ARCHITECTURAL RESEARCH, Vol. 12, No. 2(December 2010), pp. 15-22

Developing an User Location Prediction Model for Ubiquitous Computing based on a Spatial Information Management Technique

Jinwon Choi and Yungil Lee
Department of Housing and Interior Design, Yonsei University, Seoul, Korea
Department of Architecture, Hoseo University, Asan, Chungnam, Korea

Abstract

Our prediction model is based on the development of "Semantic Location Model." It embodies geometrical and topological information which can increase the efficiency in prediction and make it easy to manipulate the prediction model. Data mining is being implemented to extract the inhabitant's location patterns generated day by day. As a result, the self-learning system will be able to semantically predict the inhabitant's location in advance. This context-aware system brings about the key component of the ubiquitous computing environment. First, we explain the semantic location model and data mining methods. Then the location prediction model for the ubiquitous computing system is described in details. Finally, the prototype system is introduced to demonstrate and evaluate our prediction model.

Keywords : Prediction, Data Mining, Semantic Location Model, Ubiquitous Computing, BIM (Building Information Modeling)

1. INTRODUCTION

Recently, many prediction techniques have been studied and implemented in several smart-home projects such as Aware Home of GIT (Lesser et al. 1999), Intelligent Room of MIT (Torrance, 1995), the Neural Network House (Mozer 1998) at the University of Colorado Boulder and MavHome (Cook et al. 2003) of the University of Texas at Arlington. However, most of them focus on applying their systems without taking into account spatial information. Consequently, vague information is merely offered, because the inhabitant's locations in such systems are only defined by the consideration of simple geometrical positions. In this paper, we propose a location prediction model and a process of predicting the inhabitant's location using the data mining theories to solve the problems of the existing prediction techniques as we stated previously. Our prediction model is different from those systems in that it is based on the development of a BIM (Building Information Modeling)-based data structure called "Semantic Location Model" which was introduced in our previous research. Semantic Location Model embodies geometrical and topological information which describes the relation between inhabitants and space. This can increase the efficiency in prediction and make it easy to manipulate the prediction model. Data mining is being implemented to extract the inhabitant's location patterns generated day by day. As a result, the self-learning system will be able to semantically predict the inhabitant's location in advance. It can bring about the ubiquitous computing environment where possible accidents can be detected and eliminated. Also, some routines and repetitive tasks can be automated in advance.

2. RESEARCH BOUNDARY AND A SPATIAL INFORMATION MANAGEMENT TECHNOLOGY FOR PREDICTION

This paper focuses on predicting the inhabitant's location because it provides information about activity and intention, and provides information about the devices available to the user (Lee et al. 2004). As a result, the ubiquitous computing environment can react more precisely to the inhabitant's needs. In this section, the research boundary, the problems in the existing prediction models and the concept of the semantic location model are explained.

(1) Research Boundary

Unlike the pedestrian simulation, which simulates the pedestrian movement in order to help designers understand the relation between space and human behavior (Okasaki and Matsushita 1993), our research focuses on developing a prediction model for the ubiquitous computing environment. This prediction model would predict the motion of an inhabitant in a real-time manner by tracing the previous movements of the inhabitant within a residential space. Since each inhabitant has his or her behavior and need, the smart environment should react to each inhabitant in different ways. Furthermore, the interactions between an inhabitant and contexts resulting from the inhabitant's locations are investigated. This paper is based on the assumption that the numerical positions of the inhabitant are obviously traced by sensors and there is only one inhabitant being considered in our prediction model during a period of time.

(2) Problems in Existing Prediction

Several prediction techniques for the ubiquitous computing environment have been implemented in many smart home projects as we stated previously. Figure2 shows us the role of location model. It is the crucial technique to realize the ubiquitous computing environment because the exact location tracking of inhabitant is the fundamental information for personalized service. Without approaching the BIM-based semantic model, the relation between the inhabitant and the spatial elements is not considered as an input; this brings about many problems in creating, implementing and manipulating, as in the following issues:

1. Coarse prediction: Some existing prediction models do not apply location model to their systems. This brings about a lack of accuracy in terms of spatial information. For instance, some systems use only the numerical position to stand for all the characteristics of a room. As the result, the accuracy of the prediction is diminished.
2. Not semantic: Some prediction models include the concept of location modeling. Yet, they have not applied the semantic approach. Since the relationships among inhabitants, objects and spaces are the main keys to establishing the ubiquitous computing environment, the prediction model cannot predict meaningful results without considering that spatial information.
3. Inefficiency in manipulation: Spatial information is complicated in relation to its components. Each location is unique in its properties. Without implementing semantic location modeling, it requires great effort to create the database and the prediction model.
4. Change of physical context: If some components in the environment are changed in most existing prediction models, it consumes a great amount of time to manipulate or modify the database and the prediction model.

3) Semantic Location Model

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. The model should also accommodate not only numerical coordinates of user's position but also the relationships between user and physical environment. (Lee et al. 2004) a semantic location model is a well-defined structure of data about a situation according to its location. It can make the description of a physical situation exact and rich. It has both geometrical and topological information as shown in Figure 1.

Geometrical information depends on distance measurements, while topological information concerns relationships among spaces, spatial elements, objects and users. The model recognizes the spatial network as well as relationships between space and building materials. Moreover, we can also use our location model to predict the next coming locations and behaviors of inhabitants. By integrating BIM-based data structure with semantic location modeling and data mining techniques, the new prediction model can solve problems occurring in the existing systems. Since our hierarchical semantic location model embodies geometrical and topological information describing the relation between inhabitants and space, the output of predictions still contains that information. This can increase the efficiency in prediction. Also, generation and manipulation are easy because of the component-based and object-oriented characteristics.

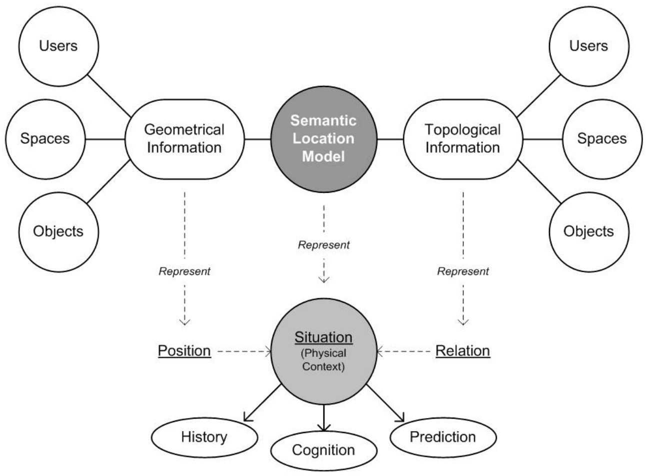


Figure 1. The Concept of the Semantic Location Model

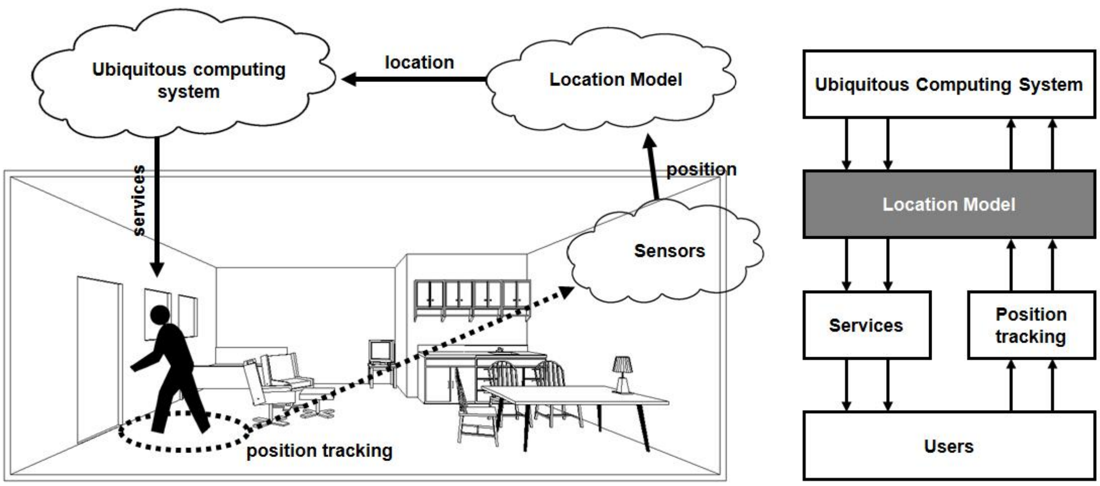


Figure 2. The Role of Location Model in the Ubiquitous Computing Environment

Table 1. The List of Prominent Data Mining Methods

Method	Classification	Clustering Segmentation	Prediction	Dependence Analysis
Time series analysis	●		●	
Decision trees	●		●	
Naïve Bayes classifiers	●		●	
Probabilistic networks	●			●
Neural networks	●	●	●	
K-nearest neighbour	●		●	
Fuzzy cluster analysis		●		

Knowledge discovery in databases (KDD) (Fayyad et al. 1996) is the nontrivial process of identifying valid, novel, potentially useful and ultimately understandable patterns in data. The KDD process (Borgelt and Kruse, 2002) consists of several steps. Among those steps, data mining is the most important one. Its goal is prediction, generalizing a pattern to other data (Edelstein, 2003). The prominent data mining tasks as classify as follows:

1. Classification: Classification aims to identify the characteristics that indicate the group to which each case belongs. It can be used both to understand the existing data and to predict how new instances will behave (Two Crows Corporation, 1999).
2. Clustering and segmentation: Clustering finds groups that are very different from each other and whose members are very similar to each other. It is a way to segment data into groups that are not previously defined, whereas segmentation refers to the general problem of identifying groups that have common characteristics (Two Crows Corporation, 1999).
3. Prediction: Prediction is a task which aims at using the description of patterns and relationships in the data which are already gathered to predict the future events.
4. Dependence and association analysis: This aims to discover which cases are frequently occurring together and what is the relation among them.

Research in data mining is highly interdisciplinary. Methods for solving the tasks named above have been developed in a large variety of research areas. Some prominent methods and their suitable tasks are shown in Table 1. Usually, several methods must be combined in order to achieve good results.

3. SEMANTIC LOCATION PREDICTION MODEL

In this section, the location prediction model is defined. We also describe how the system predicts the next inhabitant's location based on our semantic location model.

(1) The Location Prediction Model

In this paper, the location prediction model means both the data structure of the semantic location for prediction and the process of predicting the inhabitant's location based on data mining techniques. Figure 3 shows the data structure of the location prediction model. It is composed of a prediction data model and the semantic location model. The prediction data model contains both location lists and location pattern lists. The location lists are the sequence of locations. They contain the past and the current location data that are frequently changed according to the inhabitant's movement. The location pattern lists are loaded on the prediction model when the inhabitant paces in the space. They are compared with the current location sequence, and then the next location is predicted in the prediction model. In this manner, the ubiquitous computing system can effectively manage and search the location data using this location prediction model.

(2) The Process of Predicting the Inhabitant's Locations

This research paper is based on the assumption that the numerical positions of the inhabitant are obviously traced by sensors. The traced information is composed of the inhabitant's position, direction, date, time and interacted objects that are interpreted into a location based on the structure of the semantic location model. The overall location prediction processes are shown in Figure 4. The recognized locations are sequentially stored in the data storage as location sequences. They contain the past and the current location data that are frequently changed according to the inhabitant's movement. As time goes by, the location database will become larger in size. After that, Neural Network, a data mining method suitable for large data set with high signal-to-noise ratio (Two Crows Corporation, 1999), is performed to classify and cluster the new location patterns from input location lists.

(3) The Location Pattern Defining Process

During daytime, the system traces the inhabitant's locations and stores them in the database as location sequences (Figure 6) while the inhabitants are moving. During nighttime, the system analyzes all records of the location sequence in the storage to define the new location patterns. After that, those patterns are appended into the existing location pattern database. In this manner, the ubiquitous computing system gains more intelligence as days go by.

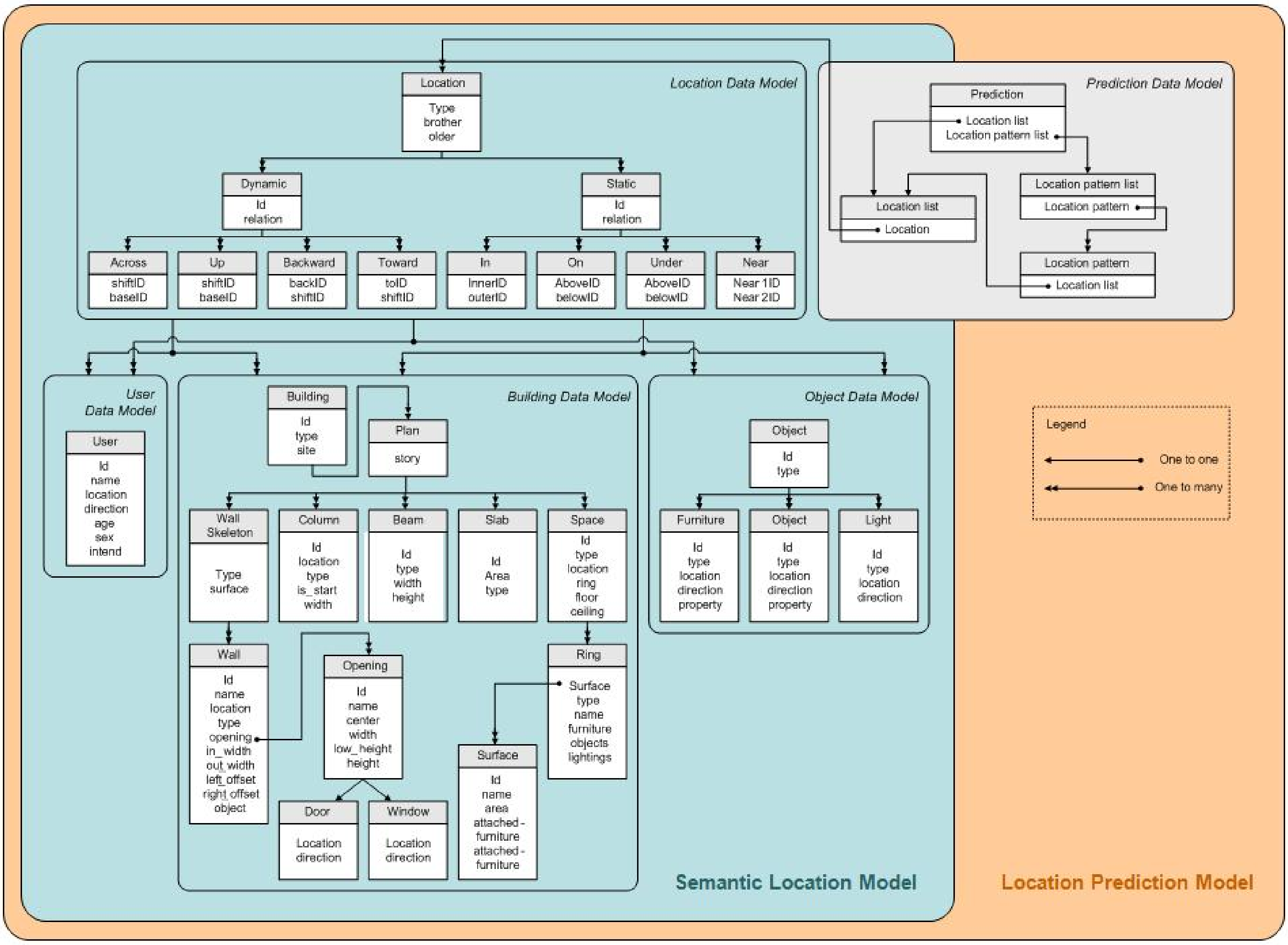


Figure 3. The Data Structure of the Location Prediction Model

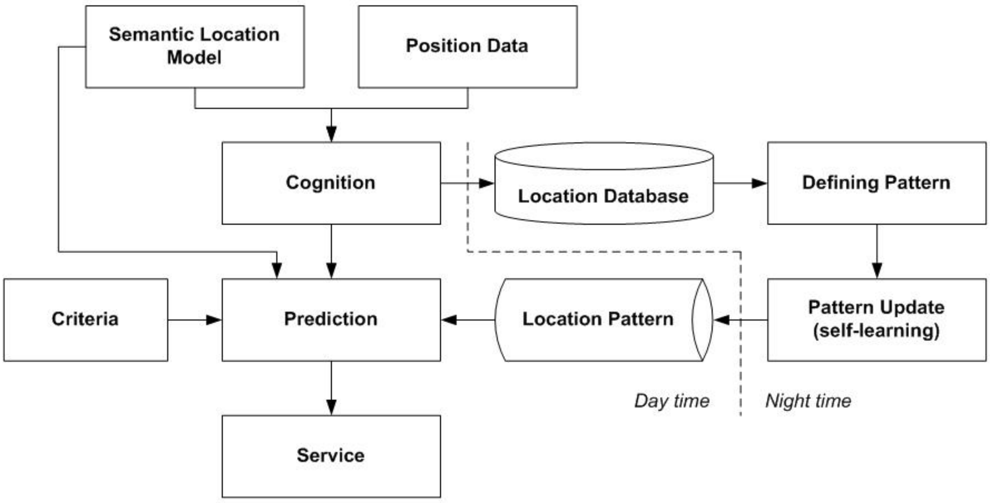


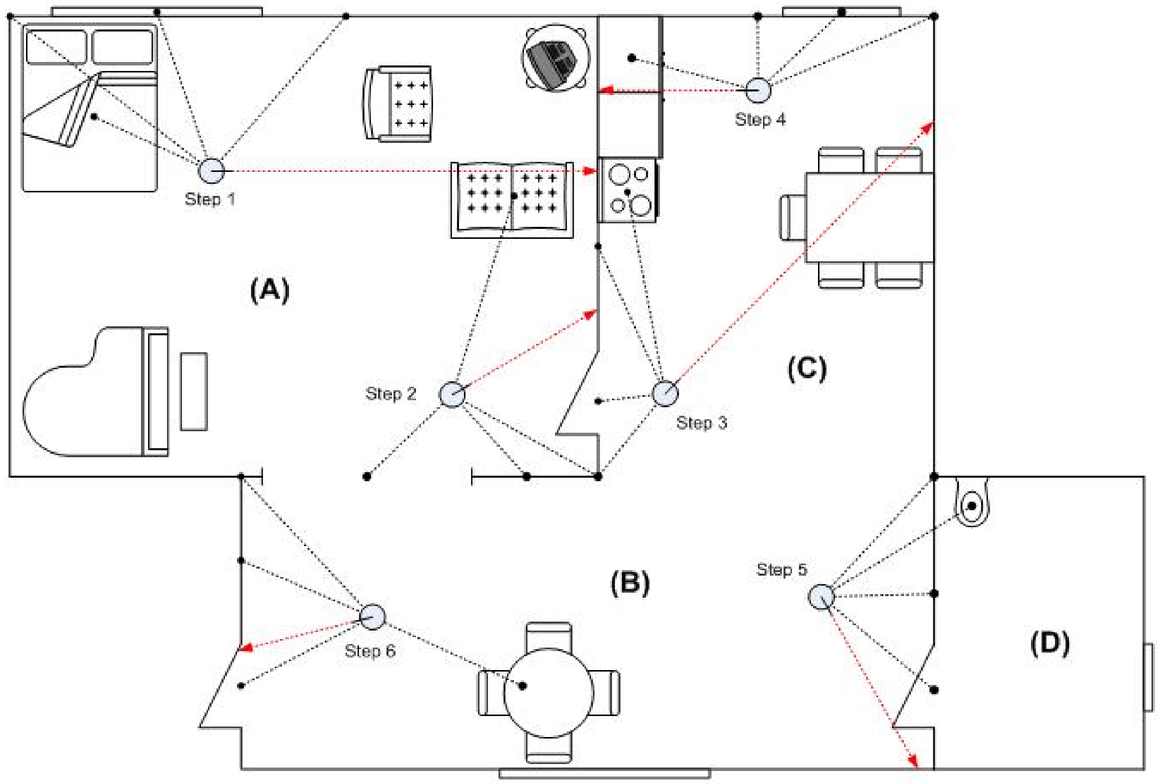
Figure 4. The Location Prediction Processes

(4) The Search Process of the Location Pattern

During daytime, the ubiquitous computing system regularly loads the location patterns from the database and stores them in the cache memory, then searches for the similar location patterns with the current location sequence. Figure 6 shows the process of searching the location pattern. The current location and the previous locations are the key locations for searching the similar location patterns.

(5) The Prediction Process of Location

The ubiquitous system can predict the future inhabitant's location by matching the current location sequence with the results of searching similar location patterns which contain the weight of criteria including frequency, importance, constraint, etc. By comparing the weight of those criteria, the system could predict where the inhabitants will move to and decide what kind of service the inhabitants will need. In some circumstances, the prediction model can predict the future location based on predefined criteria and constraints without using any patterns. This is because the system based on the semantic location model can understand the limitation of the inhabitant's behavior. The physical space provides some basic standards of movement and judgments to the inhabitants.

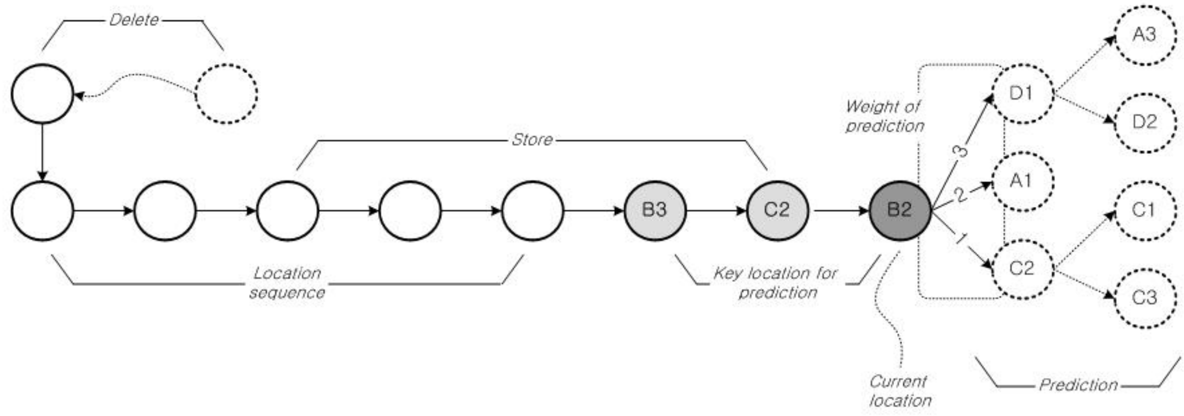


Step	Geometry		Space	Wall	Opening		Object	Column	Direction	Time
	x	y			Window	Door				
1	20.34	15.34	A	1	1	-	Chair 1	1	0.00 ...	10:32
2	35.22	30.02	A	5	-	1	Chair 2	6	20.00 ...	10:35
3	43,67	30.02	C	7	-	2	Stove 1	6	43.98 ...	10:39
4	48.65	10.12	C	2	2	-	Shelf 1	3	180.00 ...	10:42
5	46.85	45.67	B	12	-	3	Stool 1	7	292.23 ...	10:46
6	30.20	43.44	B	17	-	4	Table 2	5	191.20 ...	10:50
...	...	...		...	...	...	...		...	...

Figure 5. The Representation of Stored Location Sequences

4. PROTOTYPE SYSTEM – "VITRUVIUS"

According to the previous section, a prediction model is presented and simulated by a prototype system, called "Vitruvius," an intelligent CAAD system developed for multi-purposes. In this paper, it is developed as a simulator for the prediction model. The graphic user interface of Vitruvius is shown in Figure 7. We assume that the inhabitant's location is traced by sensors located in all rooms. Then the system shows the current location and all possible coming locations on the drawing panel by searching for similar location patterns. The semantic information of each location and all possible coming locations are also displayed on the location panel in real-time. The result of the location prediction for each state is reported on the report panel with the lists of tasks according to the matched pattern. Those tasks will be used to automate some appliances or objects in advance, to perform a ubiquitous computing environment.



Locations by orders Geometry Wall Opening					Possibility	Pattern Name	Actions
1st	2nd	3rd	4th	5th			
B3	C2	B2	D1	A3	15	Dressing	Turn off curtain “C1”
B3	C2	B2	D1	D2	45	Showering	Turn on light “L8”
B3	C2	B2	A1	-	30	Watching TV	Turn off curtain “C1” ,turn on light “L2”
B3	C2	B2	C2	C1	5	Cooking breakfast	Turn on light “L6”, microwave “M1”
B3	C2	B2	C2	C3	5	Washing dishes	Turn on light “L6”

Figure 6. The Search and Prediction Processes of Location

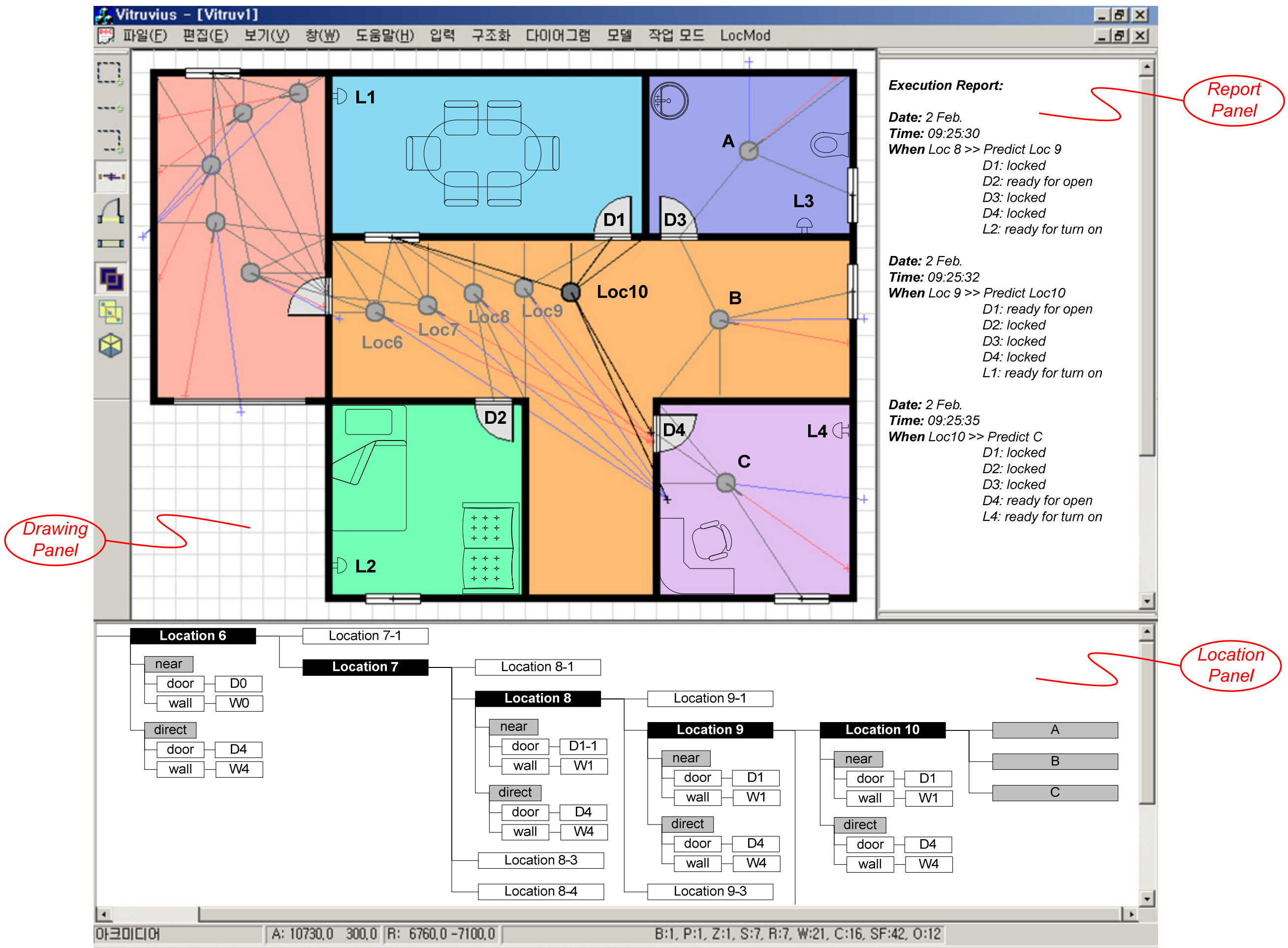


Figure 7. The Graphic User Interface of “Vitruvius”

Figure 8 shows us the execution examples of Vitruvius to predict the user's location and to provide the proper service to the user. Each step illustrates how Vitruvius to recognize and predict user's location according to the location pattern. Based on the user's position, Vitruvius generates his/her situation with semantic location model. Step 01 shows the initial location. Vitruvius already knows the relative situation with surroundings including wall, window, door and etc. User's orientation is one of the most important factors to predict the user's opinion. In Step 02, Vitruvius reconfigures the situation according to user's orientation in the real time manner. Vitruvius predicts and presents the possible next position based on the patterns. The blue symbol represents the most possible next position because the user's orientation target to door although other positions is regarded as the most reasonable next step according to the database. At this time, Vitruvius ready to prepare service to open the door which is near to the user. In Step 04, the prediction of the next location is changed by user's orientation dynamically. Vitruvius follows the user's position and reconfigures the prediction like Step 05 and 06. Through the simulation in Vitruvius, we can evaluation the possibilities of applying the practical situation and also see intensely how to work between inhabitant and LBS system based on our prediction model.

5. CONCLUSION

The location prediction method should be based on the semantic location model, because location is not a numerical position at all. In this manner, we proposed a location prediction model and a process of predicting the inhabitant's location using the data mining theories. In this paper, we design a location prediction model and test it in Vitruvius to evaluate the performance of our model. Through this study, we can figure out several benefits of this model as follows:

First, the suggested location prediction model makes a more detailed location prediction possible. It also contains several benefits, including creating, implementing and manipulating a ubiquitous computing system based on LBS (Location based service) because it is based on a spatial management technique.

Second, the result of the prediction is useful in that it enhances the interactions between inhabitants and the ubiquitous computing environment. For example, the predicted location can be used to promote an accident prevention system, trigger an appropriate task for each inhabitant and reinforce the energy saving in a residential space.

Third, the proposed location prediction model would be suitable for a self-growing and an autonomic computing paradigm. Especially, it is fundamental technology for the environment for ubiquitous computing because the personalized service for inhabitants is one of the most important tasks in the ubiquitous computing system.

However, the proposed model is limited in the coarse grid system which is a simplified coordination system to observe the result conveniently. For future research, we need to not only use the more complicated coordination system like real world but also consider various semantic situations to apply the practical fields. And also, we need to apply our model to various applications in detail.

ACKNOWLEDGEMENTS

This research was supported by a grant (07KLSGC04) from Cutting-edge Urban Development - Korean Land Spatialization Research Project funded by Ministry of Land, Transport and Maritime Affairs

REFERENCES

Choi, J. W. 1997. A Development of an Intelligent CAD Engine to Support Architectural Design Collaboration. Korea CAD/CAM Journal, 53-59.

Cook, D. J., M. Youngblood, E. Heierman, K. Gopalratnam, S. Rao, A. Litvin, and F. Khawaja. 2003. MavHome: An Agent-Based Smart Home. Proceedings of the IEEE International Conference on Pervasive Computing and Communications, 521-524. New York: The Institute of Electrical and Electronic Engineers.

Edelstein, H. 2003. Data Mining in Depth: Description is Not Prediction. DM Review Magazine. (March). (http://www.dmreview.com/article_sub.cfm?articleId=6388; accessed 24 November 2004)

Fayyad, U. M. 1996. Advances in Knowledge Discovery and Data Mining, eds. U.M. Fayyad, G. Piatetsky-Shapiro, P. Smyth, and R. Uthurusamy. California: AAAI Press and MIT Press.

Lee, Y. G., Lee, I. J. and Choi. J. W. 2004. Location Modeling for Ubiquitous Computing based on Spatial Information Management Technology. Proceedings of CAADRIA2004, 787-801. Seoul: Yonsei University Press.

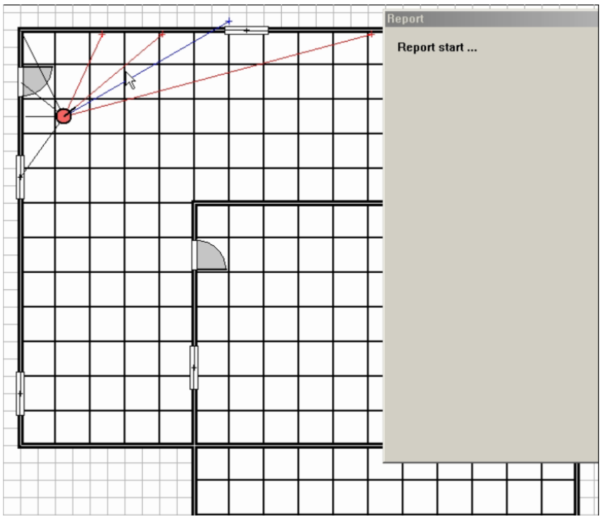
Lesser, V., M. Atioghetchi, B. Benyo, B. Horling, A. Raja, R. Vincent, T. Wagner, X. Ping, and S. X. Zhang. 1999. The intelligent home test bed. Proceedings of the Autonomy Control Software Workshop.

Mozer, M. 1998. The neural network house: An environment that adapts to its inhabitants. Proceedings of the AAAI Spring Symposium on Intelligent Environments, 110 – 114. California: AAAI Press and MIT Press.

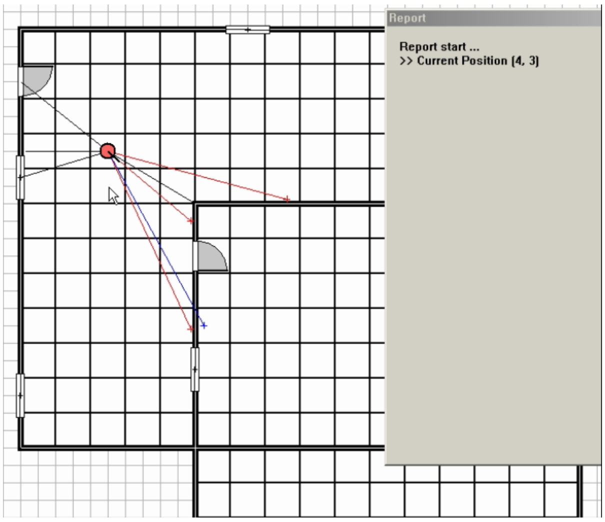
Okazaki, S. and Matsushita, S. 1993. A Study of Simulation Model for Pedestrian Movement with Evacuation and Queuing. Proceedings of the International Conference on Engineering for crowd safety, London: ELSEVIER.

Torrance, M. C. 1995. Advances in human-computer interaction: The intelligent room. Working Notes of the CHI 95 Research Symposium.

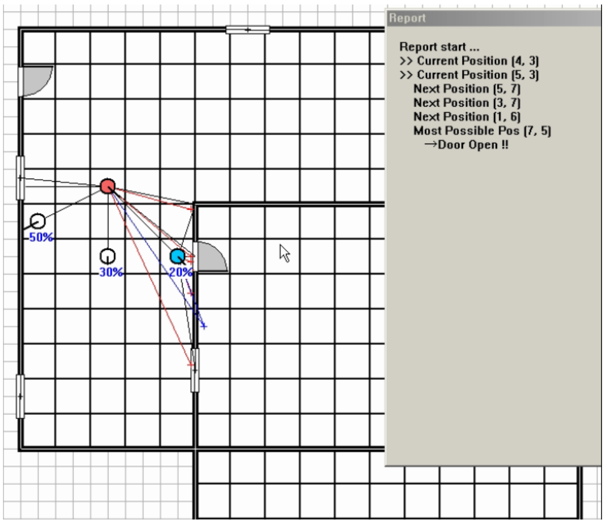
Two Crows Corporation.1999. Introduction to Data Mining and Knowledge Discovery, 3rd ed. Maryland: Two Crows Corporation.



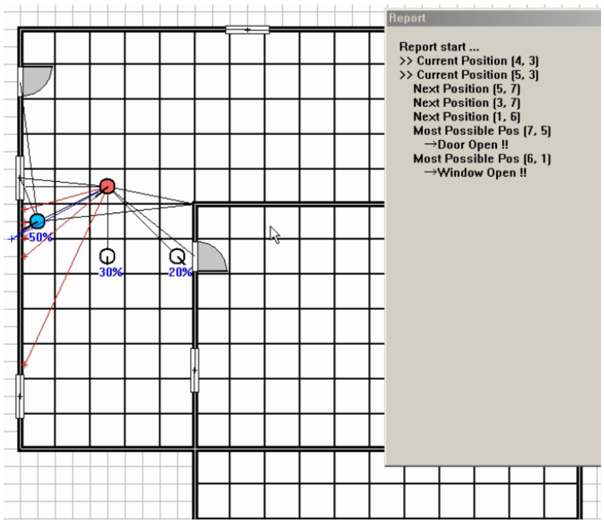
Step 01: Starting location



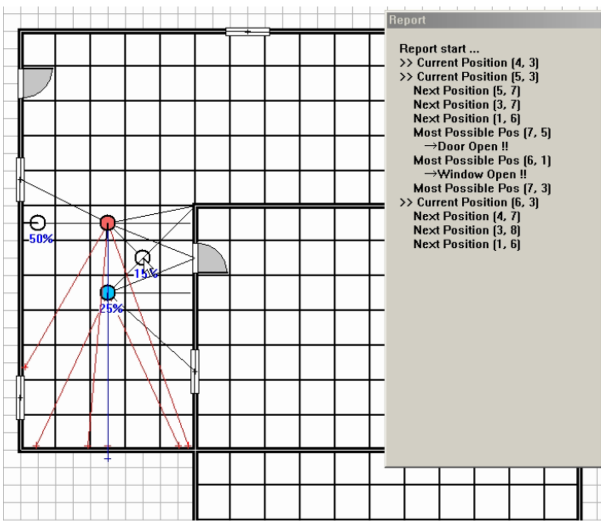
Step 02: Location tracing



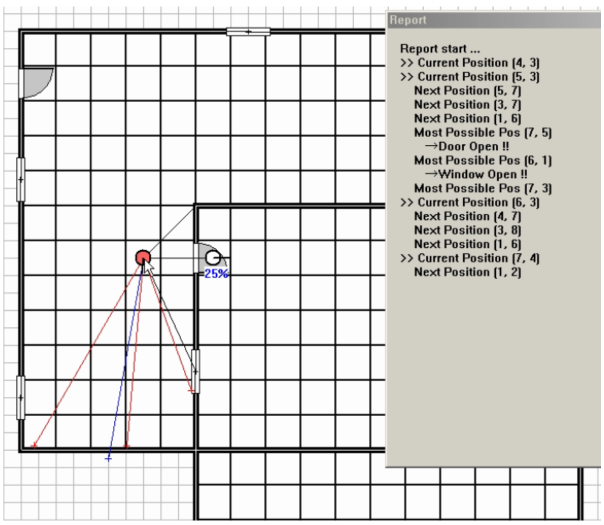
Step 03: Prediction & Visualization of the next location



Step 04: Reconfigure of prediction



Step 05: Prediction & Visualization of the next location



Step 06: Prediction of the next location & preparation of user-centered service

Figure 8. The Execution Examples of "Vitruvius"

(Date of Submission : 2010.5.3)