Semantics and Modeling of Indoor Moving Objects

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Abstract

Moving objects in indoor space has been a research focus in recent years, as most people live and work in indoor space, e.g. working in office, living in apartment, etc. In this paper, we make a first step in indoor moving object management. We focus on the conceptual modeling of indoor space as well as indoor moving objects, and aim to describe the semantics and properties of indoor moving objects. Firstly, a conceptual modeling framework for indoor space is defined, based on which we propose a semantic description of indoor moving objects. Compared with previous models, our model takes into account the relationships among rooms, doors, sensors and moving objects, and uses a layered approach to represent indoor space and indoor moving objects. The model proposed can be further extended to meet different needs in indoor moving object monitoring and tracking.

Keywords: *indoor space, moving objects, conceptual model*

1. Introduction

With the rapid development of wireless communication, sensors and Internet of Things (IoT), location-based services (LBS) has been a hot research topic in recent years. Location-based service involves many issues, among which moving object data management has received a lot of attention in the last decade. Traditional moving object data management focused on GPS-supported moving objects in outdoor environment [1-2], and little effort has been done on moving objects in indoor space. However, people spend most of their time in indoor space, such as office building, shopping mall, metro station and museum. Recently, wireless positioning techniques like RFID, wifi and Bluetooth offer opportunities for us to track indoor moving objects. Thus it brings new challenges in indoor moving objects management [3].

Indoor space has some unique features, compared with outdoor space. Firstly, the moving of objects is constrained by rooms and doors. In particular, objects have to pass by the door when moving from one room to another one. Secondly, the distance measurement is different from that in outdoor space. The latter usually employs the Euler distance. However, this is not applicable in indoor space, due to the existence of doors and rooms. Finally, the positioning ways in indoor space usually use sensors like RFID and Bluetooth, which are differing from the GPS receiver in outdoor environment. The indoor positioning techniques are not able to report the precise positions of indoor moving objects.

Based on those unique properties of indoor space, a lot of data models were presented to represent indoor space and indoor moving objects, such as the object feature model [6,7], the geometric model [8,9], and the symbolic models [10-13]. The symbolic model, as the most popular model in indoor space, uses a graph consisting of rooms, doors and sensors to represent indoor space and indoor moving objects. However, as those models were proposed for specific applications, they were only able to represent partial semantics of indoor space and can not suit for different applications.

In this paper, we analyze the semantics of indoor space and present a cell-based formalization for indoor space, which defines the indoor space as a set of rooms, doors and sensors (Section 3). Furthermore, we propose a layered approach to representing moving objects in indoor space called LayeredModel. This model can well describe the relationships among indoor space, sensors and moving objects (Section 4).

2. Related work

Indoor space has received much attention in recent years. Previous work related with indoor space focused on the modeling of indoor space. The indoor space models can be divided into three categories according to the different ways to describe indoor objects, which are the object feature model, the geometric model and the symbolic model. Among them, the object feature model mainly expresses the properties of indoor space and the relationship between operations and types. In the literature [6], the authors used the UML-based class model, CityUML/IndoorML, to describe the relationship among objects in indoor space. In [7], an ontology-based model named ONALIN was proposed for the navigation in the indoor space. The geometry model concerns about the geometric representation of indoor space, which is mainly used to visualize the indoor space. The 2D-3D hybrid model proposed in [8] supports the visualization of indoor space and the navigation in indoor space. The prismatic model in [9] can well analyze the topology of indoor space. A topology-based semantic model was presented in [10], in which the indoor space is represented as a single set of objects for the analysis of indoor space. The lattice-based semantic model [11] used lattice structure to represent the indoor space, which is mainly used for the navigation in indoor space.

Most of previous models used a graph-based technique to represent indoor space and indoor moving objects. All the graph-based models take either rooms or doors as the nodes, and have some limitations on supporting various applications. For example, the deployment model [4,5] uses rooms as the nodes and sensors as the edges between rooms. It can effectively support indoor moving objects tracking and monitoring, but is not efficient when executing a KNN search on indoor moving objects.

3. Semantic Modeling of Indoor Space

3.1 Elements of Indoor Space

An indoor space consists of some cells (rooms). Rooms are connected by doors. When an object wants to pass from room A to room B, it has to pass by the door connecting those two rooms. We assume that some positioning sensors are deployed in indoor space. The typical sensors are RFID readers, hence in this paper we assume that RFID readers are used as the positioning devices and moving objects are equipped with RFID tags. Therefore, when a moving object is passing by a RFID reader, the reader will record the RFID tag identifier. A RFID reader has a limited range when sensing RFID tags. Such a range can be represented as a circle.

Figure1 shows an example of indoor space, in which there are seven rooms (r_1 to r_7) connected by nine doors (d_1 to d_9). There are also nine sensors deployed in Fig.1 (s_1 to s_9). When a moving object (mo_i) is passing by a sensor, the sensor will record its tag information and send to the server.

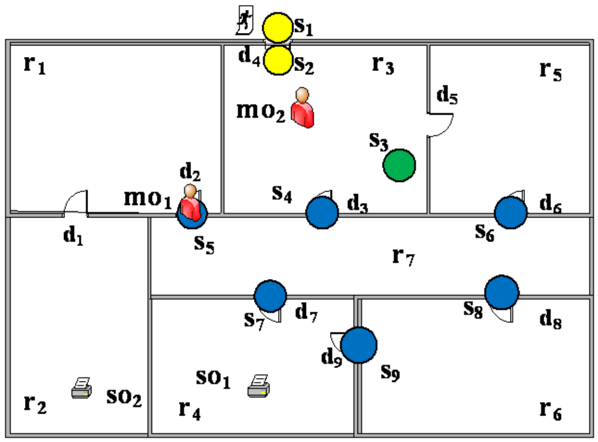

Figure 1. An Example of Indoor Space

Generally, an indoor space consists of the following elements that are needed to be considered when modeling indoor space, as shown in Table 1.

Table 1. Elements of Indoor Space

Element	Description
Room	The basic geometric partitions of indoor space. A room usually has one or more doors, and rooms are not overlapped.
Door	A door connects a room to another one, or to outdoor space if it is the entrance gate of a building.
Sensor	In this paper, sensors refer to RFID readers. They are deployed on doors or in rooms to detect moving objects.
Static Objects	Static objects are located in rooms, such as a printer, a computer, or a FAX machine. Note we are not necessary to record all the static objects in the indoor space, but only need to concentrate on those objects of interests.

3.2 Deployment of RFID Readers

According to the deployed locations and functions, RFID readers can be divided into three types [4]:

(1) *Presence Device* (PR). Those devices refer to the sensors located in rooms. The PR devices are used to determine whether moving objects appear in specific rooms. For example, the sensor s_3 in Fig.1 is a PR device.

(2) *Undirected Partitioning Devices* (UP). Those devices are deployed on doors and aim at detecting moving objects passing by doors. For example, the sensor s_4 in Fig.1 is a UP device. The UP devices can not detect the moving direction of objects.

(3) *Directed Partitioning Devices* (DP). Those devices are paired and deployed on doors to detect both moving objects and their moving directions. For example, the sensors pair s_1 and s_2 in Fig.1 are DP devices.

3.3 Definition of Indoor Space

Definition 1. The indoor space *IS* is defined as a quadruple:

$$IS = (R, D, S, SO, connect, deploy, locate),$$

Where *R* is the set of rooms, *D* is the set of doors, *S* is the set of sensors, *SO* is the set of the static objects of interests, *connect* is the connecting relationships among rooms and doors, and *deploy* is the deployment information of sensors. ■

Definition 2. The connecting relationship among rooms in the indoor space *IS* is defined as *connect*(*IS*), which maps each door into two rooms and indicates that they are connected by the door:

$$connect(IS) = D \rightarrow R \times R,$$

Where *D* is the set of door and *R* is the set of rooms. ■

Definition 3. The deployment of sensors in the indoor space *IS* is defined as *deploy*(*IS*):

$$deploy(IS) = S \rightarrow \{D \mid R\},$$

Where *S* is the set of sensors, *D* is the set of door, and *R* is the set of rooms. ■

Definition 4. The locations of the static objects in the indoor space *IS* are defined as *locate*(*IS*):

$$locate(IS) = SO \rightarrow R,$$

Where *SO* is the set of static objects, *R* is the set of rooms. ■

4. Semantic Modeling of Indoor Moving Objects

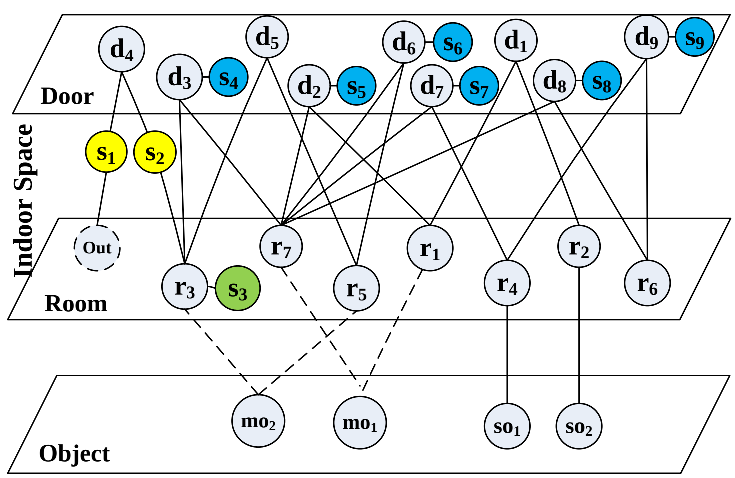

Figure 2. Modeling Indoor Moving Objects

In this section, we discuss the LayeredModel (as shown in Fig.2) for moving objects in indoor space. As the indoor space is basically static, we use the definition in Section 3 to represent the indoor space as a set of rooms, doors, static objects, and sensors, together with the deployment, connectivity, and location information about those entities. For moving objects, we use RFID tags as the identifiers of the moving objects, and record their trajectories through the detected data stream from sensors.

Figure 3 shows the entities and their relationships in LayeredModel. According to the *LayeredModel*, the entities in indoor environment are classified into five types, i.e., rooms, doors, sensors, static objects, and moving objects. The rooms, doors, sensors and static objects form the indoor space, and those entities are basically kept unchanged. The moving objects typically are people moving in the indoor space, which we need an effective way to keep tracking of their locations, visiting durations, moving patterns, and other interested information. Those information about moving objects are useful in many application scenarios, such as custom analysis in shopping malls, abnormal object detection in subway station, and workers' performance analysis in factories.

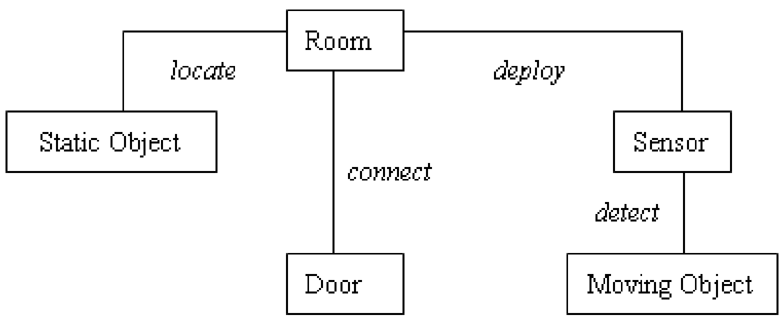

Figure 3. The Entities and Relationships in *LayeredModel*

The formal definition of the LayeredModel is as follows.

Definition 5. The data structure of the *LayeredModel* is defined as follows:

$$\text{LayeredModel} = (MO, LDDM, IS),$$

Where *MO* is the set of moving objects in the indoor space *IS*, *LDDM* is a set of matrixes. A matrix *LDDM*(*i*) defines the distance between each two doors in the room *R*(*i*). ■

Definition 6. A moving object *MO*(*i*) in LayeredModel is identified by its RFID tag. We define each moving object as a trajectory recording each state when the object was detected by the sensors:

$$MO(i) = (tagID,\ \ attributes,\ \ trajectory),$$

where *attributes* are user-defined information to describe the moving object. *trajectory* is defined as follows:

$$trajectory = \{r \mid r = < tagID,\ \ sensorID,\ \ time >\},$$

and *tagID* is the RFID tag identifying the moving object, *sensorID* is the number of RFID reader, *time* is the time instant when the moving object was first detected by the sensor. ■

5. Conclusions

Indoor space has received much attention in recent years as most people work and live in indoor space. In this paper, we present a new conceptual model for indoor space and indoor moving objects, which is called LayeredModel. Compared with previous models, our model takes into account the relationships among rooms, doors, sensors and moving objects, and uses a layered approach to represent indoor space and indoor moving objects.

However, this paper only gave an abstractive description for indoor space and indoor moving objects. There is a lot of future work needed to be further explored. We will construct a logical data model based on the semantic model, and define formal data structures and data operations to represent and manipulate the entities in indoor space.

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