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# Incorporating topography in a cellular automata model to simulate residents evacuation in a mountain area in China

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ABSTRACT

In China, both the mountainous areas and the number of people who live in mountain areas occupy a significant proportion. When production accidents or natural disasters happen, the residents in mountain areas should be evacuated and the evacuation is of obvious importance to public safety. But it is a pity that there are few studies on safety evacuation in rough terrain. The particularity of the complex terrain in mountain areas, however, makes it difficult to study pedestrian evacuation. In this paper, a three-dimensional surface cellular automata model is proposed to numerically simulate the real time dynamic evacuation of residents. The model takes into account topographic characteristics (the slope gradient) of the environment and the biomechanics characteristics (weight and leg extensor power) of the residents to calculate the walking speed. This paper only focuses on the influence of topography and the physiological parameters are defined as constants according to a statistical report. Velocity varies with the topography. In order to simulate the behavior of a crowd with varying movement velocities, and a numerical algorithm is used to determine the time step of iteration. By doing so, a numerical simulation can be conducted in a 3D surface CA model. Moreover, considering residents evacuation around a gas well in a mountain area as a case, a visualization system for a three-dimensional simulation of pedestrian evacuation is developed. In the simulation process, population behaviors of congestion, queuing and collision avoidance can be observed. The simulation results are explained reasonably. Therefore, the model presented in this paper can realize a 3D dynamic simulation of pedestrian evacuation vividly in complex terrain and predict the evacuation procedure and evacuation time required, which can supply some valuable information for emergency management.



## 1. Introduction

In China, the mountainous area accounts for more than 66.7% of the total land area. 647 million people, who make up 55.7% of the total population, live in mountain areas. Mountain areas usually have complex geological structures, which result in the frequent occurrence of natural disasters, such as mountain torrent, rock fall, landslide, debris flow, typhoons and earthquakes. Meanwhile, a large number of enterprises with severe pollution and high risk, such as mine, oil and gas fields, and nuclear power stations, mainly lie in remote mountain areas. Inhabitants in mountain areas have many times been evacuated due to the production accidents or natural disasters. For example, as the result of the '12.23' Kaixian blowout

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accident in the year 2003, 243 people died and 65 632 people were evacuated [1]. Therefore, the study of safety evacuation for residents in mountain areas has important significance in theory and practice.

Doubtless walking is the primary evacuating way of the residents in suburban or remote mountain areas. The evacuation case of "12.23" has certified that fact. Many scholars have done a lot of research on pedestrian evacuation. On the basis of real-world case studies and exercises, many computer models have been developed for simulating personnel evacuation. The most prevalent models consist of the social force model, magnetic force model and cellular automata model.

The social force model is a continuous model, which describes the time-dependent position and velocity of pedestrians by solving the differential equations of motion. But it is difficult to simulate the overlap and collision between pedestrians [2]. Besides, the differential equations take into account too many relevant factors. Due to its complex rules, the social force model is not good at computational efficiency when it is used to deal with complicated environments.

The magnetic force model was proposed in 1979 by Okazaki and Matsushita, and since then it has not been widely used because the parameters in the model could not be verified by experimental data.

Muramatsu et al. [3] applied the cellular automata (CA) model to study pedestrian flow firstly with the help of the lattice gas model of biased random walkers without back step. The jamming transition in bi-directional flow and at a crossing was studied based on the CA model by Muramatsu et al. [4,5]. Afterwards, the CA model was extended to study the pedestrian flow in special building structures by Tajima and Nagatani et al. [6–11]. The movement of pedestrians can be discussed in detail with the CA model. Typical phenomena observed in actual evacuation, e.g. self-organization and group behavior, are reproduced through the model. The CA model has simple, flexible and reliable calculating rules, so it is widely used in pedestrian flow simulation.

However, most of the population evacuation models are created to quantify and simulate the behavior and movement for complex buildings on a two-dimensional plane. So far, there is no evacuation model for uneven terrain.

The CA model combined with a Digital Elevation Model (DEM) can be used to simulate the pedestrian movement in mountain areas. A 3-dimensional (3D) surface CA model is proposed in this paper. The curved surface of the original terrain is constructed by the DEM and divided into grids with regular space in the $x$ and $y$ directions. Considering the influence of terrain, the model adopts a previously important achievement to compute the walking speed of pedestrians. Velocity varies with different vertical distance between grids. In order to simulate the behavior of a crowd in the 3D surface CA model, a numerical algorithm is used to determine the time step of iteration to deal with varying movement velocities.

As an example of its application, we design a program to simulate the residents evacuation around a gas well in the DaBa mountains. Based on the 3D surface CA model, a new virtual simulation system of 3D movements on complex terrain is designed and realized by adopting Visual C++ 6.0 and OpenGL graphics standards in this paper. The system can describe pedestrian evacuation in mountain areas more accurately and visually.

## 2. 3D surface CA model

A 3D surface CA model is developed to numerically simulate the 3D real time dynamic evacuation of residents in mountain areas in discontinuous forms of time and space.

The complex topography and road net can be represented by DEM Data obtained from NASA and aerial images captured in the software Google Earth. The evacuation space is discretized by grids with a size of 0.4 m $\times$ 0.4 m in the $x$ and $y$ directions [12]. Each grid serves as a cell. Each cell can be valued as 0 or 1, which means that the cell is empty, or occupied by a pedestrian or an obstacle object. A cell can be occupied by only one person at the same time. A pedestrian can move to an empty neighboring cell in each time step.

In this manuscript, it is assumed that all the occupants evacuate from their current position to the designed safety rendezvous in an open space with complex topography such as mountain areas. In case of a sudden incident, the road is the most efficient route for pedestrian evacuation. The land is covered by terraced fields and trees mostly and the road net is quietly simple. In most cases, many people will not be located on the road originally when they receive the evacuation announcement. They must run to the nearest road first and then evacuate along the road towards the predetermined destination which is usually by the wayside.

The calculation flowchart of pedestrian evacuation is described in Fig. 1.

### 2.1. The rules of movement of pedestrians

The 3D surface CA model uses the simplest von Neuman neighborhood model. Assuming that the pedestrian would not move back, the pedestrian in each cell determines his next position according to the three neighboring cells. The rules of movement are listed in Table 1.

Each pedestrian moves from the original position in accordance with the above rules until he reaches his destination, then he will be deleted from the model. Repeat the process until everyone reaches his desired destination.

### 2.2. Walking speed

Walking speed is one of the most important parameters in evacuation models. It is influenced by many factors, e.g. age, gender, body size, health condition and other physical characteristics, crowd density, ground slope, etc. This paper focuses