Indoor Spatial Awareness Initiative and Standard for Indoor Spatial Data

Ki-Joune Li and Jiyeong Lee

Abstract— **With the rapid progress of spatial information services and ubiquitous computing technologies, the space that we are dealing with is no longer limited to outdoor space but being extended to indoor space. Indoor space differs from outdoor space, which makes it difficult to realize spatial information services for indoor space. In order to extend the scope of spatial information services to indoor space, and provide integrated and seamless services, it is required to establish new theories, data models, database management systems for indoor spatial data, and applications for indoor space. For this reason, a multi-national research initiative has been launched in 2007 to provide a theoretical background of indoor spatial theory and develop data models, indoor spatial database systems, and application services. In this paper, we present an overview of the research initiative. In particular, we focus on an international standardization activity for indoor spatial data, called IndoorGML and application of this standard to robotics.**

I. INTRODUCTION

Spatial awareness is a fundamental functional requirement of ubiquitous computing and used in many applications of ubiquitous computing as an essential component. However the spatial awareness has been emphasized on outdoor space rather than indoor space and few work have been done for indoor spatial awareness. The spatial awareness for indoor space is important for several reasons as follows.

First, we spend most of our daily life in indoor space. According to [1] and [2], 70% of cellular calls and 80% of data connections originate from indoors and we spend 80%-90% in indoor space. In fact, the indoor space should be the first target of spatial information services. Second, it is easier to implement computing infrastructure in indoor space than outdoor. The area where several hardware infrastructure such as sensors and wireless communication should be installed is limited in indoor space compared with outdoor space. Third, the nature of space in spatial information services is evolving from macro space to micro space. For example at the early generation of spatial and geographic information services in 1980s, the scope of space covered an immense area for example an entire country or city and the resolution was very coarse. In 1990, with the advent of car navigation systems and web map services, the scope of space has been reduced to the size of town and the accuracy has been improved. Since late 1990s, the spatial awareness becomes very popular even to individual pedestrians and scope of space is much reduced. For example we need spatial information on an underground metro station. An interesting observation is shown in figure 1, which implies that the user population of spatial information increases as the size of space is reduced to micro scale.

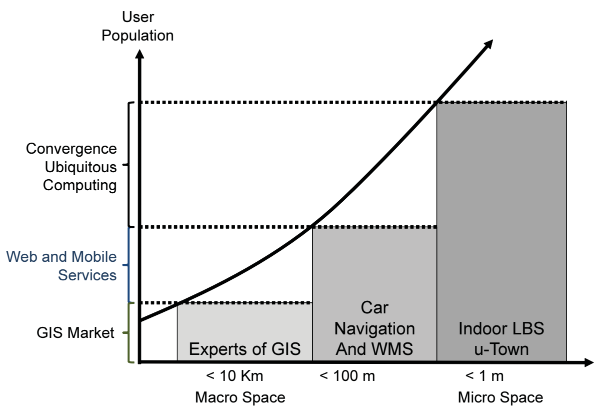

Fig. 1. Evolution of Scale

For this reason, an ambitious research initiative has been launched in 2007 supported by the Ministry of Land, Transportation and Maritime Affairs of the South Korea government. This initiative includes several companies and research teams from South Korea, the United States, Germany, and Denmark and aims to provide a vertical integration of core technologies for the *Indoor Spatial Awareness*(ISA) [4].

In particular, we focus on the standardization of indoor spatial data to provide the interoperability between different systems and environments of indoor spatial information services. It is planned to standardize the exchange format of indoor spatial data, called *IndoorGML*, under the OGC (Open Geospatial Consortium) [3].

This paper is a report on a research project rather than an academic paper and presents an overview of the ISA initiative, the basic concepts of indoor spatial data models, and the tentative standard of indoor spatial data called IndoorGML. And it also shows an example on the application of the IndoorGML to robotics. It is organized as follows. In the next section, the overall structure of ISA initiative is shown, and we present the indoor spatial data model in section III, and the indoor spatial data engine in section IV. The indoorGML is explained in section V with an example of application to robotics and we conclude the paper in section VI.

Ki-Joune Li is with the department of computer science and engineering, Pusan National University, South Korea `lik@pnu.kr`

Jiyeong Lee is with the department of geoinformatics, University of Seoul, South Korea `jlee@uos.ac.kr`

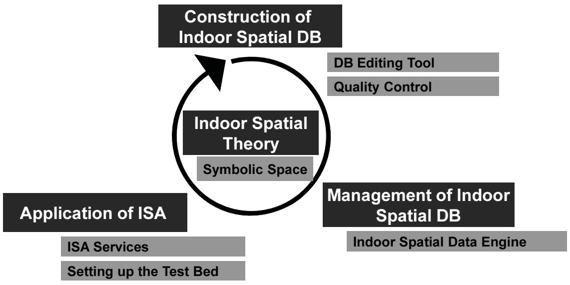

Fig. 2. Principal Components of Indoor Spatial Information Systems

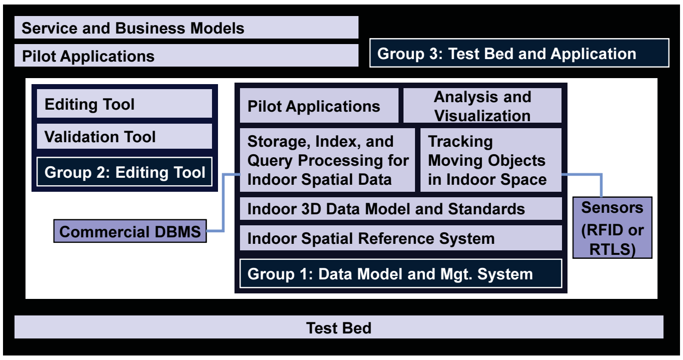

Fig. 3. Architecture of ISA Initiative

II. INDOOR SPATIAL AWARENESS INITIATIVE

In general, the principal components of information systems and services are composed of building databases, management of databases, application systems, and the theoretical base as shown by figure 2. Each component in figure 2 corresponds with an objective of the ISA initiative summarized as

- Fundamental theoretical background for indoor space,
- Tool for building indoor spatial databases,
- Indoor spatial database management systems, and
- ISA services and a test bed for ISA services

The first component of ISA initiative is to setup a fundamental theoretic basis of the remaining components. In particular, the indoor spatial theory provides basic concepts of indoor spatial data models. Despite a number of spatial theories for outdoor, very few researches have been done for indoor spatial theory, which differs from outdoor space such as Euclidian space or road network space. We introduced a new notion of space, called *symbolic space*, which is a major difference from outdoor space. And based on the concept of symbolic space, the indoor spatial data model has been developed. The second component is the tool for building indoor spatial data. Like most information systems, indoor spatial databases mainly determine not only the cost of entire system development but also the quality of indoor spatial information services. It is therefore extremely important to develop an efficient tool for building accurate indoor spatial databases in economic ways.

The third component is the development of an indoor spatial data engine, which differs from conventional spatial database systems in two aspects. Firstly, it must reflect the geometric and topologic properties of indoor spatial objects. Secondly, it must handle the data stream coming from indoor positioning sensors for moving objects in indoor space. The final component of the ISA initiative is the applications of indoor spatial information developed on the top of the indoor spatial data engine and data model. We have chosen a site of convention center as the target application. The overall architecture of components in ISA initiative is shown in figure 3.

III. INDOOR SPATIAL DATA MODEL AND THEORY

The major differences of the indoor space from the outdoor space include the constraints of space. No constraint is in Euclidean outdoor space, while the natures of indoor space are determined by the constraints of architectural components, such as doors, corridors, floors, walls, and stairs. In order to analyze the indoor space, the description and understanding of these architectural components are major tasks and we need a data model to describe the constraints in indoor space. In architectural engineering communities, several data models have been proposed for this purpose and one of which is IFC (Industry Foundation Classes)[5] proposed by the IAI (the International Alliance for Interoperability)[6]. However, this model is focused on the architectural engineering aspects, such like construction management and facility management rather than spatial information services. An indoor spatial data model for GIS view point is suggested to describe the interior 3D space as the LOD 4 of CityGML [7], which is an international standard of OGC. This model is much closer to the data model for spatial information systems than IFC but mainly intended to the visualization of indoor space rather than indoor spatial services and analysis, which may be complicated like evacuation routing analysis.

A complete spatial data model has been made by ISO/TC211 [9], which contains most possible entities of spatial features including geometries and topologies. This model is widely accepted by most application schema of spatial data and the geography markup language has been developed based on this model. However ISO 19107 and GML are intended for outdoor space. As the application schemas of outdoor space are defined on the top of spatial theory and ISO 19107 (the left of figure 4), the goal of indoor spatial theory and indoor spatial data model is to provide a basis of application schemas for indoor space as shown on the right part of figure 4.

An important requirement for indoor spatial data model is related with the notion of *cellular space* (or *symbolic space*[8][11][15][16]). While a region query in outdoor space is given with coordinates such as (x_1,y_1) and (x_2,y_2), the query in indoor space is often based on cellular notation like

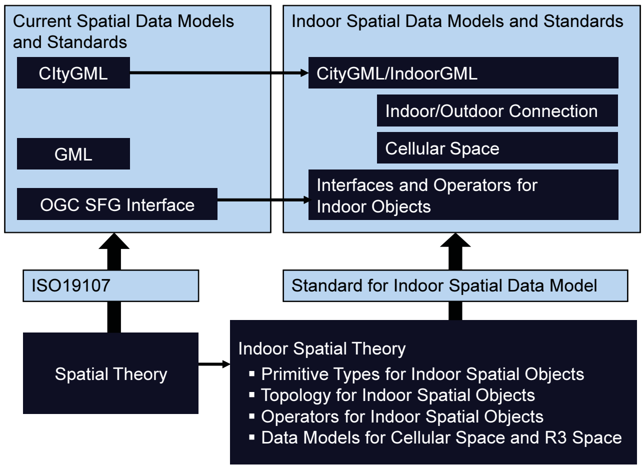

Fig. 4. New Spatial Theory for Indoor Space

"How many persons are in room 422?". The room number of this example is a cell identifier, which differs from the coordinates in Euclidean space. For example, the location in a train, which belongs to indoor space, is not identified by its coordinates but by the wagon and seat numbers.

While the Euclidean space has geometric and topological properties, the cellular space has only topological properties, which are to be explicitly specified. Among several types of topology in indoor space, the connectivity between indoor space and outdoor space should be seriously considered as well as the topology between indoor cells. For example, the entrance of a building is an important topology to connect an indoor space with outdoor space and provides a seamless service such as seamless navigation service.

Consequently the spatial information described by cell identifier should be differently stored, managed and processed. Certain space theories and data models developed for spatial information systems of outdoor space must be replaced with new ones [12] due to the difference between cellular space and Euclidean space.

Another important requirement of indoor spatial data model is related with sensor coverage in indoor space. In order to implement indoor positioning systems, we need to install a number of sensors in a given indoor space. Then the entire indoor space contains not only cellular spaces separated by walls and floors but also coverage spaces of sensors. For this reason, multilayered space model was proposed to describe multiple layers of sensor coverage geometry and topology [14].

IV. INDOOR SPATIAL DATA ENGINE

Since the properties of indoor space differ from those in outdoor space, the management systems for indoor spatial databases have different functionalities, which are summarized as follows;

- Representation, storage, indexing, and query processing for cellular spatial databases, 3D geometric databases, and moving objects in indoor space.

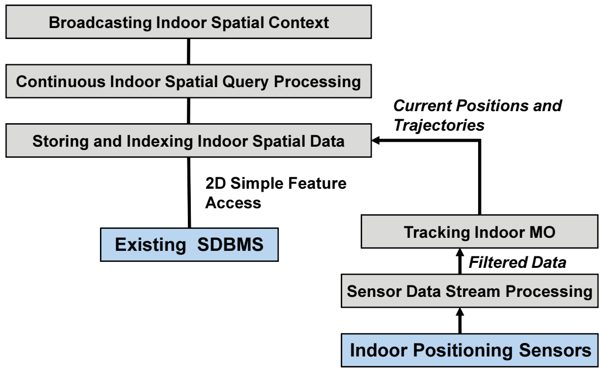

Fig. 5. Architecture of ISA Data Engine

- Integration of cellular space and Euclidean space,
- Realtime tracking of moving objects [19], and
- Continuous query processing for moving objects and broadcasting to clients.

The architecture of the indoor spatial database server, called ISA data engine, is shown in figure 5. The first function of ISA data engine is to store and manage indoor spatial objects in a database server. The engine provides a set of primitive object types for indoor spatial objects including stationary objects such as rooms, corridors, stairs, doors, and windows, and mobile objects. The geometry of stationary objects is based on *prism model* [20]. By the prism model, each geometry object in indoor space is represented by the upper and lower boundaries as shown in figure 6. It has several advantages over the 3D solid model of ISO 19107. First it is simple and efficient since most indoor spatial objects are vertically aligned. We reduce a large amount of data size by the prism model. Second, any spatial database management can be used for ISA data engine, if it supports the Simple Feature Access specification of OGC [17]. Third, the performance of query processing is significantly improved by the prism model, compared with spatial database management systems supporting 3D solid model.

The second function of ISA data engine is tracking of mobile objects in indoor space. The detail mechanism of tracking depends on the type of indoor positioning sensors, which are classified into two categories; presence sensors such as RFID and image sensors, and coordinate sensors such as WiFi, UWB, and RTLS sensors [21]. While the position in an outdoor space is relatively easily collected (e.g. by GPS), the indoor positioning technologies are unfortunately immature. No single technology provides a stable positioning method but hybrid approaches are being considered for indoor positioning. And several aspects of indoor space are closely related with the indoor positioning technology. For example, when RFID technology is used for the indoor positioning, the granularity of cell is differently defined from other technologies and tracking methods for RFID are therefore different. Other parts of spatial information systems should be tuned for RFID technique.

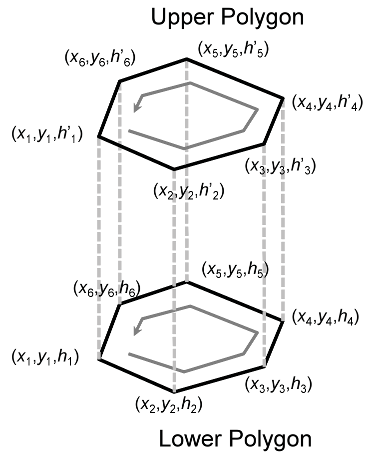

Fig. 6. Prism Model

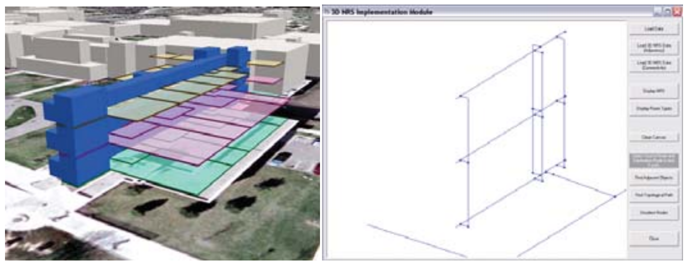

Fig. 7. Example of Geometric Graph

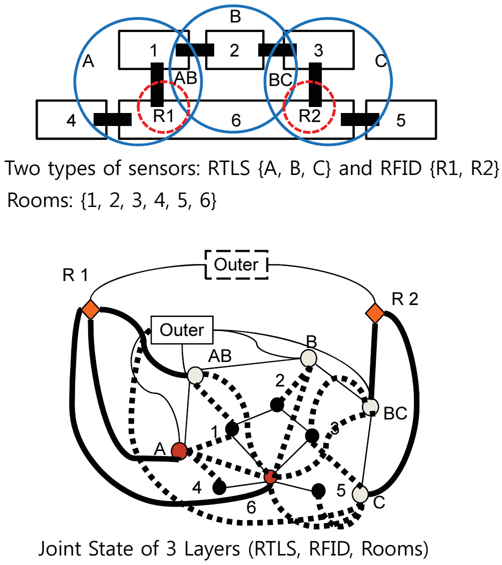

Fig. 8. Multi-Layered Space Model [13]

As mentioned in the previous section, most applications of indoor spatial information rely on symbolic spatial reference systems rather than coordinate reference systems. It means that the location data collected from positioning sensors should be converted to cell identifiers of symbolic space. In order to carry out the conversion process, we are implementing a tracking method in indoor symbolic space for presence sensors, and a map matching mechanism for coordinate sensors.

The third important function of the engine is to provide indoor spatial data to clients. In general, the client receives the data from server by submitting a query to the server. However the clients must periodically issue queries to server to monitor the situation of indoor space, which may result in a serious degradation of performance when there are a large number of clients. In order to solve the scalability problem, the ISA data engine employs two approaches; continuous query and broadcasting. The engine checks the databases if the registered queries are satisfied when there is any related change of state. And if there are any triggered query results, then the engine broadcasts it to all clients.

V. IndoorGML

We are developing a standard format (IndoorGML) for exchanging indoor spatial data to provide interoperability between different systems. It complements the expressive power of standards of 3D data format such as CityGML with two additional features;

- Geometric graph for indoor navigation routes in a symbolic space, and
- Multi-Layered space model for the interconnection between symbolic spaces.

The navigation routes in an indoor symbolic space can be simply described by a graph $S = (N, E)$, where N is the set of cells in a given indoor space and E is the set of connections between cells. However we need more information to analyze routing in indoor space, for example to calculate the shortest path between two given cells or points. We therefore define a geometric graph $S_G = (N_G, E_G)$, where $N_G = \{(c_i, p_i)|c_i \in C\}$ and $E = \{(c_i, c_j, a_{ij})|c_i, c_j \in C\}$. Note that C is the entire set of cells in a given indoor symbolic space, p_i is the representative position (i.e. centroid) of cell c_i, and a_{ij} is an attribute of the edge. As shown in figure 7, the nodes and edges of the geometric graph imply the rooms, corridors and the connections respectively. And the attribute may be defined by users.

The second component of IndoorGML is the relationship between several symbolic spaces. While the geometric graph is to describe the network topology within a given indoor symbolic space, the multi-layered space model is to interconnect several indoor symbolic spaces. For example as shown in figure 8, a given space is differently described by three symbolic spaces for RTLS, RFID, and rooms respectively. While the thin lines in the lower part of the figure represent the connections within an indoor symbolic space, the thick solid and dotted lines represent the relationship between indoor symbolic spaces, called *joint states*. The joint states are very useful to analyze the navigation in indoor space where several types of sensors are installed.

IndoorGML, which is defined as an XML schema, does not contain geometry of indoor spatial objects. This is because there are several standards for the 3D geometric

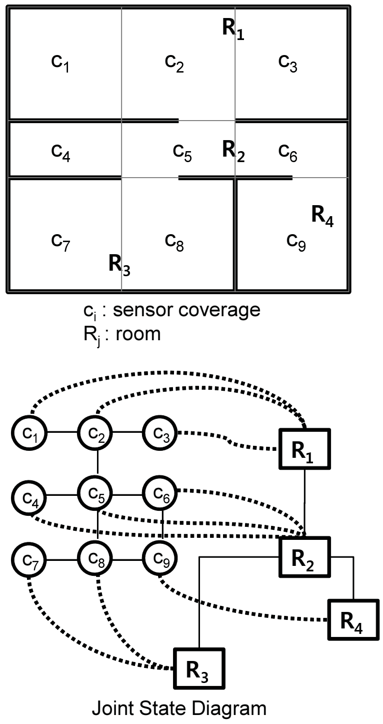

Fig. 9. IndoorGML and Robot Localization

description of indoor objects, such as CityGML and IFCxml.

We expect that IndoorGML may be also used in robot localization. Figure 9 shows an example of a floor plan and positioning sensor deployment. We assume that 9 presence sensors are installed in a grid manner where each coverage area is denoted by c_i. If a robot is detected by the sensor in c_1 in the figure, then we see that the robot is in room R_1 and approximately calculate the optimal path and the distance from the current position to R_4. By increasing the number of sensors, we can improve the accuracy of navigation routing of robots.

VI. CONCLUSION

Indoor space is a new application area of spatial information. Due to the difference from outdoor space, the conventional spatial theory, methodologies, and systems, which have been developed for outdoor applications, cannot be directly applied to the application of indoor spatial information. In this paper, we presented the ISA (Indoor Spatial Awareness) research initiative. The objectives of the ISA initiative are to establish the fundamental theoretical background for indoor space and to develop a tool for building indoor spatial databases, indoor spatial database management systems, and services of indoor spatial information.

We outlined the basic concepts and overall architecture of each component of the ISA initiative. In particular, we focused on the standardization issues of indoor spatial information and discussed on IndoorGML, which is a candidate of standard for exchanging indoor spatial data. The further detail information about the ISA initiative is found at [4].

VII. ACKNOWLEDGMENTS

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