A Cellular Automaton Model for Crowd Evacuation and Its Auto-Defined Obstacle Avoidance Attribute

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Abstract. In this paper, a crowd evacuation model based on Cellular Automata (CA) is described. The model takes advantage of the inherent ability of CA to represent sufficiently phenomena of arbitrary complexity and to be simulated precisely by digital computers as well. Pedestrian movement depends on their distance from the closest exit, which is defined dynamically. The adoption of Manhattan distance as the reference metric provides calculation simplicity, computational speed and improves significantly computational performance. Moreover, the model applies an efficient method to overcome obstacles. The latter is based on the generation of a virtual field along obstacles. A pedestrian moves along the axis of the obstacle towards the direction that the field increases its values, leading her/him to avoid the obstacle effectively. Distinct features of crowd dynamics and measurements on different distributions of pedestrians have been used to evaluate the response of the model.

Keywords: Cellular Automata, Crowd Modeling, Pedestrian Evacuation, Obstacle Avoidance.

1 Introduction

Various models that try to efficiently approach crowd movement during evacuation have been presented in literature, proposing theoretical and applicable solutions. Deep insight in crowd dynamics has resulted in better understanding of pedestrian behaviour as well in substantial changes regarding the architecture of such constructions. Crowd safety and comfort in highly congested places not only depend on the design and the function of the area, but also on the behaviour of each individual. Results prove that people under panic tend to lose their individuality, display herding behaviour and it is possible not to make use of means of emergent evacuation effectively [1].

Pedestrian dynamics have been reported following a great variety of approaching methods, thus indicating the importance of the issue. In particular, CA-inspired methods as well as lattice-gas and social force models or agent-based and fluid-dynamic methods have been proposed to investigate and reveal the attributes of crowd evacuation [2]. All approaches can be qualitatively distinguished, focusing on different characteristics that each of them dominantly display.

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On the other hand, evacuation could be defined as a non linear problem with numerous factors affecting it. A system of partial differential equations could effectively approach it, but this would lead to a very computationally demanding system, in terms of processing time, complexity as well as power consumption. CA can certainly act as an alternative to such systems, because they can compute values of physical quantities over finite areas (CA cells) at discrete time steps. Literature reports various CA-based models investigating crowd behaviour under various circumstances. Interactions among pedestrians, friction effects [3] and herding behaviour [4] as well as the impact of environmental conditions [5] and bi-directional pedestrian behaviour [6] has been examined. Furthermore, CA models that focus on human behaviours, such as inertial effects, unadventurous effect and group effect have been also developed [7].

2 The CA Model and Characteristic Measurements

The presented model is based on CA; hence its simulation mechanism is matrix-driven, discretising a floor area into a grid. The grid of the automaton is homogeneous and isotropic, while the CA cells are able to exist in two possible states; either free or occupied by exactly one particle. Each cell is equivalent to the minimum area, which a person could occupy and defined equal to $0.4m \times 0.4m$ [8]. During each time step, an individual chooses to move in one of the eight possible directions of its closest neighbourhood. Each particle moves towards the direction which is closest to an exit.

The motion mechanism issues from a potential field approach, based on Manhattan metric, which is calculated by the following equation:

$$\left\| \vec{x} \right\| = |\Delta x| + |\Delta y| \tag{1}$$

The gradient descent on the potential function defines the direction of movement, thus introducing a kind of global space knowledge for pedestrians. The model is inherently emergent, as the interactions among simple parts can simulate complex phenomena such as crowd dynamics.

The method used for the calculation of the potential field is a flood fill method, where the distance is calculated by moving a cell to closest neighbour cell and summing up the distances [9]. This operation is recursively applied to all surrounding cells. If a cell is occupied by an obstacle then this obstacle cell will not flood its neighbours. Algorithmically, the aforementioned method is based on an $n \times 9$ matrix, calculated for each occupied cell. The elements represent all possible updated spatial and temporal states of the occupied cell (Fig. 1). Variable n indicates the number of the exits. Each element of the *i-th* row (i=1, ..., 9) specifies the distance of the occupied cell and its eight neighbours from the i-th exit. The occupied cell is always represented by the fifth cell of each row, whereas all other cells represent the eight closest neighbours, i.e. the north-west (NW), north (N), north-east (NE), west (W), east (E), south-west (SW), south (S) and south-east (SE) neighbour, respectively. As soon as all possible routes are detected, i.e. as soon as each of the $n \times 9$ elements of the matrix is calculated, the shortest prevails. Consequently, both the destination exit and the direction during next step are defined. The former is represented by the row of the minimum value element and the latter is indicated by its column.