SPACEANNOTATOR: A HIGH PRECISION LOCATION BASED ASSET MANAGEMENT SYSTEM IN INDOOR ENVIRONMENT

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Abstract

Asset management is urgently needed in supply chain which requires to solve two basic problems 1) what assets do we have; and 2) where they are? Existing methods exploit barcode and RFID technologies to retrieve the information and quantity of assets. However, the location of asset is still hard to obtain for the lack of suitable location technologies. In this paper, a high precision location based asset management system named SpaceAnnotator is proposed. SpaceAnnotator is implemented based on TOA positioning method using Ultrasound and RF signals. Leveraging the centimeter level positioning accuracy provided by the positioning system, SpaceAnnotator maps the IDs of objects to their locations. Based on the location information, location based service (LBS) in provided for asset management. Compared with conventional location based asset management system, SpaceAnnotator works well even in managing small volume objects for its high accuracy.

Keywords: LBS; Asset management system; LAMS; high precision positioning.

1 Introduction

Location, as the most essential context of object, can be exploited to provide context-aware services to users, which is called Location Based Services (LBS). Location based Asset Management System (LAMS) is an important instance of LBS, in which, the type, quality, and positions of massive amount assets are managed in real-time, forming fundamental for supply chain and warehouse applications. So far, there are already research results and engineering implementation focusing on LAMS. Since how the ID of an object is mapped to its corresponding location plays key role in LAMS, positioning technologies are the basic need of LAMS. The most well known positioning system is GPS[1]. However due to its dependence of satellite, GPS is not functional in indoor environment and lack of high positioning accuracy [2]. RFID, Camera and radio signal intensity (RSI) indicator are involved to provide positioning ability in indoor environment for LAMS. D. Chen[3] proposed a method to sample the related position of each book in shelf by snapping photos with Smartphone, whose application scene is limited. BlueBot [4] using robot equipped RFID-reader to achieve indoor location-sensing, but meter level precision is not suitable for fine-grained asset application. RSI based positioning methods are widely used in wireless sensor network (WSN) such as [5][6]. However lack of stability and precision are its major limitation for asset management. A more accurate and universal LAMS is desired.

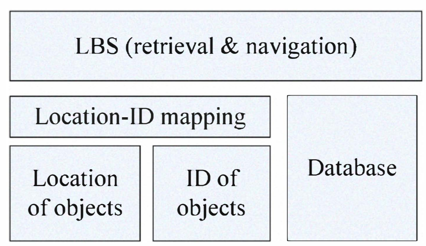

Figure 1 System architecture of SpaceAnnotator

In this paper we proposed SpaceAnnotator, a high precision location based asset management system in indoor environment. The overall system architecture is shown in Fig. 1. Accurate positioning result is provided by ultrasound positioning subsystem [7][8]. SpaceAnnotator is designed for fine-grained ID-position mapping. By integration with asset database, it provides foundation for various LBS.

SpaceAnnotator contains four components as shown in Fig.2. A PDA with RFID/Barcode reader and positioning accessory is used for sensing asset information. A ultrasound positioning subsystem, which captures data from PDA and then outputs position-ID mapping for the asset that the PDA is sensing. A server provides navigation and query service to users for asset management. Detail information of assets such as name, manufactory and picture are obtained from a database by using the ID as index.

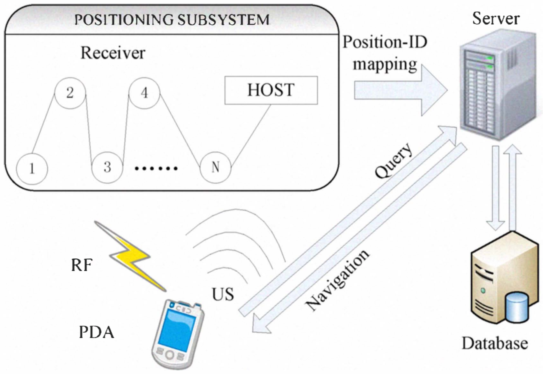

Figure 2 Components in SpaceAnnotator

Compared with conventional LAMS, there are two main advantages:

1) Centimeter level positioning precision, therefore, small volume object such as book and CD can be managed by SpaceAnnotator.
2) Using RFID/Barcode as identifier makes SpaceAnnotator good compatibility and cost-effective.

The rest part of this paper is organized as follows. The system structure of Space Annotator will be described in Section 2; followed by key algorithms of SpaceAnnotator in Section 3; Prototype in Section 4;the performance of the SpaceAnnotator will be shown by adequate experiment in Section 5; Section 6 gives the conclusion of this paper and discussion of future work.

2 System overview

Location sensing is the foundation of LAMS. In SpaceAnnotator, ultrasound TOA based positioning subsystem is employed to provide location stream with centimeter-level precision[8].

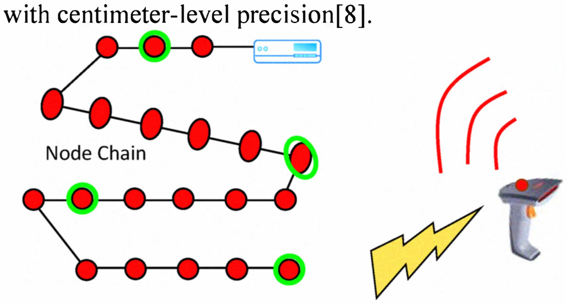

Figure 3 Structure of positioning subsystem

Figure 3 shows the structure of positioning subsystem. Reference nodes are installed in fixed positions of room. 40Khz ultrasound sensor and radio modules are embedded in each node. In each positioning routine, ID of object is read through RFID/Barcode reader in PDA. Then PDA sends a radio sync packet and a ultrasound pulse simultaneously. Each reference node measures its distance to PDA by counting arrival time difference between sync packet and ultrasound pulse. Then all measured distance are collected by a host-device in the subsystem. Finally, An Extended Kalman Filter (EKF) is run by the host-device to calculate and output the position of the PDA.

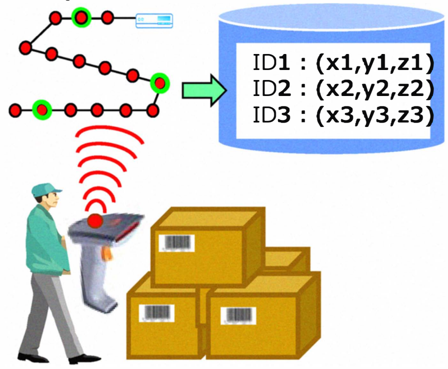

Figure 4 Asset registration

With this positioning subsystem, workflow of asset registration is shown in Figure 4. Warehouseman holds the PDA to read the RFID/Barcode on the object. Assuming ID_i is read, then positioning routine is triggered to measure the position X_i of PDA. Finally, server builds (ID_i, X_i) mapping to record the asset ID and position. To simplify this process, transferring ID and positioning are merged to one step by encoding the ID into sync packet in positioning.

The workflow of navigation is shown in Figure 5. When warehouseman wants to seek an object with ID_0, a self-positioning process is started on him/her PDA to get current position X_0. Then a query contain (ID_0, X_0) is submitted to the server. The server sends back an optimal path to the PDA, which is shown on the PDA screen to guide the warehouseman .

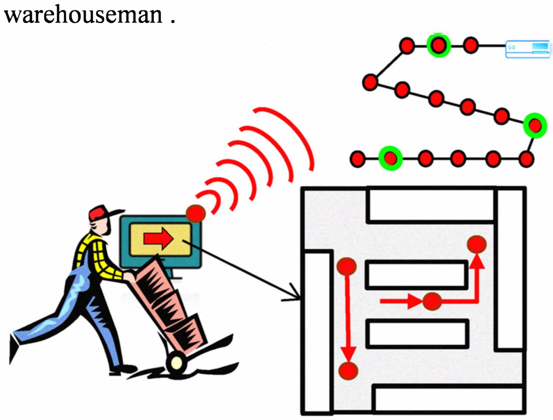

Figure 5 Navigating mode.

Based on (id, pos) mapping, LBS such as asset retrieval and asset displaying are also provided. For convenience, in SpaceAnnotator, these LBS are presented on web. User can use any device with a browser to get the latest status of warehouse. By using Ajax push technology, positions of assets and warehouseman can be updated in real-time. Figure 6 shows the web page of an online asset management demo. Left-half shows the real time status of warehouse. Right-half shows list of registered assets.

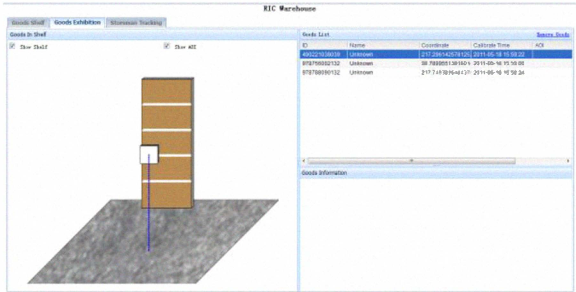

Figure 6 Web based asset manage interface

3 Key algorithms

Previous system structure gives a general design of SpaceAnnotator. To make the system work in practical scene, some algorithms are proposed to solve challenges existing in real Warehouse.

3.1 Zone matching algorithm

In warehouse, asset is stored with two modes. They can be either stacked freely or put into some predefined small zone, such as shelf, drawer or cabinet. For previous mode, people always want to know the precise position. For the later mode, to know which small zone it is occupying is more useful. So in SpaceAnnotator, a zone calibration and detection algorithm is exploited[10]. The location features of the small zones are calibrated offline by K Nearest Neighbor (KNN) method and the online zone detection is carried out by Least Square Estimation.

3.2 NLOS filtration algorithm

High precision location stream is the foundation of LAMS. Because of obstacles in warehouse and poor penetration of ultrasound, Non Light of Sight (NLOS) interference happens easily in warehouse when ultrasound positioning subsystem is used. As a result the measured distances are often longer than the real distances. Figure 7 shows average value of measured distances at 10 different positions in a warehouse. The solid bars stand for calculated distances, while the hollow bars stand for the real distance. It is found that one third of the measured distances are invalid. Similar experiment result could be found in [9]

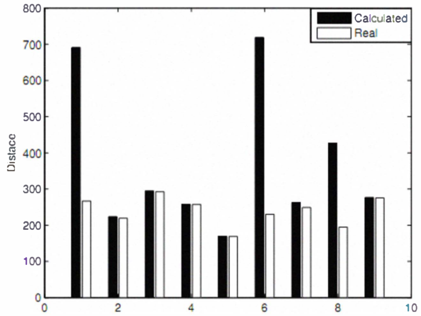

Figure 7 Distances measured in warehouse without fake-spot.

In order to solve this problem a novel algorithm named Fake-spot are proposed. Fake-spot is an iterative linear regression algorithm. The flowchart of fake-spot algorithm is shown in Figure 8. First all measured distances are copied to the valid distances set (VDS), which are input to EKF positioning algorithm to calculate a fake-spot. Then Fake-distances could be calculated from fake-spot. All distances in VDS and its corresponding fake-distances are compared. If their difference exceeds a threshold, this distance is judged as an outlier. The loop will continue until no outlier is found in one loop; then all distances in VDS are outputted as valid distances.

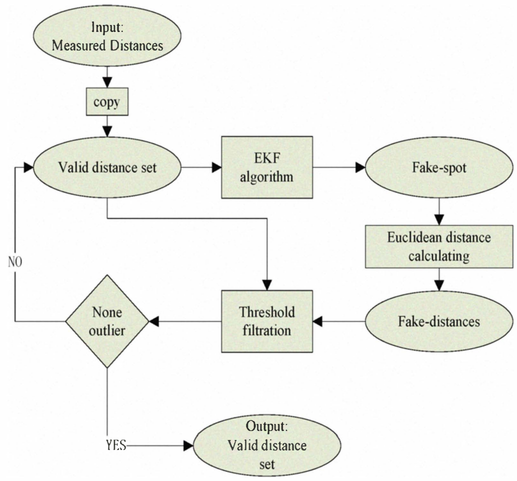

Figure 8 Flowchart of Fake-spot algorithm.

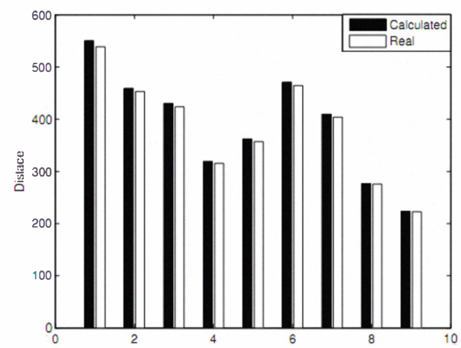

Figure 9 Distances measured in warehouse with fake-spot

Figure 9 shows measured distances from same condition as Figure 7. The only difference is the employing of fake-spot algorithm. It is found that almost all NLOS interferences are eliminated, which verified the effectiveness of fake-spot algorithm.

4 System prototype

To verify system design and algorithms, prototype of SpaceAnnotator is implemented. Top subfigure in Figure 10 shows receivers, cables and host in positioning subsystem. The bottom one in figure shows how they are installed in experiment warehouse.

Figure 10 Prototypes of positioning subsystem.

As figure 11 shows, industrial PDA and dual screen android PAD are selected as handhold devices. The left one is PDA with small weight and long battery life, which is suitable for asset operation such as registering and position updating. The right one is a PAD with big screen which is suitable for navigation and status checking. In both of the devices, a ultrasound & radio emitter accessory is plugged into the USB-host port.

Figure 11 Prototype of PDA

Fig. 12 shows experiment scene of SpaceAnnotator, whose size is a 6m * 4m *3m. In this experimental warehouse, Shelf and tables are set up for holding assets. CDs, books and bottles are used as experiment objects.

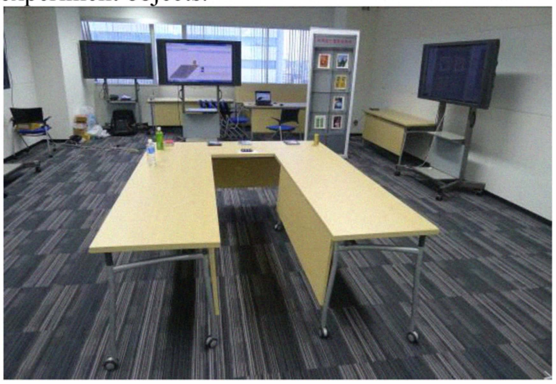

Figure 12 Experiment scene

Figure 13 shows the positioning subsystem installed in this room. 15 ultrasound receivers are mounted on the ceiling of this room to work as reference point for position calculation.

5 Performance evaluation

Using this prototype, adequate experiments are carried out to show the performance of the SpaceAnnotator.

40 points in the warehouse are selected as experiment points. Positions of all the points are measured manually by Laser rangefinder as ground truth. Then SpaceAnnotator is used to measure positions of all these points. The 3D-view of contrast is shown in Fig 14. Red points stand for real position while the green points stand for positioning result. We can find out that in center of the room positioning results are close to the real position. While in corner the positioning error are much bigger.

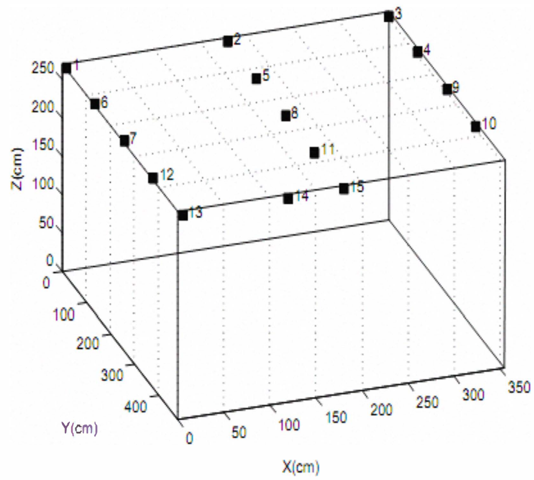

Figure 13 Deployment of receivers in positioning subsystem.

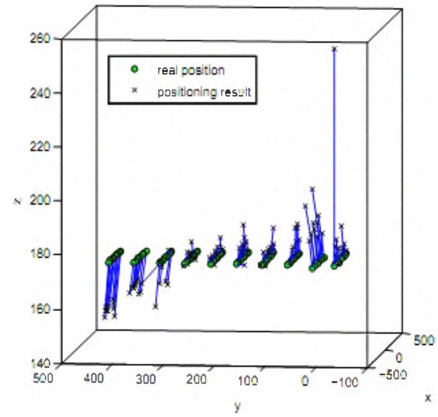

Figure 14 3D view of positioning error

Top view of same experiment is shown in Figure 15. Positioning error in x-y planet is much smaller than in 3D space. The cause is that all receivers are deployed in x-y planet, so resolution in z-axis is smaller than in x-y planet. Like 3D view, error in corner is bigger than in the center of the room.

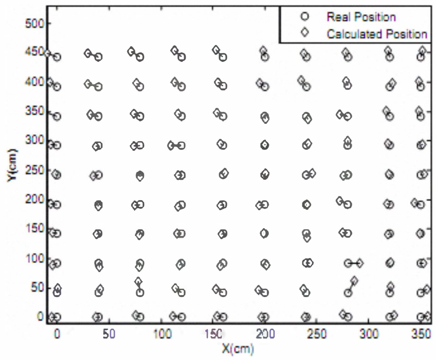

Figure 15 Deployment of receivers in positioning subsystem.

Figure 16 gives the CDF of positioning result. The error is defined as the Euclidean distance between real position and positioning result. We can find that in average, 90% of the error is smaller than 10 centimeter, which means that all object bigger than 10 centimeter is supported in SpaceAnnotator.

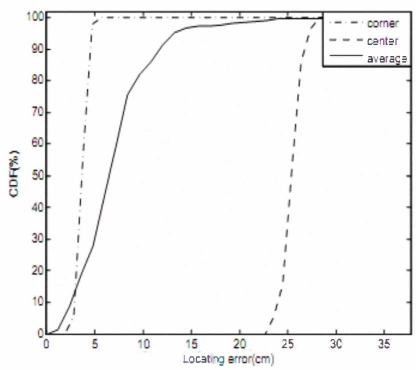

Figure 16 CDF of positioning error.

6 Conclusions

Location based asset management is a promising application of IoT. In this paper, we proposed a novel LAMS named SpaceAnnotator, by exploiting ultrasound TOA positioning and barcode ID scanning technologies. Position and asset ID is mapped and LBS such as asset retrieval and navigation are provided. To solve practical problems from real warehouse, NLOS algorithm and shelf matching algorithm are involved. In order to evaluate the performance of SpaceAnnotator protocol, some experiments are carried out, which shows that SpaceAnnotator can provide centimeter level positioning resolution. But because of the poor penetration ability and short valid distance of ultrasound, location precision of current SpaceAnnotator varied greatly in different position of a warehouse. Hybrid location methods and location based complement method would be the research focus of next step to solve this problem.

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