CELLULAR AUTOMATA MODEL FOR PEDESTRIAN EVACUATION IN FIRE SPREADING CONDITIONS

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ABSTRACT. In this paper, a two-dimensional cellular automata model presented to simulate pedestrians evacuation in fire spreading conditions. In this proposed model, the movement of pedestrians is represented as "chaotic", mimicking panic egress behaviors during a fire evacuation. This model includes a fire circular front shape based on the spiral movement technique. Simulation results show that this model can be used to predict the number of pedestrians who have evacuated safely or have been killed.

Keywords: cellular automata, pedestrian simulation, fire circular front shape, fire–spiral movement technique

INTRODUCTION

Inefficient evacuation will result in a large number of casualties and property losses if fire occurs in a large place. According to statistics, a total of 131,705 fires occurred in China in 2010, in which 1,108 people had been killed and 513 people were injured. These fires had resulted in direct economic losses of 1.77 billion Yuan (Zheng, Jia, Li, & Zhu, 2011). From 2007 to 2011, a total of 128,959 fire accidents occurred in Malaysia, in which 413 people were killed and 380 people were injured. These disasters resulted in direct economic losses of RM 390,595.7 million (Department of Statistics, 2012). Given the loss of lives and properties in fire disasters, the study of evacuation has become extremely necessary and important.

Large fires pose dangers; hence, real fire evacuation experiments are not possible to be conducted. Therefore, with the development of computer technology, computer simulation has become an important and feasible tool. Simulation of pedestrian movement in panic situations, such as in fire disasters, will help us predict and analyze pedestrian behavior during these panic situations.

The succeeding section briefly describes the background of pedestrian evacuation in fire spreading conditions and the gaps found in the current models. The third section describes the proposed cellular automata (CA)-based simulation model to simulate the pedestrian flow and the fire spreading process, and then the preliminary simulation results are detailed. Finally, this paper concludes with recommendations to the proposed simulation model for subsequent improvements.

EXISTING FIRE EVACUATION MODELS

Researchers have examined evacuation scenarios, such as during fire accidents in inhabited areas that include shopping centers, schools, theaters, and stadiums, in which pedestrians exhibit extreme panic. However, researchers have mainly investigated fire accidents in a static scenarios (Cao, Song, Liu, & Mu, 2014; Y. Yang, Deng, Xie, & Jiang, 2014) examining the discrepancy between reality and simulations. The nature of fire spreading could be in contrast to the simulation run conducted by researchers who may use inaccurate fire circular front shape in their proposed models (Cao et al., 2014; Curiac, Banias, Volosencu, & Pescaru, 2010; Finney, 2006; Georgoudas, Sirakoulis, & Andreadis, 2007; Sirakoulis, Karafyllidis, & Thanailakis, 2005; Tissera, Printista, & Luque, 2012; Lizhong Yang, Weifeng Fang, Rui Huang, & Zhihua Deng, 2002; LZ Yang, WF Fang, R Huang, & ZH Deng, 2002; L. Yang, Zhao, Li, Fang, & Fan, 2004; Y. Yang et al., 2014; Zheng et al., 2011).

Despite the use of the CA model to represent the fire spreading process, previous studies could not provide an accurate fire circular front shape. Researchers tend to assume only three scenarios for the starting points of fire accidents: the center, one of the corners, and near exits (Cao et al., 2014; Curiac et al., 2010; Georgoudas et al., 2007; Muzy et al., 2006; Y. Yang et al., 2014; Zheng et al., 2011).

These scenarios are not randomly assigned, which may lead to a comprehensive understanding of individual behavior when fire accidents occur. Moreover, most fire evacuation simulations focus on evacuation time and do not have a mechanism to monitor the numbers of pedestrians who have evacuated safely, killed, or injured during the fire disaster (Cao et al., 2014; Hu, Sun, Gao, Wei, & You, 2014; Tissera et al., 2012; Y. Yang et al., 2014; Zheng et al., 2011).

METHODOLOGY

In this research, the CA model is enhanced based on existing simulation models (Hassan & Tucker, 2010a, 2010c) to represent the fire spreading process in a spiral manner and the pedestrian movement inside the system in panic situations, that is, under the effects of a fire disaster.

CA-Based Simulation Model

In this simulation, the space in the CA model is mapped according to the semantics of the floor plan (i.e., room, corridor, etc.) in a uniform grid. This model is defined on a discrete $W \times W$ cell grid in a two-dimensional system. Small cells that can be occupied by at most one pedestrian (or a piece of a wall or fire) are arranged within W based on the exclusion principle. The model simulates pedestrians (or a piece of wall or fire) as entities (automata) in cells. Each cell, at each time step, is either empty or occupied by a pedestrian (or a piece of a wall or fire). To note, walls will always occupy the same cell in every time step because they are considered permanent objects and some empty cells on the walls can act as exits. The time is treated as discrete, and the pedestrians move synchronously in each time step. For each time step, every pedestrian can move to only one cell, that is, the pedestrian moves with $Vmax = 1$.

Figure 1 shows the schematic of pedestrian flow, with walls and fire on a two-dimensional cell grid. The space is modeled as grid cells. The walls are represented as green squares, the fire is represented as red, and the white cells can be occupied by a pedestrian or an obstacle. The occupancy of a cell depends on the rules of a localized neighborhood, which are updated every time. In each time step, each cell can accommodate one of two states, namely, occupied and unoccupied. This model contains four types of pedestrians, namely, *left*, *right*, *up*, and *down* pedestrians, as shown in Figure 1. The arrow shapes are all pedestrians, with black arrows being pedestrians moving to the right and left and magenta arrows being pedestrians moving to the up and down. The pedestrians share the same movement goal of finding the escape route of the room during fire spreading. To gain more realistic results and to model pedestrian interactions in more detail, three factors are considered in this CA pedestrian simulation model. These three factors that determine the pedestrian movement to one of the neighboring cells with transition probabilities are (i) the desired direction of motion (e.g., exits), (ii) interactions with other pedestrians, and (iii) interactions with the infrastructure (walls, fire etc.).

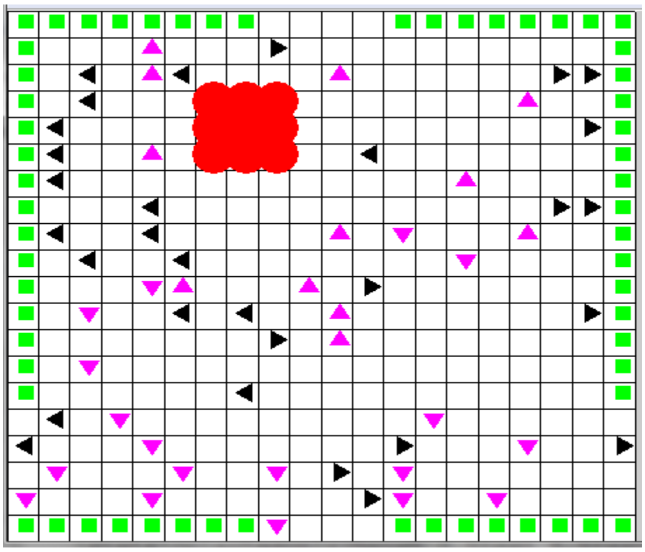

Figure 1. Pedestrians Flow During The Fire Spreading Process

Fire Spreading based on the Spiral Movement Technique

In the fire spreading process, the initial starting point of the fire will spread in a spiral manner to one cell of its neighborhood cells based on the configuration of Moore's neighborhoods for each time step. This spiral shape in the fire movement during the spreading process will show the fire circular front more accurately in comparison with other models such as (Curiac et al., 2010; Y. Yang et al., 2014; Zheng et al., 2011).

Figure 2 shows pseudo-code for fire using spiral way based on the CA model. In figure 2 definitions of terms employed is as follows: first, *fdir* represents fire spreading direction. Second, *lastfire* represents the last burning position (cell) in the system. Third, *grid* represents the number of positions (cells) in whole system *W* x *W* and, last one, *burned* represents burned positions (cells) in the system. As mentioned above, the fire starting point initialized randomly inside system *W* x *W*. After that, it will spread to one of its neighboring positions. This incremental process of fire spreading will produce the spiral shape of fire during spreading process. In the pseudo-code above, we assumed that fire spreading direction is taking left course (*initial direction (fdir) =left*) and *lastfire* is the lower position of initial fire position as shown in Figure 3.

```
initial direction (fdir) =left
initial lastfire is lower position of initial fire position
Procedure FireSpread (grid){/* grid = number of positions in the system*/
If burned < grid {     /* burned = number of burned positions in the system */
switch(fdir){ /* fdir = the direction of fire spread*/
case left{
if lastfire is in the diagonal position of left-lower corner of burning area   /* last-fire = last of burning position */
        fdir = up;
else{
if lastfire is in aposition of the system{
        burn lastfire position in the system;
                burned= burned+1;
                }
Move lastfire to the left position;
} }
```

Figure 2. Pseudo-code for The Left Case of Fire Spreading Process Based on Spiral Movement Technique

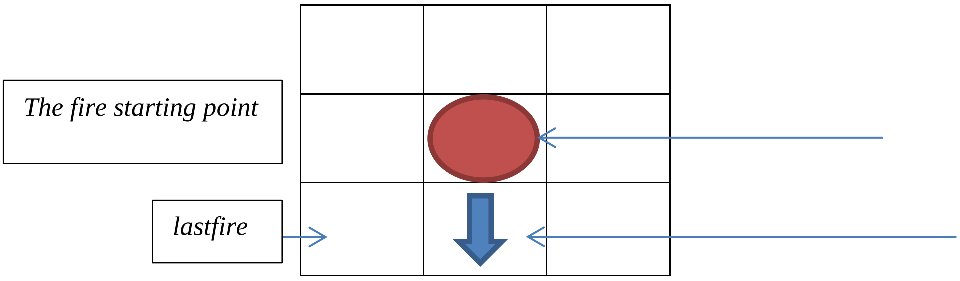

Figure 3. Fire Spreading Process Based on Spiral Movement Technique

As mention above, we assumed that fire spreading direction is taking the left course. Therefore, it will be directed to the left case in the pseudo-code depicted above, and it will check the position of the *lastfire* in reference to the first fire position. If the *lastfire* position is in the diagonal position of the left-lower corner of burning area (i.e. the fire starting point), it will change the direction speed *fdir* from left direction to up direction and exit from the left case and enter the upper-case next iteration. Figure 3 shows fire spreading process based on spiral movement technique. If the first condition in the left case not true, the other scenario will apply. That is, the code will proceed to *else branch*, and, hence, burn current cell (*lastfire*) and increment number of the burned cells and proceed to the left side. Above that, the code will continue to remain in left case, and, repeatedly carry out the processes described above (i.e. left case first condition). This incremental process of fire spreading will produce the spiral shape of fire during spreading process.

SIMULATION RESULTS

The figure below show the fire spreading process after 1 Time Step, 2 Time Steps, 3 Time Steps, 5 Time Steps, 7 Time Steps, 8 Time Steps, 10 Time Steps, 11 Time Steps and 100 Time Steps, Respectively. The fire circular front shape is more realistic than the traditional models (Cao et al., 2014; Curiac et al., 2010; Y. Yang et al., 2014). In our simulation, all pedestrians share the same movement goal of finding the escape route to the exit during a fire disaster. When all pedestrians leave the room or reach the last iteration, the simulation procedure is terminated, as shown in Figure 4.

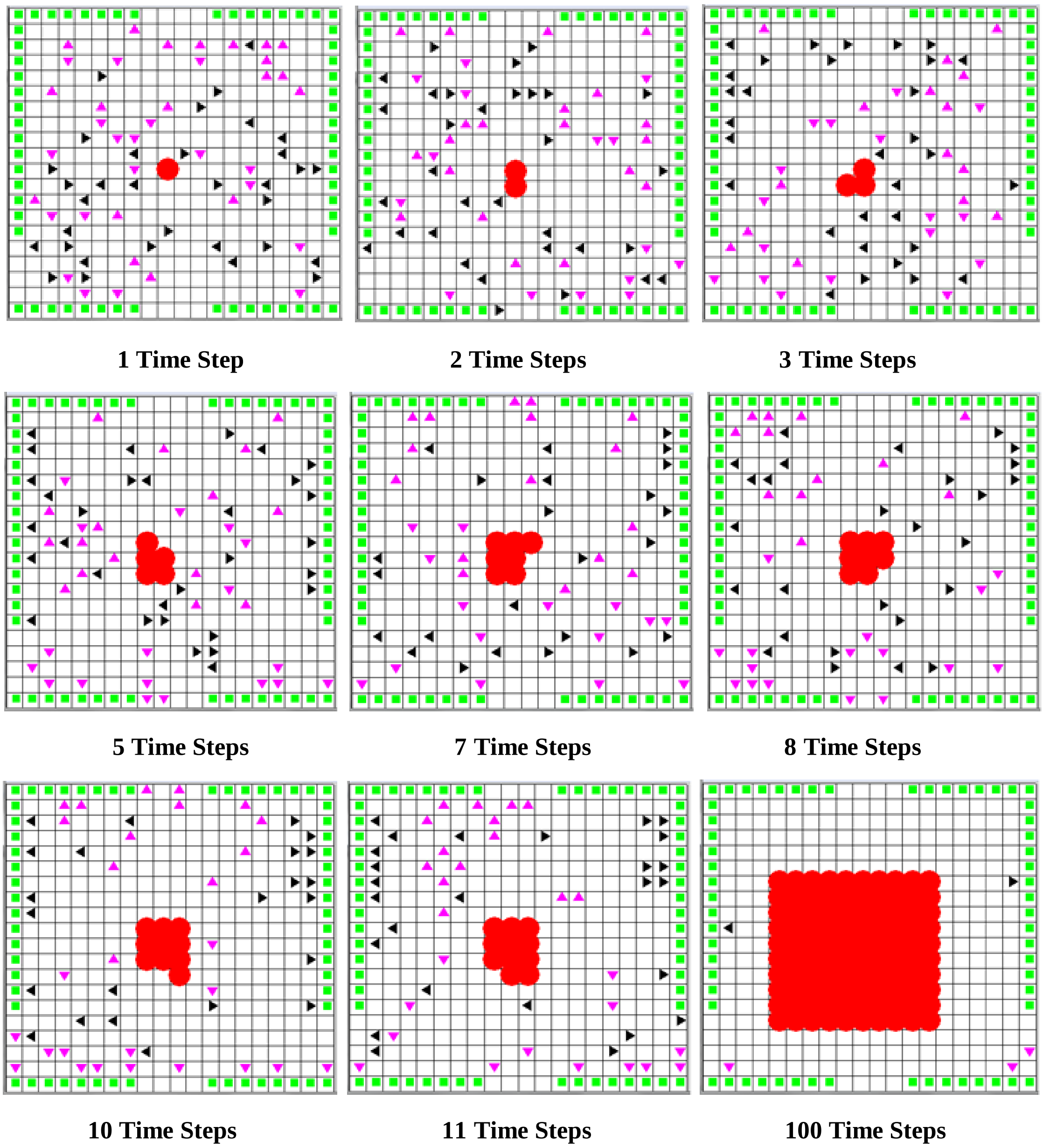

Figure 4. The Fire Spreading Process Based on the Spiral Movement Technique. After 1 Time Step, 2 Time Steps, 3 Time Steps, 5 Time Steps, 7 Time Steps, 8 Time Steps, 10 Time Steps, 11 Time Steps and 100 Time Steps, Respectively

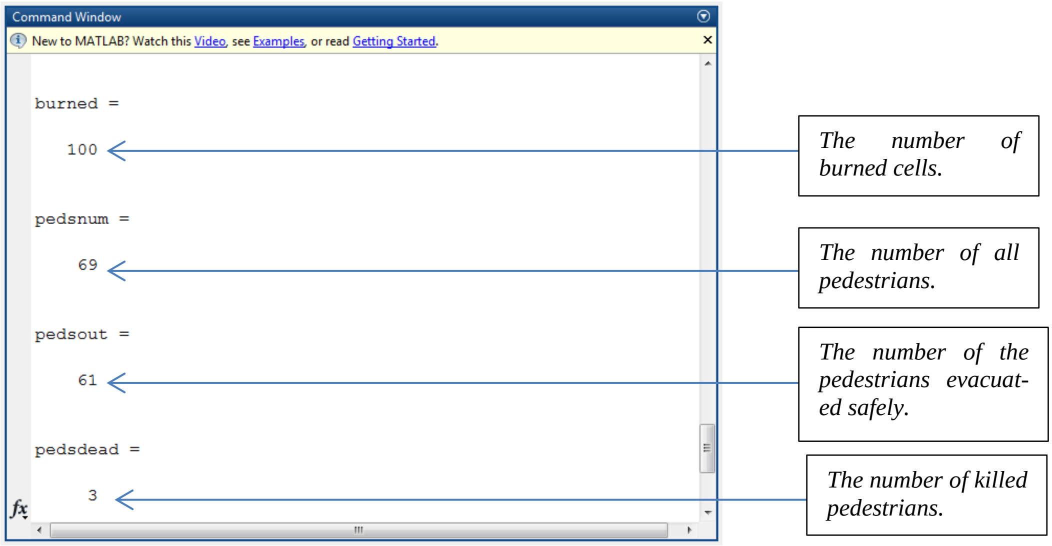

Figure 5. The Simulation Results

The figure shows the number of burned cells (*burned*) and the number of all pedestrians in the entire system $W \times W$ (*pedsum*). The number of pedestrians who have evacuated safely, that is, the pedestrians who find the exit and leave the room during the fire disaster (*pedsout*), and the number of pedestrians who have been killed by the fire (*pedsdead*) are also indicated. By analyzing these variables, we can obtain information that will help us predict pedestrian behavior during fire disasters and design a suitable evacuation plan that enables control of crowd movements in different situations such as fire disasters.

CONCLUSION

We propose a new model of fire evacuation on the basis of CA model. In our proposed model, the fire starting point initializes randomly inside a room and then begins to spread to one of its neighborhoods. Therefore, the fire is not static. The fire spreading process is represented on the basis of the spiral movement technique. Simulation result shows that the proposed model can produce a fire circular front shape better than traditional models. Pedestrians are represented as moving in a "chaotic" manner to mimic the panic egress behavior during fire evacuation. The pedestrians are distributed randomly inside a room, and their movement inside the system is simulated based on the CA model. The simulation includes variables such as the number of pedestrians who have been killed and the number of pedestrians who have evacuated safely. These variables will help us predict how the flow will behave under different circumstances such as fire disasters. The newly proposed model can produce a fire circular front shape better than traditional models and provide guidance in the design of an evacuation strategy in a fire accident. The future work will involve utilizing actual data to combine the proposed model with an optimal spatial layout model during fire evacuation.

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