accident or emergency.
For some owners, they want to create a better user experience to customers, via indoor positioning techniques, provide real-time information in video or augmented reality experiences. There are also some people hope to use indoor positioning to provide more effective emergency services.
On the other hand, GPS is not available in indoor scenario, furthermore, there always be no network in construction areas, leading to limitation of the deployment of network-based positioning. Real-time positioning on construction sites in indoor areas remains valuable work, particularly useful on major projects and for company level review.
Thus, it is necessary to integrate innovative technologies into construction. No single solution works perfectly in all environments, furthermore, wireless signal is usually affected by refraction, reflection and severe multipath effects in indoor areas, and there has been no perfect signal propagation model indoor environment so far. For that reason, devices may support more than one positioning solution and switch between them as needed.
The paper provides a brief introduction of emerging technologies in indoor positioning, in consideration of a non-GPS environment indoor. The applicability and feasibility of indoor positioning for several typical construction types will be discussed. The choice of positioning algorithms and tools will be compared according to different indoor construction environments.
This paper is organized as follows. Chapter 2 shows the typical indoor positioning techniques and their performance comparison, introduce Indoor positioning implement in construction. Chapter 3 analyses demand of indoor positioning on construction site. Chapter 4 shows the positioning algorithms corresponding to different positioning principles, presents the necessity to apply indoor positioning techniques in construction process, then proposes a indoor positioning system framework which integrate UWB and RFID. Chapter 5 concludes the paper and gives possible future directions for research on wireless positioning in indoor areas.

2 Background

In this section typical indoor positioning techniques are illustrated.

2.1 Indoor positioning techniques

GPS (Global positioning system) is the most widely used satellite-based positioning tool, which offers maximum coverage. However, line-of-sight transmission between receivers and satellites is not possible in an indoor environment, thus GPS can not be used indoors. To address these limitations in GPS-denied environments, several alternative technologies have been suggested, such as: Wi-Fi, RFID (Radio Frequency Identification), UWB and WLAN (Wireless Local Area Networks). Taking into account of feasibility in practice, the following performance bench-marking for indoor wireless location system should be considered: accuracy, complexity, scalability, robustness, and cost (Liu, H. et al 2007). An overview of indoor positioning techniques is presented as following:

Table 1 An overview of indoor positioning techniques

Indoor positioning technology	accuracy	complexity	scalability	robustness	Deployment& cost
Wi-Fi	3-5m	moderate	good	good	Easy and economical

RFID(active)	3-5m	Depends on nodes density placed	medium	good	Easy and cheap
WLAN	4-6m	moderate	good	good	Easy and economical
UWB	10-50cm	Depends on sensors density	good	poor	Easy but expensive

2.2 UWB

UWB (Ultra Wide Band) is a network of receivers and tags communicating with each other over a large bandwidth (>500 MHz). UWB technology offers various advantages over other positioning technologies: no line-of-sight requirement, no multipath distortion, less interference, high penetration ability for localization and tracking applications. Thus UWB technique provides a higher accuracy. According to existed experiment, position uncertainty of UWB ranges between 10 to 50 cm (Khoury, H. M., & Kamat, V. R. 2009). Using UWB technology in positioning systems has been a popular way of improving the positioning accuracy. (Zhang, Y. 2006) But it also has some limitations in practice, despite its high accuracy, the cost of UWB is also higher.

2.3 RFID

RFID (Radio Frequency Identification) is a means of storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit. RFID technology is applicable to the built environment because of its non-line-of-sight characteristic, wireless communication and on-board data storage capacities, and its wide use in the building industry (Ergen, E., & Akinci, B 2007). RFID as a wireless technology enables flexible and cheap identification of individual person or device. There are two kinds of RFID technologies, passive RFID and active RFID. The coverage area of active RFID can reach 2-300m, which is much longer than passive RFID, thus active RFID is usually applied in indoor positioning. Active RFID tags are self-powered and regularly send out signals to receivers within the area of interest. This is the reverse of GPS. Knowing the location of the receiving sensors allows for accurate indoor locating in near real-time. The passive (without battery) RFID is most suitable for an indoor application of tracking workers or materials (Costin, A. et al 2012a).

2.4 Indoor positioning implement in construction

Sunkyu Woo et al investigated the feasibility of a Wi-Fi-based indoor positioning system for construction sites. Using the fingerprint method of Received Signal Strength Indication (RSSI) from each Access Point (AP), a series of experiments were conducted at a shield tunnel construction site in Guangzhou, China. The results showed that the Wi-Fi-based indoor positioning system was accurate within 5 m of error for that site, proving the utility of the system for tracking the approximate locations of labor at construction sites (Woo, S. et al, 2011.).
Alessandro Carbonari et al reports the development of a first prototype for the proactive safety management and real-time signaling of potential overhead hazards based on an ultra wide band (UWB) tracking technology, showed that the proposed technologies can be reliably used for the implementation of proactive safety management policies on outdoor construction sites, where localization can be accurate enough to provide reliable data for the implementation of the algorithm (Carbonari, A. et al 2011).
Fieldwork tracking based on UWB has been tested in a steel bearing structure, demonstrating position accuracy significantly better than 1 m indoors and the ability to locate accurately when deployed across the site where the steel structure was being erected (Teizer, J. et al 2007a).
Real-time localization allows for the measurement of the speed and the trajectories of construction resources. The analyses of travel patterns were then used to improve work practice and the management of safety policies (Teizer, J. et al 2008b).

Precision positioning for moving targets is also the key issue urban rail traffic safety assurance and operational energy saving, LIN Hui et al propose a novel UWB, Multi Sensors and Wi-Fi Mesh integration methods which is specially designed for underground tunnels, culverts and architectural indoor environments. (Lin, H. et al 2010)

A large amounts of documents integrate indoor positioning with BIM in building, such as building fire emergency response operations, facility operations, navigate any user or utility in an unfamiliar facility. The ability to locate people quickly and accurately in buildings is critical to the success of building fire emergency response operations, and can potentially contribute to the reduction of various building fire-caused casualties and injuries.

Nan Li et al introduces an environment aware beacon deployment algorithm designed by the authors to support a sequence based localization schema for locating first responders and trapped occupants at building fire emergency scenes. The algorithm yielded an average room-level accuracy of 87.1% and 32.1% less deployment effort on average compared with random beacon placements. Results showed that the room-level accuracy could remain above 80% when up to 54% of all deployed nodes were damaged. (Li, N. et al 2014)

Saurabh Taneja et al evaluates algorithms that utilize a navigation network created from BIM-based floor plans for correcting inertial positioning data, presents the evaluation of the performance of the two map-matching algorithms in field tests carried out in one of the heavily utilized academic facilities in Pittsburgh, PA. (Akinci et al 2011)

Uwe Rüppel et al develop a solution for response and recovery to support rescuers in finding the shortest way within a complex building, the fire guidance system enables a generation of digital route cards from a building model using Building Information Modeling (BIM). For this optimal detection of positions, a Multi-Method-Approach (MMA) has been developed, which consists of WLAN, Ultra-Wide-Band and Radio Frequency Identification (RFID). (Uwe Rüppel et al 2010)

A. Costin et al develop a navigation algorithm to help a person navigate through facilities, utilizes current localization techniques, performance characteristics of passive RFID, and a BIM model. The results show algorithm has the potential to enable anybody to navigate the shortest and quickest route, saving time, money and, in an event of an emergency, lives. (Costin, A. et al 2013b)

3 Demand analysis of indoor positioning on construction site

3.1 Special patterns and distributions of the construction site

Generally speaking, a typical construction site can be divided into four parts: outdoor areas, preparation areas, interaction areas and indoor areas. A simple architecture of a typical construction site is presented as follows.

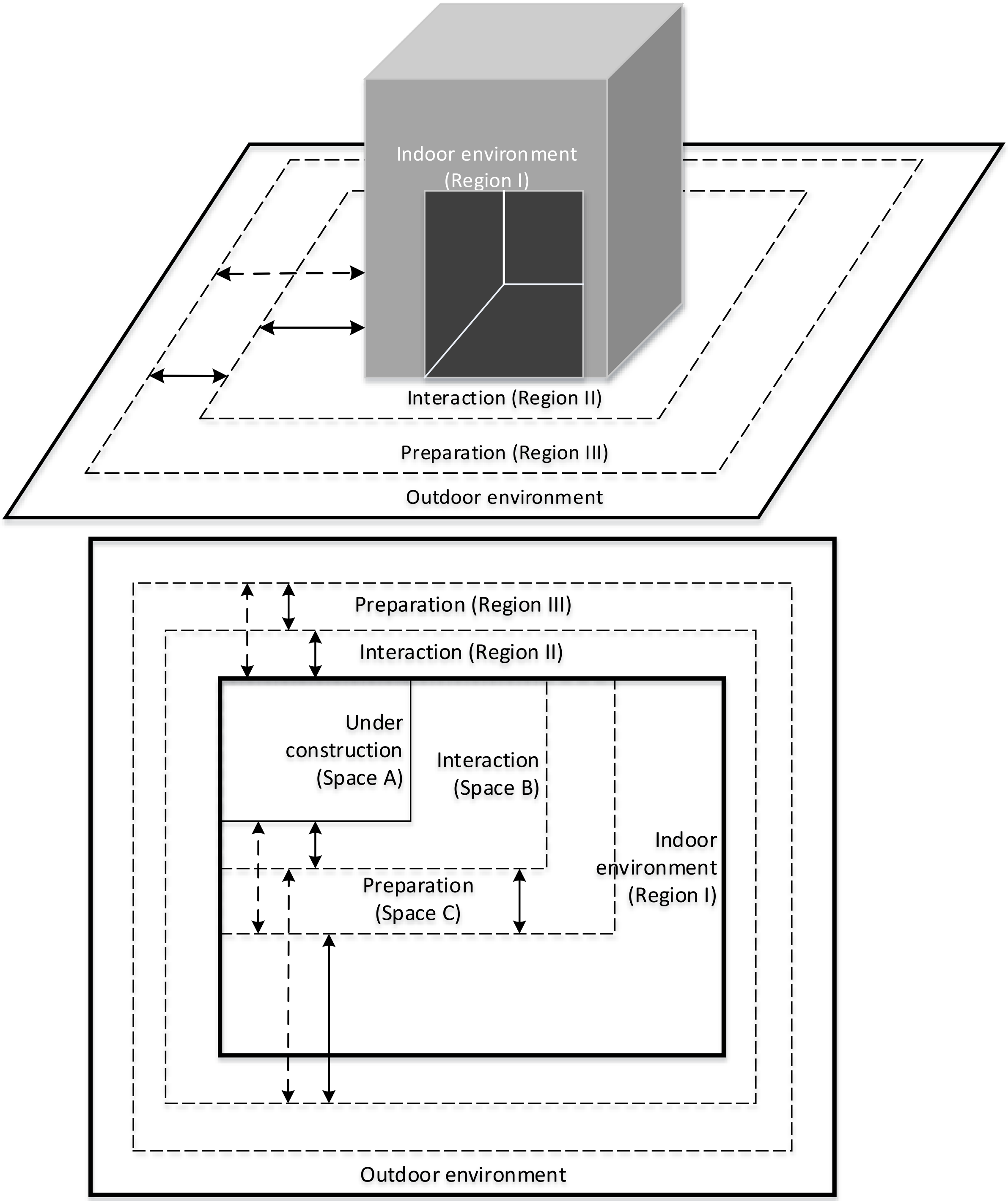

Figure 1 a simple architecture of a construction site

3.2 Positioning demands of specific construction area

In outdoor environment of a construction site, the location information is easier to know via GNSS or other techniques such as laser scanning and photography. Although the accuracy of GPS is not that high, bigger area, simple structure and function in outdoor construction sites make it feasible and easier to positioning outdoors.

While in indoor areas, small, various functional areas are closely connected, the function includes: construction, project status check and prepare for FM, all these lead to high-accuracy positioning indoors.

Specifically, in interaction areas, it need frequency interaction between material, workforce and other construction information, includes internal with internal, external with external and internal with external. Based on these considerations, connectivity degree should be considered in indoor positioning.
Preparation areas aim to provide backup for construction activities, thus accessibility is of great value in these area. It can depend on actual necessity of the project to decide whether set these areas or not.

3.3 Requirements of indoor positioning in specific construction area

As is depicted above, accuracy, complexity, scalability, robustness, and cost are always considered as the performance bench-marking in indoor wireless location system based on feasibility in practice. On the other hand, techniques should be improved from a point view of positioning goal. For example, it demands high-accuracy location information instead of its real-time trajectory in Space A, because construction activities are carried out according to the construction segment, are relatively fixed step, furthermore, indoor positioning is to provide workers with indication in specific working position. While in Space B, it requires more relatively dynamic indoor location information to assist in planning route of material and workers. It is more flexible in Space C, because it can be decided by project requirements.

4 Process control system based on UWB and RFID

For an indoor positioning system, two main impact factor are positioning algorithms and wireless techniques, which mainly effect its accuracy, complexity, scalability, robustness, and cost. Among them, accuracy and affordability are the two criteria used most frequently in designing and evaluating the solutions. However, the balance between each criterion and the difficulty of dealing with the tradeoffs between them lead to no single solution satisfying all criteria mentioned above. Thus, it is of great value to integrate two or more techniques together, this paper chooses UWB and FRID in indoor positioning system.

4.1 Algorithms

This part shows the measuring principles for location sensing and the positioning algorithms corresponding to different measuring principles.
The basic localization algorithm are mainly three types: triangulation, positioning algorithms using scene analysis and proximity (Hui Liu et al 2007). Triangulation uses the geometric properties of triangles to estimate the target location. It has two derivations: lateration and angulation. Another one is scene analysis; which RSS-based location fingerprinting is commonly used in it. The main challenge to the techniques is that the received signal strength could be affected by diffraction, reflection, and scattering in the propagation indoor scenario. Another is proximity algorithms, which provide symbolic relative location information, the complexity relies on the density of sensors, which each of them having a well-known position. This method is relatively simple to implement, can be implemented over different types of physical media. Active RFID are often based on proximity algorithms, whereas UWB are often use triangulation.

4.2 Construction process control

Control has always formed the end purpose for systems of planning and scheduling construction work. Since it was developed in the late 1950s, it was a direct response to the lack of control provided by antecedent systems, which therefore had not been able to predict the consequences of delay or any other change on a project (Kenley, R., & Seppänen, O. 2006). There is little sensitivity to the reality of construction in such methods of control. Real-time positioning on construction sites in indoor areas remains valuable work, particularly useful on major projects and for company level review. Traditional construction management relies on planning and scheduling to a large extent, there is no real-time or efficient feedback of the information about construction process, that would reveal whether the cause of the problem may be continuing to influence the project, such as workforce, material and equipment.

Real-time feedback and control in construction is a predominant feature of current control systems and supports the tendency to avoid confronting problems. The recognition of the difference between tasks and activities along with the layered location-based logic provides the key to improved control. Thus, the delay consequences are understood immediately rather than some days later, failure to perform as planned can be forecast throughout the progress of a task as well.

4.3 Logical structure design

The indoor positioning system in this paper consists of three parts: Sensors, Positioning Engine, and Functions Output. The architecture of the positioning system is presented as follows.

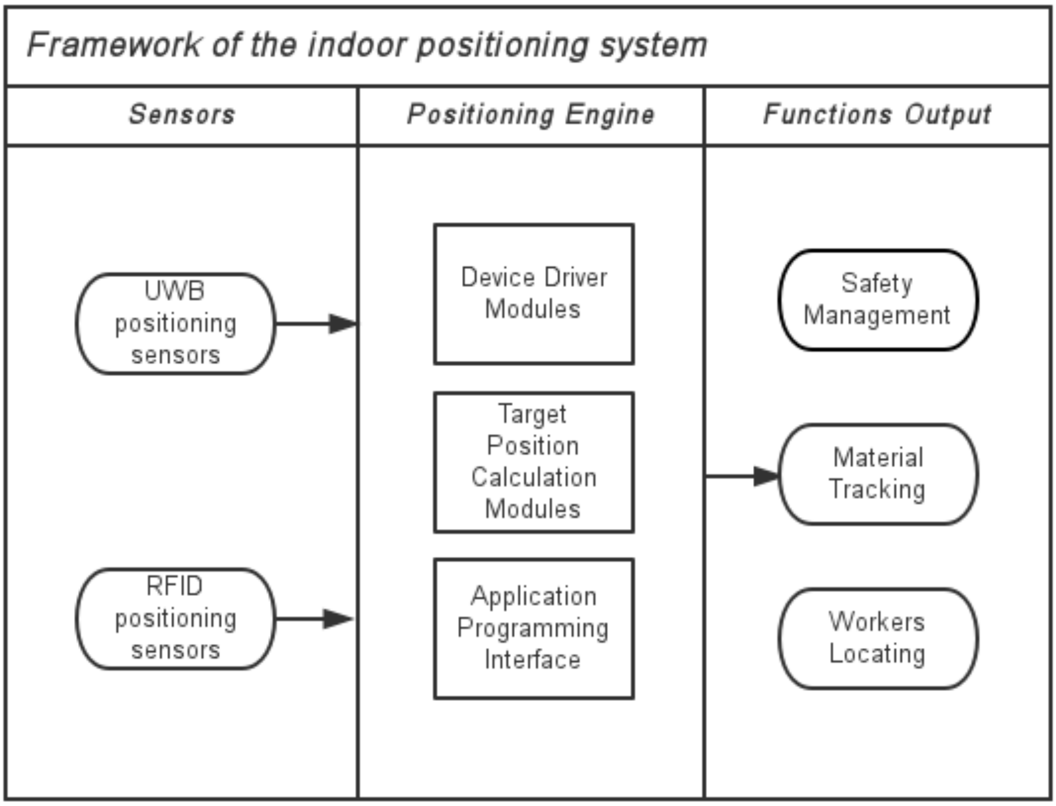

Figure 2 The architecture of the positioning system

In this indoor positioning system, step one, different location sensors collect signal intensity in the form of tags and reader devices. Readers send a command signal automatically to label tags in a certain frequency to collect feedback information. Step two occurs in positioning engine, which consists of three parts, Device Driver Module, Target Position Calculation Module, Application Programming Interface(李魏峰, & 王东 2010). Device driver module is mainly to control the underlying readers, tags and other devices, the main function of this module includes a complete modify the parameters of the reader, query status of the reader, collect tag information and processing tag events. Target Position Calculation Module is to calculate the target position via different location algorithms, which calculation data comes from information dedicated from step one. In this part, the choice of algorithms and information collected mainly decide the accuracy of the positioning system. Application program interface module is mainly responsible for packaging and classify the function of Device Driver Module and Target Position Calculation Module, and then define the various interfaces for applications routine. Step three, functions output though Application Programming Interface, includes safety management, material tracking, workers locating, etc.

5 Summary and Outlook

In recent decades, buildings of huge dimensions, both in terms of height and horizontal extension, have been erected in rapidly expanding megacities, especially in China. The management of such massive sites requires efficient tracking and positioning of materials such as concrete mixers, cranes, workers and many other resources. Although more and more domestic and foreign enterprises are carrying out research on indoor map technology and application and provide indoor LBS such as Google and Baidu, providing location-based service in big shopping mall or airport, application of indoor positioning system in construction process is not that ubiquitous. The paper analyses the necessity and demand to apply indoor positioning techniques in construction, the results show that indoor positioning combined with UWB and RFID can benefit construction process in many aspects.

In this paper, the author presents a framework rather than do the experiment to discuss the efficiency of the positioning system. Besides that, how to integrate indoor and outdoor positioning system didn't take into account, which may help in developing more efficient and robust detection systems for positioning of mobile computing nodes.

The advent of BIM can promote the efficiency of indoor positioning, owing to BIM can provide the information of the building, which can help to visualize the location estimated, and extract target attribute information. Due to time limit, the paper doesn't discuss this topic deeply, which can promote in our future works.

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