Location Modeling for Ubiquitous Computing Based on the Spatial Information Management Technology

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Abstract
Location modeling, a basis of location-aware applications, is a critical area of research in ubiquitous computing and related applications. In particular, location is a key element of contexts in architectural space. It should be defined through the comprehension of the physical environment, as the locations of users or objects are not merely numerical coordinates; they refer to situations related to the physical contexts of the users or objects. In other words, a location model for architectural space should be based on the simplification of the physical environment, the consideration of various changes, and the particular relationships among spatial data. These issues have been studied experimentally in the fields of CAAD (Computer Aided Architectural Design) research, and the results can be applied to a ubiquitous computing system. This paper draws upon CAAD theory to propose a location model and utilization method for ubiquitous computing in architectural space. At the end of the paper we present the CAAD system "Vitruius", designed to define architectural spaces appropriately and manage them easily for the ubiquitous computing environment.

Keywords: location modeling; ubiquitous computing; CAAD (Computer Aided Architectural Design); structured floor plan

1. Introduction
In a ubiquitous computing environment, in order to offer appropriate services to the user, a context-aware system must recognize the situation and environment of the user: emotion, health condition, time, schedule, weather, temperature, humidity, location, etc. Location-awareness in particular is the fundamental part of context-aware service, because location is defining data for many applications related to ubiquitous computing.

Context can be regarded as a key factor of computation, alongside the explicit input and output (Moran, 2001). Without context, output is completely determined by input. A context-aware system operates according to both input and context, and it affects both the explicit output and the context. Context is tacit and can explain explicit outputs, and can also make more effective interactions. Fig.1. shows in the scope of context relative to input and output. The locations of spaces, objects, and users form an important part of the context that a ubiquitous computing system has to aware of. For the sake of offering appropriate services to users in ubiquitous computing, the system should have precise information about the user's location; this can be provided by a well-defined location model encompassing spaces, building components, and objects.

This paper presents a location model for ubiquitous computing system in the architectural space. The research is based on CAAD theories such as "Strplan" (Choi, 1997). First, based on the review of several related studies we define a new location model. Then we present "Vitruius", a CAAD system for defining architectural spaces appropriately and storing/managing them easily for the ubiquitous computing environment.

2. Location Models
The basic models of location representation can be distinguished according to their level of abstraction. Physical and geographical models are specific. They are represented within a universally valid coordinate system, geographical nomenclature, and a set of reference systems. On the other hand, geometric, symbolic, and combined (hybrid) models are more abstract and suited for adaptation to automatic processing. The geometric model is represented by coordinate systems of points, areas, and volumes. So it is called a metric model or a coordinate model. The symbolic model is a description using abstract symbols or names that are organized hierarchically. Such a representation is convenient for human interaction. It is a so-called hierarchical model or a topological model. (Domnitcheva, 2001)
Research in location modeling has advanced in the field of Location Based Services (LBS) based on Global Positioning Systems (GPS) and Geographic Information Systems (GIS) in the mobile environment. GPS is an appropriate position sensor for outdoor location. It has many limitations, however, such as signal acquiring times and shadowing from buildings. Subsequent studies such as that of the user-centered location model (Marmasse and Schmandt, 2001) demonstrate that a set of locations can be determined by a user's patterns of mobility. The user-centered model also includes knowledge about the different patterns and destinations, and it is integrated into context-aware mobile systems. Another study introduces an augmented form of location modeling to allow for a comprehensive range of sophisticated patterns and destinations, and it is integrated into context-aware mobile systems. The model should also accommodate not only their numerical coordinates but the relationships between them. In fact, a real user or object location, called a 'semantic location' in this paper, can be represented by the composite of geometric and topological information related to the structured physical world information.

4. The Representation of Location

Monroe Beardsley (1958) suggests that "the form of an aesthetic object is the total web of relations among its parts." Webster's, for instance, defines the form of a work of art as its "structured elements," specifically "the combinations and relations to each other of various components (as lines, colors and volumes in a visual work of art or themes and elaborations in an aural work of art)."

Architectural space can be understood in the same manner. Humans do not perceive architectural space as an image, but as a hierarchical composition of various elements. Fig.3.1 describes a single indoor space composed of several building elements such as floor, wall, ceiling (or roof), door, and window. Each wall is connected with other sidewalls. Walls contain either doors or windows. The roof is on top of four walls. The limited space made of four walls is called "indoor space," and the opposite is "outdoor space." The door implies the connection of two spaces and it is the criterion of the user's transition. The window signifies being adjacent to the outside (or other space). The ceiling and the floor likewise can signify the proximity of other spaces. We can also specify relationships of inclusion. For example, the walls, the floor, and the ceiling are a part of the room, and the door and the window are a part of the walls.

3. Location Models in Ubiquitous Computing

One of the important roles for ubiquitous computing is the ability to determine where people are, what objects and software services can be used at those locations, and how people can move from place to place. (Weiser, 1993) That is to say, location provides information about activity and intent, and provides information about the devices available to the user. This allows information allows the system to determine the best means of communicating with the user (Weiser, 1993). Of course, the position of users or objects should be obtained from tracking devices such as sensors and cameras; but their numerical coordinates are not enough to adequately identify the location. In order to interpret the numerical coordinates and obtain a meaningful location, the ubiquitous system needs a kind of framework as a means of transformation, because location is significant information about the physical world, objects, and users – beyond the set of numbers. In this manner, a location model is an abstraction layer between sensors and the system, and a metaphor shared by people (Brumitt and Shafer, 2001).

Therefore, a location model in the ubiquitous computing system should consider not only the fixed physical world but also moving users and objects. The model should also accommodate not only their numerical coordinates but the relationships between them. In fact, a real user or object location, called a 'semantic location' in this paper, can be represented by the composite of geometric and topological information related to the structured physical world information.
Architectural space comprises various elements. Therefore, it is necessary to understand each occupant in the building as well as semantic structure such as linguistic comprehension shown in Fig.2.

However, buildings should be considered differently from spatial elements. Buildings are not just objects; they are empty volumes created by them. Furthermore, they have peculiar properties that differ from artifacts and also include spatial relationship and social meanings. Therefore, architectural spaces can be understood by their syntactic characteristics – relationships among spaces.

The user's (or object's) location is generally defined based on this structured spatial information that contains the relationship of elements and spaces. For example, "Kim is in the room, on the chair, beside the yellow wall," and "The TV is on the table, in the room next to mine." Also, the user's location is defined by other users, such as "Tom is near John." In Fig.4., the location of John and Kim can be described in different ways: from the desk, from the door, from Kim, etc. In addition, the user's location is divided into two types: static and dynamic. The static location contains "in", "on", "near", "beside", etc. and the dynamic location contains "toward", "backward", "down", etc. This is shown in Table 1. The dynamic location can change in real time.

Table 1. Prepositions for Static and Dynamic Locations

| Prepositions for ... | Static location | Dynamic location |
|---------------------|----------------|------------------|
| in, on, by, near, beside, next to, inside, outside, over, above, below, between, under, behind, at, in front of, opposite, to, etc | toward, backward, in direction of, down, up, into, out of, through, against, across, away from, along, round, etc |

Consequently, a location is not a numerical position or a coarse, simplified situation; it is but semantic information that contains the relational information between users and objects. Therefore, the ubiquitous computing system needs the well-defined location model that can describe the relationship of users and objects according to the characteristics of architectural space. Of course, tracking a user's position is essential, but it is not enough for an effective user-centered service. Fig.5. shows a UML diagram of the relation of elements that compose spaces.
5. What is a "Semantic Location Model"?

Recently, "semantic web" is becoming a very interesting concept on the Internet. The semantic web can be defined as the representation of data on the World Wide Web, an extension of the current web in which information is given well-defined meaning (Burners-Lee et al., 2001). We can understand a semantic location model in the same way: a well-defined structure of data about a situation according to its location. A semantic location model can make the description of a physical situation exact and rich: it has both geometrical and topological information. Geometrical information depends on distance measurements, while topological information concerns relationships among spaces, spatial elements, objects, and users.

![Fig.6. The Concept of the Semantic Location Model](image)

6. Semantic Location Modeling

There are many considerable factors to solve in order to make an effective location model: standard of definition for the relationship of spatial information, simplification of the complex physical environment, correspondence to various location changes, amassment of location information, etc. Traditionally, these problems have been studied actively in the fields of CAAD; now they can be applied effectively to develop a location model for ubiquitous computing systems. In order to make a semantic location model, as previously stated, there are several strategies:

- The appropriate definition for symbols of location and their relationships: a location model should not only consider the characteristics of architectural space, but also be based on them.
- Correspondence to the change of space: an object-oriented data structure should be used.
- Reflection of user's intention: a location model should not only recognize the exact user's location, but also record the location history and predict the future location.
- Consideration of multiple spaces and users: the ubiquitous computing system is not for a single space and user. A location model can be used for multiple spaces and users.
- Standardization of file formats: a location model for the ubiquitous computing system should support heterogeneous software and devices.
- Consideration of static and dynamic locations.
- Easy management of data: an actual architectural floor plan is too complicated to be used for a location-aware system. The simplification of floor plan data is required for the location model.

![Fig.7. The Example of Using the Semantic Location Model](image)

This paper proposes a new location model based on 'Strplan', shown in Fig.8. Strplan is structurally well-defined and also has some hierarchical components. To make it more effective, we consider a component-based and object-oriented approach so that the system recognizes the spatial network as well as relationships between space and building materials. The component has its own data and methods for operating in various situations. Strplan has many features: 1) an object-oriented approach, 2) definition of relationship between objects, 3) management of spatial information and its relationship, 5) instant and consistent management of information, 6) level of details, 7) auto-generation of 3D model, and 8) foundation of a robust building data model. Strplan is suitable for making a semantic location model.

7. Vitruvius: a CAAD System for Semantic Location Model

In this chapter, we present a specific CAAD system named "Vitruvius." Vitruvius, based on the semantic location model we develop, can authorize and store locations efficiently, as previously stated. The location database can be used effectively as predefined communication interface information in the ubiquitous computing system.

Vitruvius semantically recognizes the human location related with the space and spatial elements,
and indicates the location based on the semantic location model (Fig.8.), shown in Fig.9.

8. System Implementation
As soon as the human's location is identified, Vitruvius automatically determines the nearest building components such as surface, wall, door, window, column, and object on the floor within that room. Fig.9. shows the example of human location that uses both the static location and the dynamic location in Vitruvius. We have implemented a 'LocMode' in the Vitruvius system. This mode can show the nearest components, the direction to move, and the room to move. The simulation of the semantic location model is shown in Fig.10., under several spaces and users.

9. Advanced Applications
The semantic location model in Vitruvius can be applied to various applications for the ubiquitous computing environment. In this paper, we suggest two applications: visible area checking and a prediction model.

- Visible Area Checking
When a person is placed in a space, the visible view angle is defined. According to this range, Vitruvius automatically discovers a visible area. Fig.12. shows the process of visibility checking through calculating the visible area in the space. It is important that a ubiquitous system recognize the visible area of the person based on the semantic location model; it makes the indoor LBS more efficient and complete.

- Recording Semantic Locations for a Prediction Model
We can consider another challenge involving the location model. Optimizing the semantic location model in Vitruvius, the semantic information about a person's movement and path can be saved as a data set. As the data is overwritten, it is recorded in the database as a previous location. The database thus accumulates a history of the person's semantic locations. Based on a sequence of semantic locations we can develop a so-called prediction model to support more intelligent LBS (Location Based Service) with semantic information in the ubiquitous environment. The concept diagram is shown in Fig.11.

10. Conclusion and Discussion
In this paper, we suggest a new location model: the "semantic location model", which contains a well-defined data structure based on spatial management technology. We introduced a prototypical CAAD...
system, "Vitruvius," based on the semantic location model. The semantic location model is a well-defined data structure of situations related with positions. The model can make the description of physical situations exact and rich because it has both geometrical and topological information. Utilizing the model, a ubiquitous system can recognize the context of a user's location and offer appropriate services. We have also summarized two example applications of the semantic location model in Vitruvius: prediction of user's intent and the recognition of visible area. The proposed location model can be applied to ubiquitous computing systems such as LBS, virtual reality / augmented reality environments, intelligent buildings, etc. For future research we need to study various applications in depth.

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| Visible Area | Visibility Checking | Visible Area | Visibility Checking |
|--------------|---------------------|--------------|---------------------|
| There are no interceptive wall, visible area can be finding by simply triangulation method | | There are interceptive wall, visible area can be finding by more complicated subtraction triangulation method |

![Diagram of visibility checking process]

Fig.12. The Process of Visibility Checking

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