EXTENDING A PEDESTRIAN SIMULATION MODEL TO REAL-WORLD APPLICATIONS

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ABSTRACT:

Although recent advances in sensor technologies draw our attention to indoor spaces, no fully functional indoor 3D models are available as of now. Researchers in 3D modeling field have focused on representing 3D volumes using B-rep method and suggested different theoretical types of topological relationships. However, very few of them are related with explicit implementations for indoor spaces. Pedestrian evacuation simulation has been an active topic that targets scientific investigation of crowd behaviors in indoor areas. However, most simulations found in the related literature have been carried out using experimental settings without being linked to real-world applications. The purpose of our study is to propose a method to extend a pedestrian model to real world applications. First, we suggest a simplified 3D model that can be efficiently applied to indoor simulation and show how to build the model using a spatial DBMS. Then, we show a process to perform a pedestrian simulation using the proposed 3D model of a real campus building.

1. INTRODUCTION

While GPS-based outdoor LBS applications are becoming mature solutions, localization sensors such as RFID and UWB are drawing our attention to indoor spaces for navigation and facility management. However, compared to different technologies discussed widely for indoor applications, no fully functional implementations are available as of now. The primary reason is that indoor model is much more complex than outdoor model and indoor model has not been fully established yet.

Another reason is that indoor-related research efforts have been taken place in different academic communities. Pedestrian simulation (or crowd simulation) modeling area is a typical example that have not integrated with data modeling or real-world applications. The researchers in this area seek to investigate pedestrian behaviors in indoor environments. They are mostly devoted to developing scientific models that better explain pedestrian behaviors. Although there are some commercial evacuation simulators (e.g, EXODUS, SIMULEX), they are not related with real-time environment using indoor sensors.

In this study, we present a framework to extend pedestrian simulation models to real-world applications. For this, we see two problems as the most important factors that need to be resolved first; one is, we need proper indoor data model for simulation. Most data shown in pedestrian research are simple polygon types drawn either artificially or by CAD floor plans. To be able to use semantic information as shown in the outdoor LBS applications, we need similar topological data model for indoor spaces that can store semantic attributes. The other is, the data for indoor applications should be geo-referenced and stored in databases. Current commercial packages mostly use proprietary file-based data types. Such file-based data may suffice for the purpose of simulation or visualization in a single building. However, in order to deal with many buildings and communicate with real-time indoor localization sensors, building data should be stored in databases with real coordinates.

In this paper, we suggest a solution to above two problems. We propose a 3D indoor data model that can be adapted to pedestrian simulation models. The proposed model is less complex than those in theoretical 3D model research while retaining topological properties for semantic queries and computations. We show the process to build the data in a spatial database and apply it to a pedestrian simulation model. The simulation is illustrated using a campus building.

2. RELATED WORKS

Pedestrian navigation or evacuation problems in indoor spaces have been dealt with in different contexts and frameworks. Examples include those areas as architecture, cognitive science, robot navigation, indoor sensors and pedestrian behavior simulation. We will discuss them here in two viewpoints; data modeling and crowd simulation.

Indoor models are dealt with in different contexts in the recent studies (Becker et al. 2008, Hillier 1996, Kwan et al. 2005, Lorenz et al. 2006, Meijers et al. 2005, Pu et al. 2005, Tsetsos et al. 2005). While proposing the space syntax theory, Hillier (1996) used a linear structure called ‘axial line’ for computing indoor accessibility. Lorenz *et al*. (2006) suggested a hierarchically structured graph to support wayfinding. Tsetsos *et al*. (2005) introduced ontological concepts into the wayfinding and also used hierarchical graph. Becker *et al*. (2008) related their indoor model with sensor network by introducing connections between topographic and sensor layers. Some researchers (Kwan *et al*. 2005, Meijers *et al*. 2005, Pu *et al*. 2005) who are devoted to 3D data modelling applied indoor network structure to evacuation. With some variations, these studies shares similar properties in that they model indoor 3D spaces using reduced dimension for representing relationships and connectivity between spaces. For example, 3D rooms are represented using 2D polygons or cells, and then, they are reduced to one dimension graphs for the connection of those cells.

Although these models mentioned above are more focused on data models than on pedestrian behaviors, they can be largely categorized into macroscopic models in the perspective of behavior science. They primarily use node-link-based graphs as the data format. They consider pedestrians as a homogeneous group to be assigned to nodes or links for movements and do not take into account the individual interactions during the movement. Microscopic models emphasize individual agent's movement and their responses to other agents and physical environment such as walls and obstacles. Microscopic models are mainly based on simulation and use fine-grained grid cells as the base format for simulation. They have been used by experts in different domains including architectural design for the analytical purposes of the structural implications on the human movement especially in emergency situations.

Different micro-simulation models have been proposed over the last decades (Schreckenberg 2001) and there is a growing interest to use cellular automata as the base of micro-simulation (Blue *et al*. 1999, Klupfel *et al*. 2002). Kirchner and colleagues (Kirchner *et al*. 2002) have proposed CA-based floor field model, where two kinds of fields—static and dynamic—are introduced to represent interactions of agents. The floor field model uses grid cells as the data structure and computes movement of an agent at each time step choosing the next destination among adjacent cells. This makes computer simulation very effective. In this paper, using Kirchner's model as our base model, we show how we applied our DBMS-based 3D data structure to cell-based pedestrian simulation.

3. FLOOR-BASED 3D INDOOR MODEL

In pedestrian simulation models, movements taking place on the floor surfaces in the building are concerned. Along with the floor surface geometry, some semantic information contained in exits and rooms are needed in computing simulation parameters which will be described in the next section. Thus, instead of using the complex topological relationships found in 3D data model literature, we can focus on the 2D floor surfaces with semantic information of them. 2D topological data structure has been already developed and become a well-known standard GIS format.

In our previous study (Park *et al*. 2007) we had proposed a file-based 2D-3D hybrid data model in order to realize both 2D topology and 3D visualization functionalities. We used two separate models, 2D GIS layers and 3D models, and combined them using a database table as the means of linkage.

First, we created 2D GIS layers (shapefiles) using CAD building floor plans. A 2D building floor was then decomposed into separated compartments and assigned IDs. Then, the IDs of layer's room polygons along with other attribute values such as owner's name and status of use are stored in a database table.

(a) 2D layer model (b) DB table (c) 3D model

Figure 1. Integrating a 2D-GIS floor layer and a 3D model

While polygons in GIS layers are inherently divided separately and topological relationships are defined between them, most 3D models used for the visualization of a building are not constructed such way.

Thus, we first had to model a 3D building by creating isolated spaces. Not only floors but all rooms in a floor are explicitly divided into individual spaces. Then, the same ID values of spaces as those corresponding spaces in the 2D GIS layer are assigned. Once both models are constructed following the process described in the above, each space from the two models now shares the identical IDs. Through the shared data table, spatial objects from both sides are synchronized together (Figure 1). Using this method, we were able to perform analyses and queries using the semantic information stored in 2D layers along with 3D visualization. Figure 2 shows a test routing simulation under a fire situation. The routing results computed from 2D layer attributes avoiding the fire spot are displayed in 2D and 3D.

Figure 2. Evacuation routing simulation under emergency

Although this file-based approach was satisfactory in incorporating semantic and topological functionality into a 3D model, it has some drawbacks. First, two models are created separately and need additional table for linkage, which makes consistent maintenance difficult. Second, building a 3D model by separating compartments requires additional time and cost. Finally, such file-based models are not easy to store many buildings and, most importantly, they cannot be integrated with client/server applications such as sensor systems (i.e. RFID, UWB, thermal sensors).

To solve these problems in our previous study, we proposed a new approach in this study that uses a DBMS instead of files. Because semantic information is now extracted from database tables and used for analyses and 2D/3D visualization, the new model does not require an additional table for linkage. This data model has a multi-layered structure based on 2D building floor plans as the previous file-based model. It retains 2D topology because building floor plans are converted into 2D GIS layers (shapefiles) and then are stored in a spatial database. Thus, it is possible to perform topology-based analyses and operations provided by the DBMS. Also, all records containing geometries can be visualized for 2D and 3D.

Most simulations in pedestrian behavior research are carried out using simple 2D rectangles for the validation of models. However, in order to extend pedestrian simulation models to real-world 3D data, we also need a means to represent the connections between floors through stairs. Indoor navigation studies which were discussed in the previous section use graph structure for representing stairs. However, for the pedestrian simulation, stairs should also be treated as same grid cells as other room compartments. Figure 3 illustrates a simplified situation taken place in a 3D environment.

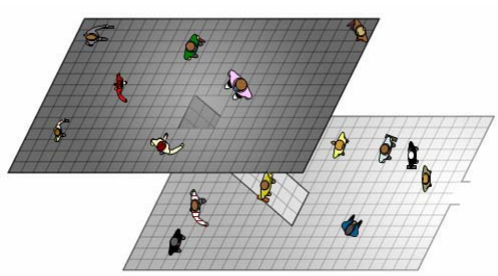


Figure 3. Pedestrian movement on 3D floor surfaces

For the connection of floors, we also converted the stairs to a simple set of connected polygons and then stored in the DBMS. Figure 4 illustrates the process for storing indoor objects in a database. This shows that we used only the bottom part of a room polyhedron.

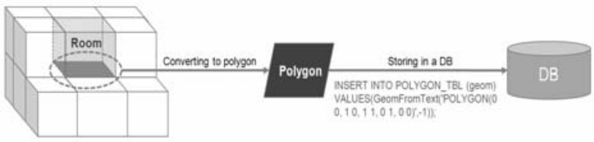


Figure 4. An example of storing rooms floors in a spatial DB

This approach can well fit in DBMS-based applications due to less complex and simplified data construction process. Using a DBMS against file format gives many merits including data sharing, management, security, back-up and speed. It is also possible to integrate with sensor systems by storing the sensor information in the database. In this study, we used PostgreSQL/PostGIS for the DBMS. PostgreSQL is an open source object-relational database system, freely downloadable. To display indoor objects in 3D stored in the database, we used OpenGL library and it also interacts with the PostGIS database for the data retrieval and visualization (Figure 5).

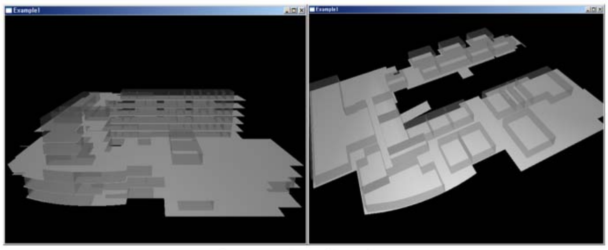


Figure 5. 3D visualization using data from a spatial DBMS

The pedestrian model that we have chosen to use in this study (described in the following section) uses grid cells as the base data format. Thus, in order to apply 3D data stored in the DB to pedestrian simulation, we should first convert the floor plan data of vector type into grid cells. Figure 6 illustrates the data processing for converting the queried polygon geometry to grid cells.

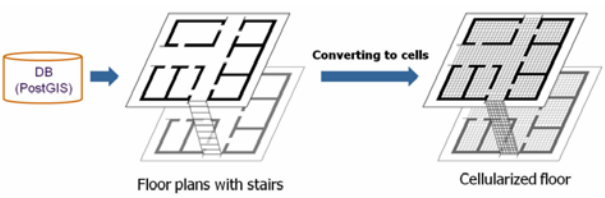


Figure 6. Converting floor plans read from DB to grid cells

4. EXTENDED PEDESTRIAN SIMULATION MODEL

Among different micro-pedestrian models, two approaches are getting attention; social force model and floor field model. A frequently cited model of former type is advanced by Helbing and collegues (Helbing *et al*. 1997, 2001) and is based on strong mathematical calculation acted on agents to determine its movement to destination (e.g. exits). Helbing's model considers the effects of each agent upon all other agents and physical environment (Figure 7) leading to the computation of $O(n^2)$ complexity, which is unfavorable for computer-based simulation with many agents (Henein *et al*. 2005, 2007).

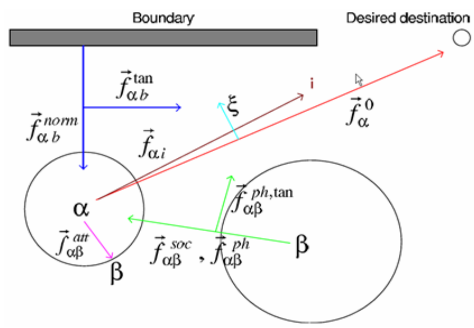


Figure 7. Helbing's social force model

On the other hand, Kirchner and colleagues (Kirchner *et al*. 2002) proposed the floor field model that uses computationally more efficient cellular automata (CA) approach. In his model, local movement rules that only consider adjacent cells are defined to translate Helbing's long-ranged interaction of agents into a local interaction. Although this model considers only local interactions, they showed that the resulting global phenomena share properties from the social force model such as lane formation, oscillations at bottlenecks, and fast-is-slower effects.

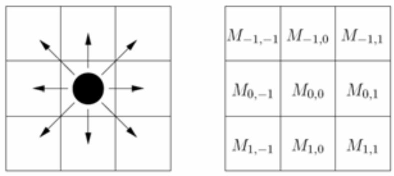


Figure 8. An agent and its possible transition (Schadschneider 2001)

The basic data structure of Kirchner model is grid cells and each cell represents the position of an agent and contains two types of numeric values which the agent consults to move. These values are stored in two layers; *static field* and *dynamic field*. A cell in the static field indicates the shortest distance to an exit. An agent is in position to know the direction to the nearest exit by these values of its nearby cells.
While the static field has fixed values computed by the physical distance, the dynamic field stores dynamically changing values indicating agents' virtual traces left as they move along their paths. As an ant uses its pheromone for mating (Bonabeau 1999), the dynamic field is similarly modeled where an agent diffuses its influence and gradually diminishes it as it moves. Without having direct knowledge of where other agents are, it can follow other nearby agents by consulting dynamic values.
It is possible to simulate different pedestrian strategies by varying the degree to which an agent is sensitive to static or dynamic field (k_s and k_d in Eq. (1)). For example, we can model

herding behaviors in panic situation by increasing sensitivity to the dynamic field. Each agent can move to adjacent nine cells including itself at each time step $t \rightarrow t+1$ according to probabilities p_{ij}, which is the normalization of the following score.

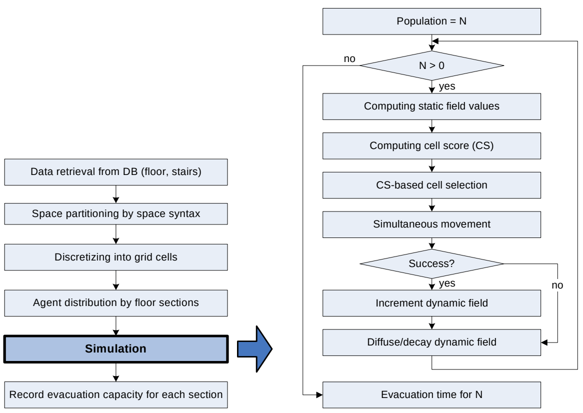
$$Score(i) = exp(k_d D_i) \times exp(k_s S_i) \times \xi_i \times \eta_i \quad (1)$$

where,

$Score(i)$: the score at cell i
D_i : the value of the dynamic field in cell i
S_i : the value of the static field in cell i
k_d and k_s : scaling parameters governing the degree to which an agent is sensitive to dynamic or static field respectively
ξ_i : 0 for forbidden cells (e.g. walls, obstacles) and 1 otherwise
η_i : 0 if an agent is on the cell, and 1 otherwise.

Based on the formula (1), we revised the 'diffuse & decay' rule of the dynamic field value D_i. We will not discuss how we improved the rule here since the focus is not on the pedestrian model in this paper. Instead, we will briefly describe how our data model has been applied to the model followed by some test results with visualization of the developed simulator.

Floor plan data are first read in from PostGIS DB, and then go through celluarization process for the simulation. The polygon geometry data along with stair cases also in the form of polygons are discretized into cells of size 40cm×40cm considering the human shoulder widths. Not only the geometry data but also semantic information such as exits, rooms and other obstacles is retrieved from the database. For example, exits are used in computing the static field value of each cell, which is the shortest distance from the nearest exit. In the simulation, we randomly located varying number of pedestrians. In real situations, the random data may be replaced with the real pedestrians acquired by location sensors. Figure 9-(a) shows the process from data retrieval, space partitioning to simulation, and (b) shows the update rules in the simulation. Having decided which cells to move based on the score described in (1), all agents move simultaneously and increment dynamic value. Among any agents competing for a cell, only one is selected randomly for no two agents can occupy one cell. Dynamic field value, D_i is, then, diffused and decayed.



(a) (b)
Figure 9. Processes from data retrieval to simulation

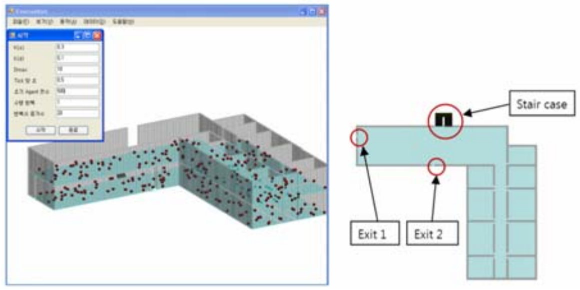
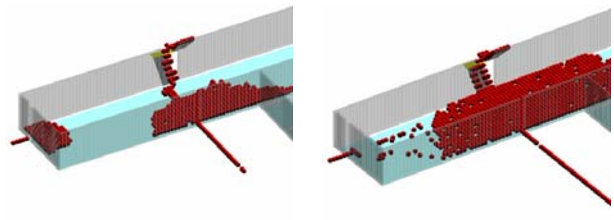


Figure 10. A snapshot of evacuation simulation with a 3D view

Figure 10 shows a 2D and a 3D view of the simulator. In order to implement 3D visualization, we used OpenGL and developed the simulator using C# language. The retrieved geometry information along with stairs was used for rendering in OpenGL and vertical walls were also displayed using the height values stored in the database.

We carried out simulations by varying the parameters k_d and k_s. $k_d = 0$ causes the agents flow directly towards exits without any herding behaviors while $k_s = 0$ makes them wander around without any clue of direction to exits. Figure 11 shows that $k_d > 0$ begins to show the herding behaviors following other agents to the second exit (Exit 1). Table 1 shows the effect of k_d on the evacuation time and the use rate of the second exit. 2000 agents were used for the test. We observed that the use rate of the side exit gets increased in proportion to k_d.


(a) $k_d = 0$ (b) $k_d/k_s = 0.5$
Figure 11. The effect of varying k_d

	k_d=0	k_d=0.05	k_d=0.1	k_d=0.25	k_d=0.5	k_d=1.0
Exit1	120	351	422	484	566	689
Exit2	1880	1649	1578	1516	1434	1311
evactime	945	723	702	688	670	632

Table 1. The effect of varying k_d on evacuation time and use of the side exit

5. CONLCUDING REMARKS

Real-time indoor LBS using localization sensors require proper indoor data model that can be implemented in DBMS. A pedestrian simulation model has been chosen as an application that can take advantage of such real-time environment. The issues that need to be solved beforehand were data model and DBMS implementation. Focusing on the fact that pedestrian models investigate movements taking place on the floor surfaces and use information obtainable from the surfaces, we suggested a less complex 3D indoor model that can be applied to pedestrian simulation. We showed the building process of this model in a DBMS.

We used the floor field model as the pedestrian model because it has shown efficiency in computation and flexibility of adjusting behavioral parameters. We showed how our model is applied to the floor field model and also improved its diffusion and decay rule so that it can be better fit in real 3D environment. Using a simple two-story campus building, we carried out some simulations by varying parameters.
Since the primary purpose of this study was not the scientific improvement of simulation model, we have not described evidence of our improvement. Considerable work remains in the development of our system. The model needs to be tested and calibrated in different real-world data. Also it needs to be tested in conjunction with localization sensors.

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