Integration Method of Multi-grid Evacuation Model in 3D Virtual Indoor Environment

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Abstract

Indoor evacuation model can provide scientific guidance for security solution design and emergency plan making in indoor environment, and virtual 3D scene can make the evacuation simulation more intuitive. An integration method of multi-grid evacuation model in 3D virtual indoor environment is proposed here. It maps 3D scene to 2D plane and establishes the grid table first, and then for each grid, calculates the shortest distance to accessible exits. After that, using the route selection method of multi-grid model to calculate the target position for each pedestrian in one time-step and matching the position to 3D scene, and invoking the action library to simulate the movement. Besides, the effect of ground slope is taken into account on pedestrian velocity. Experiment shows that the method is feasible and effective.

Keywords: *virtual indoor scene, multi-grid evacuation model, integration*

1. Introduction

In process of urban construction, many large and complex indoor environments, such as commercial building, office building, parking lot and airport are gradually becoming the important places for living and work. In recent years, due to fire, earthquake, criminal activities and some other unexpected factors, the personal safety accidents in the indoor environment have happened frequently. In order to avoid or reduce the expense of disaster, many researches focus on the analysis of pedestrian indoor motion characteristics. Various evacuation models can simulate the evacuation process. For example, Wang [1] calculated the safe evacuation time and route by taking the geometric continuous evacuation space, and constructed 3D models for building, fire and pedestrian to simulate the fire evacuation process; Tang [2] proposed a pedestrian evacuation model according to the fire scene based on GIS technology and realized real-time spatial analysis; Salvador [3] proposed an optimized evacuation model and summarized the principles of solving indoor evacuation problems. Zhao [4] proposed the self-organized criticality to reveal some hidden features of crowd movement. However, these studies didn’t fully consider the interaction between different pedestrians as well as between the pedestrians and buildings in the actual evacuation the accuracy of evacuation simulation will be affected to some extents. In accordance with the different physical space simulation methods, Xu [5] divided the existing models into discrete model (such as cellular automaton model, CA) and continuous model (such as society force model, SF), and proposed the multi-grid model based on these two types. It considered the interaction between different pedestrians and even pedestrian and building, at the same time, it has the advantage of high computation speed of the discrete model. Yuan [6] took into account the factors which affect the pedestrian evacuation route selection, such as the physical condition, the ability of respond to emergencies, the distance to exits and the changing of disaster source, and proposed an improved CA model. Liang [7] simulated the multi-grid model by using multi-Go software and proposed recommendations according to the evacuation simulation results. Li [8] analyzed the evacuation phenomenon in stairway and introduced the multi-grid stairwell evacuation model. Most of the simulations are based on the 2D plane, while it will be more realistic if performed in 3D scene.

Based on analysis above, integrating multi-grid evacuation model in virtual indoor scene can make the simulation more efficient and realistic, and easy for subsequent analysis and understanding.

2. Multi-grid Model

During the evacuation simulation, the distribution of pedestrian might be influenced due to the inconsistent of pedestrian's shoulder width and thickness, and the phenomenon of blocking and extrusion might caused by moving expectation and the interactions between pedestrian and building such as repulsion and friction. Traditional CA [9] model defined the grid size as 0.4(m) × 0.4(m) according to the average of pedestrian's shoulder width, each pedestrian occupies one grid, the distance between pedestrians is equal to the shoulder width, further more the distance that pedestrian moves during single time-step (time for pedestrian position updating) is equal to the one grid length. This method can not reflect the subtle movement and also the blocking and extrusion phenomenon during the actual evacuation process.

Multi-grid model [5] subdivides the grid into 0.4/n (m) × 0.4/n (m) based on the CA model, here n is grid density. The grid length is changed to 0.4/n (m), each pedestrian occupies n × n grids, and the grid count that each pedestrian can move in a single time-step is ranged from 0 to n. The formula to calculate the pedestrian velocity in this model is:

$$V = \frac{a}{\Delta \mathrm{T}} \Delta S \tag{1}$$

Where a is side length of the grid, ΔT is the time-step, ΔS is the grid count that pedestrian can move. With the grid size reducing, the distance between pedestrians may less than the shoulder width, and pedestrian can move more grids in single time-step. In this way, it can easily reflect the subtle movement of pedestrian.

In multi-grid model, the interaction between pedestrians and even pedestrian and building will be transformed into the probability. $P_{i,j}$ is the probability of the pedestrian moves to the grid (i, j). The formula to calculate $P_{i,j}$ is as follows:

$$P_{i,j} = \overline{N} \delta_{i,j} I_{i,j} \left(\frac{1-D}{\sum_{(i,j)} \delta_{i,j}} + D_{i,j} + \sum_{P} f_{i,j} + \sum_{W} f_{i,j} \right) \tag{2}$$

Among them, D is the self-driving force that shows the movement expectation of pedestrian. Its value range is from 0 to 1, and the direction always points to the pedestrian's destination such as exit; $D_{i,j}$ is the expect projection value of pedestrian moves to the grid (i, j). It is only projected to the three closest directions, and $D_{i,j}$ in other directions is 0; if it does not breach the volume exclusion principle[5] of multi-grid model when pedestrian moves to grid (i, j), then $\delta_{i,j} = 1$, else 0; $I_{i,j}$ is the inertia factor that pedestrians maintain their last movement; $\overline{N}$ is the normalization factor; $\sum_{P} f_{i,j}$ is the interaction between pedestrians and $\sum_{W} f_{i,j}$ indicates the interaction between pedestrian and building.

It may occur that a few pedestrians compete for the same grid during actual evacuation. To simplify solve this problem, we can calculate the probability of each competitor moves to the grid by using formula 2, in which the one with maximum probability can access the grid and others should reselect other grids as their target positions.

3. Integrating Multi-grid Evacuation Model with 3D Virtual Indoor Scene

Generally, the entities in the indoor environment can be divided into three categories including pedestrians, obstacles and exits. Obstacle means the entity that pedestrian can only walk around but not across such as walls and tables. Exit presents the target position of pedestrian such as main gate and emergency exit. To integrate the multi-grid evacuation model with virtual indoor scene, firstly mapping all entities to the 2D plane where the floor in, and establishing the grid table based on the minimum bounds rectangle (MBR). Then, expressing all entities to the related position of the grid table and initializing the states of each grid, such as the accessibility and recent distance to accessible exit (RDTAE) value, and calculating the RDTAE value of each grid. Finally, calculating the target position of each pedestrian by using the route selection method of multi-grid model in single time step, and invoke the action (such as running) library to implement the animation of moving from the current position to the target position in 3D scene. The flow diagram for the integration method is shown in Figure 1.

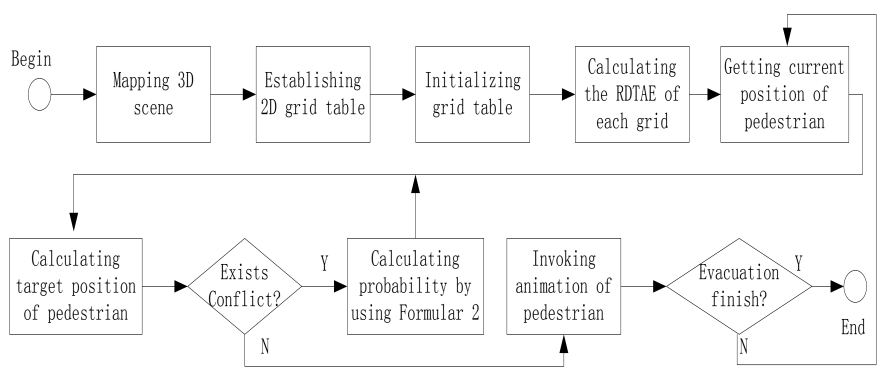

Figure 1. Integration Procedure of Multi-Grid Model with 3D Virtual Indoor Scene

3.1. Mapping 3D scene to grid table

In order to simplify the creation of the 2D grid table, the floor is selected as the reference plane. Firstly, we divide the MBR of the plane into 0.4(m) × 0.4(m) so that to form the 2D grid table G. Then we subdivide each grid in table G according to the size of n × n, and get the table G'.

It is easy to understand that with the degree of subdivision increasing, the accuracy of simulation will be improved, but the cost of calculation will also heighten at the same time. Therefore, an appropriate n should be chosen according to the performance requirements. We define the grids in table G' as grid (RowNum, ColNum, State, RDTAE), where RowNum and ColNum indicate the row number and the column number of the grid respectively, State is the accessibility of the grid, and RDTAE is the

RDTAE value of the grid. Among them, $RowNum \in \left[\mathbf{0}, \left\lfloor \frac{M}{\mathbf{0.4}} * n \right\rfloor\right]$, $ColNum \in \left[\mathbf{0}, \left\lfloor \frac{N}{\mathbf{0.4}} * n \right\rfloor\right]$, where n is the grid density, M and N indicate the horizontal width and vertical height of the MBR respectively.

Suppose that the corresponding position in 3D scene of $grid_0$ (0, 0, $State_0$, $RDTAE_0$) is P_0 (x_0, y_0, z_0), then the position of any point P (x, y, z) in 3D scene is $grid_P$ ($\left\lfloor \frac{x - x_{\mathbf{0}}}{\mathbf{0.4}} * n \right\rfloor$, $\left\lfloor \frac{z - z_{\mathbf{0}}}{\mathbf{0.4}} * n \right\rfloor$, $State_P$, $RDTAE_P$) in grid table G'.

Then, we map the obstacles and exits directly from their regions in 3D scene to the grid table. The region that is less than one grid will be processed as one grid. Pedestrian will be presented as a circular which radius is the width of the pedestrian's shoulder and center is the pedestrian centroid. The number of grid occupied by each pedestrian is n.

Finaly, we initialize the grid state and RDTAE value. The grid state of exit should be labeled as accessible and the RDTAE value should be set as 0. The grid state of obstacle and the areas in the MBR where the pedestrians cannot access should be labeled as inaccessible, and the RDTAE should be set as infinite. The grid state of others should be labeled as accessible and RDTAE should be set as infinite.

3.2. Calculating the RDTAE of each grid

The RDTAE value is important data for pedestrian evacuation route selection. To calculate the RDTAE value, a queue is introduced. Firstly, adding all exits into a queue, then get the head node of the queue in turn and decide whether its eight grids that around it can access or not, and plus 1 to the RDTAE value of the grid that is labeled as accessible to the head node which hasn't been accessed and is not in the queue, after that add this grid to the queue; plus 1 to the RDTAE value of the grid that is labeled as accessible to the head node which has been accessed and is greater than the queue head node.The pseudo code for this procedure is as follows:

```
Input: The initialized grid table
Output: The grid table with RDTAE value
Procedure:
Queue Q; //Queue, to store all accessible grids
Grid firstElem; //Type Grid, to store the information of current grid
Begin
  For each e∈{all exits} do{
        Q.Enqueue(e);} //add all exits to Q
  While(Q is not null) do{ //calculate the RDTAE value
       firstElem = Dequeue(Q); //get the head node of Q
       for each g∈{the eight grids which adjacent to firstElem} do{
               if(g.state == accessible && g.RDTAE > firstElem.RDTAE){
                      if(g hasn't been accessed){
                             if(g not in Q){
                                    Set g.RDTAE = firstElem.RDTAE + 1;
                                    Q.Enqueue(g); //add the eligible grid
                            Set g has been accessed;} //end if
         } //end if
       } //end if
```

```
        else
            if(g.RDTAE > firstElem.RDTAE + 1)
                Set g.RDTAE = firstElem.RDTAE + 1;
    } //end for
  } //end while
  } //end for
End
```

It is necessary to modify the states of grids which occupied by the pedestrians to inaccessible after calculating.

Supposed that there are K exits in an indoor environment, and the count of grids in grid table is N^2 and each of them is accessible, then the time complexity for calculating RDTAE is $O(8*K*N^2)$. However, not all grids can access all exits in actual situation.

3.3. The slope factor

Considering some planes such as stairs in indoor environment have certain slope and these planes also have an important influence on evacuation. We take the slope factor into account to make it more available. Suppose the slope degree is represented by α, when a pedestrian walks on the slope, his velocity can be divided into the horizontal and vertical. The horizontal velocity $V_x = V * \cos\alpha$ and the vertical velocity $V_y = V * \sin\alpha$ are as shown in Figure 2:

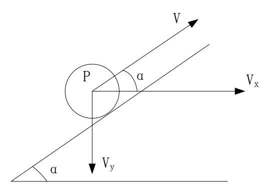

Figure 2. Diagram of Velocity Resolution

So we can get the formula 1' from the formula 1:

$$V = \frac{a}{\Delta T} \Delta S * \cos\alpha \tag{1'}$$

The range of α is [0, 90). And the center of target object will change with its movement, which can be fit into the formula as:

$$y = y_0 + \Delta L * \tan\alpha \tag{3}$$

y_0 is the vertical height of target current position, ΔL is distance that target moves along the slope, y is the final vertical height after moving.

We add the slope factor into the grid. When pedestrian walks through these grids, we should take the effects on the pedestrian velocity and position into account.

3.4. Evacuation route selection

During the process of evacuation, the position change of pedestrians in each time-step is based on the current grid RDTAE value and the target grid RDTAE value. Generally, pedestrians will try to select the route which RATAE value is reduced, and when the RDTAE value of the optional grid is increased, they will choose to wait. After deciding all pedestrians' target grids in a single time-step, the target position in 3D scene can be determined. Finally, calling the corresponding pedestrian action library, and implement the animation of pedestrians from the current position to the target position during this time-step, and updating the states of all grids and pedestrians. Repeating the process above until the pedestrian evacuation is completed. The detail evacuation route selection procedure is:

1. Firstly, the pedestrians check whether the ideal target position (RDTAE value is less than the current position's) which has not been accessed and is one of the eight grids that around the pedestrians is accessible,

   (1) if it is accessible, then select the grid as the initial target grid,

   (2) if it is inaccessible, then decide whether the less ideal target position (RDTAE value is equal to the current position of the grid) is accessible or not,

   1) if it is accessible, then select the grid as the initial target grid,

   2) if it is inaccessible, then assign the current position as the target position;

2. Decide whether there are two or more pedestrians select the same initial target position in the same time-step,

   (1) if there are, using the probability formula of multi-grid model to calculate the probability respectively, and then decide whether the maximum probability is unique or not,

   1) if it is unique, then assign the grid as the target position with the maximum probability,

   2) if it is not unique, then assign the grid randomly as the target position for any with the maximum probability;

3. Decide whether there are some pedestrians who haven't determined the target position yet,

   (1) if there are, then repeat step 1,

   (2) if there aren't, then go to step 4;

4. Decide whether the current position and the target position of each pedestrian is the same,

   (1) if it is the same, then call the static action from the action library,

   (2) if it is not the same, then call the running action from the action library, and implement the moving animation from the current position to the target position;

5. Decide whether the pedestrian evacuation is completed,

   (1) if it is completed, then output the evacuation time and finish the process,

   (2) if it is not completed, then repeat step 1.

4. Experiment and Analysis

We take a supermarket for example which ground is 110 meters long and 72 meters wide. The 3D virtual scene with some pedestrians is built by using 3D Studio Max 9.0, and the evacuation simulation is developped by using Unity3D 3.5.0. 3D Studio MAX is a 3D modeling software which developped by company Autodesk. It supports Windows 95/98, Windows NT platform and supports parallel modeling, animation making. Besides, it has the ability of multi-thread computing. Now it is widely used in making character animation and visual effects. Unity3D which developped by company Unity Technologies can be used to creating 3D video game, architectural visualizaton and 3D real-time animation. Now it is widely used in game development, film making, education and training because of its high-performance lighting system, AAA-level renderring efforts, professional development tool (JavaScript, C# and Boo) and intellective UI design. Figure 3 shows the 3D scene of the sample supermarke with pedestrians. For pedestrians, we also built the running and idle actions. Programming is using C# language in Visual Studio 2008. Figure 4 shows the initial state of the grids which belong to a region, where “1” indicates the grid is inaccessible and “0” is accessible. Figure 5 shows the RDTAE value of this region. In order to describe the RDTAE value of the inaccessible grids simply, the RDTAE value is set to “-1”. For evacuation simulation, the grid density is set to 3, the initial count of pedestrians is 50 and they are randomly distributed in the scene, the count of exits is 3, inertial factor I is 1.2, self-driving force D is 0.6, average value of the interaction force F is 2.5, the pedestrian average velocity without crowded V is 1m/s. Figure 6 shows the simulation of evacuation process, the evacuation time is 75s. Figure 7 shows the position updating of a pedestrian from initial position to exit.

Figure 3. 3D Scene of a Supermarket

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4. Grid Initial States of a Region

-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	16	17	18	19	20	21	22	23	24	25
-1	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	15	16	17	18	19	20	21	22	23	24	25
-1	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	14	15	16	17	18	19	20	21	22	23	24	25
-1	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	13	14	15	16	17	18	19	20	21	22	23	24	25
-1	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
-1	10	10	10	10	10	10	10	10	10	10	10	10	10	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
-1	9	9	9	9	9	9	9	9	9	9	9	9	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
-1	8	8	8	8	8	8	8	8	8	8	8	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
-1	7	7	7	7	7	7	7	7	7	7	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Figure 5. RDTAE Value of a Region

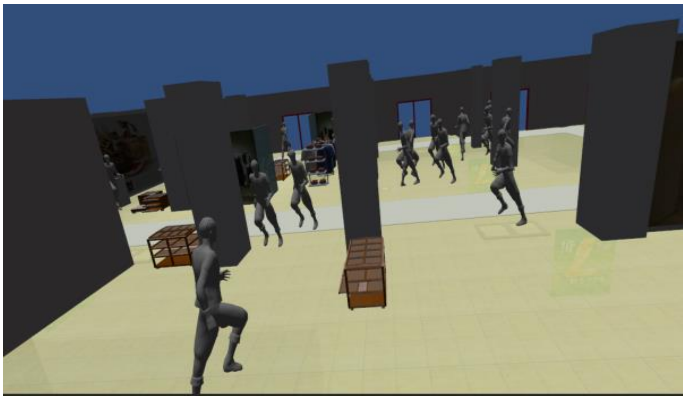

Figure 6. Evacuation simulation in 3D scene

```
Route for person which number is 25:
Row  Col   RDTAE     xIn3DScene      yIn3DScene        zIn3DScene
285  125   74    -4129.034   -414.814392089844   -771.058833333333!!
285  124   73    -4129.034   -414.814392089844   -771.192166666667!!
285  123   72    -4129.034   -414.814392089844   -771.3255!!
285  122   71    -4129.034   -414.814392089844   -771.458833333333!!
285  121   70    -4129.034   -414.814392089844   -771.592166666667!!
285  120   69    -4129.034   -414.814392089844   -771.7255!!
285  119   68    -4129.034   -414.814392089844   -771.858833333333!!
285  118   67    -4129.034   -414.814392089844   -771.992166666667!!
285  117   66    -4129.034   -414.814392089844   -772.1255!!
285  116   65    -4129.034   -414.814392089844   -772.258833333333!!
285  115   64    -4129.034   -414.814392089844   -772.392166666667!!
285  114   63    -4129.034   -414.814392089844   -772.5255!!
285  113   62    -4129.034   -414.814392089844   -772.658833333333!!
285  112   61    -4129.034   -414.814392089844   -772.792166666667!!
285  111   60    -4129.034   -414.814392089844   -772.9255!!
285  110   59    -4129.034   -414.814392089844   -773.058833333333!!
285  109   58    -4129.034   -414.814392089844   -773.192166666667!!
285  108   57    -4129.034   -414.814392089844   -773.3255!!
285  107   56    -4129.034   -414.814392089844   -773.458833333333!!
285  106   55    -4129.034   -414.814392089844   -773.592166666667!!
285  105   54    -4129.034   -414.814392089844   -773.7255!!
285  104   53    -4129.034   -414.814392089844   -773.858833333333!!
285  103   52    -4129.034   -414.814392089844   -773.992166666667!!
285  102   51    -4129.034   -414.814392089844   -774.1255!!
285  101   50    -4129.034   -414.814392089844   -774.258833333333!!
285  100   49    -4129.034   -414.814392089844   -774.392166666667!!
285  99   48   -4129.034   -414.814392089844   -774.5255!!
285  98   47   -4129.034   -414.814392089844   -774.658833333333!!
```

Figure 7. Position updating of a Pedestrian

5. Conclusions

With the peoples' activities becoming more and more frequent in indoor environment, the personal safety accidents which due to fire, earthquake, criminal activities and some other unexpected factors can be seen everywhere. To avoid or reduce the expense of these accidents, many researches aim to reveal the characteristics of pedestrian evacuation. Among them, evacuation simulation is a common research method to reappear the evacuation process. In order to make the simulation of evacuation model more intuitive, an integration method of multi-grid evacuation model in 3D virtual indoor environment is introduced. The whole procedure includes mapping 3D scene to 2D plane firstly, and establish the grid table on it. Then calculating the RDTAE value for each grid. After that, calculating the target position for each pedestrian by using the route selection method of multi-grid model in a single time-step, and matching the position to 3D scene. Finally, calling the pedestrian action from the action library to implement the animation of evacuation simulation. Besides, it takes the effect of ground slope into account while pedestrian evacuating. An example of supermarket evacuation in 3D scene validates the effective of the integration method. The simulation results can provide the scientific guidance for indoor security solution design and emergency plan making.

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References

[1] C. Wang, H. Quan, B. Xie, Z. Zhang, Y. Gao and Q. Peng, "Phiysically Based Realistic Simulation of Crowd Evacuation during a Fire", Journal of Computer-Aided Design and Computer Graphics, vol. 20, no. 8, **(2008)**, pp. 1033-1037.
[2] F. Tang, A. Ren and Z. Xu, "Gis-based Evacuation Simulation for Fire Safety", vol. 19, no. 5, **(2010)**, pp. 49-55.
[3] S. C. Pirsals and F. G. Garzon, "Basic principle for the solution of the building evacuation problem", Journal of Industrial Engineering and Management, vol. 2, no. 3, **(2009)**, pp. 499-516.
[4] R. Zhao, J. Wang, W. Ling and Q. Pu, "Self-Organized Criticality Network Based Pedestrian Evacuation Simulation in Emergency Management", Proceedings of the 2nd International Conference on Management Science and Engineering Advances in Artificial Intelligence, **(2011)**, pp. 404-410.
[5] D. X. Xuan, "Theoretical and Experimental Study of a Multi-grid Model for Pedestrian Evacuation". **(2009)**.
[6] Y. Lin, Z. Qi and Y. Kun, "Pedestrian Evacuation Modeling and Simulation Based on Improved Cellular Automata Model, Fire Science and Technology, vol. 31, no. 6, **(2012)**, pp. 571-574.
[7] L. Qiang and W. Dong, "The Computer Simulation of a Supermarket Evacuation, vol. 31, no. 3, **(2012)**, pp. 253-256.
[8] L. Zijuan, L. Gang and F. Zhiming, "Experimental and Modeling Study of Characteristics of Evacuation in Stairwell of a High-rise Building, vol. 31, no. 6, **(2012)**, pp. 571-574.
[9] M. Muramatsu, T. Irie and T. Nagatani, "Jamming transition in pedestrian counter flow", vol. 267, **(1999)**, pp. 487-498.
[10] N. Baek and K. -H. Yoo, "An Automatic Balancing Scheme for Multi-Articulated Virtual Objects", International Journal of Multimedia and Ubiquitous Engineering, vol. 8, no. 1, **(2013)**, pp. 139-150.
[11] Y. S. Son, Y. S. Lee and J. W. Jung, "Software Modules Management Techiques for Multi-Cooperate Robots based on R-Object Model in Dynamic Environments", International Journal of Multimedia and Ubiquitous Engineering, vol. 7, no. 4, **(2012)**, pp. 163-174.

[12] W. Husain and L. Y. Dih, "A Framework of a Personalized Location-based Traveler Recommendation System in Mobile Application", International Journal of Multimedia and Ubiquitous Engineering, vol. 7, no. 3, **(2012)**, pp. 11-18.
[13] H. -J. Shin, M. -G. Kang and K. -H. Choi, "Design, Modeling, and Performance Analysis of Web-based Multi-purpose Discovery Middleware in Ubiquitous Environments", International Journal of Multimedia and Ubiquitous Engineering, vol. 7, no. 3, **(2012)**, pp. 1-10.

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