Modelling Pedestrian Flow using Cellular Automata

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INTRODUCTION

Modelling pedestrian flow helps in evaluating and designing pedestrian facilities and planning response various emergency situations such as fire breakout. The focus of this study is to develop a novel cellular automata (CA) model for pedestrian flow. CA is a collection of cells on a grid of specified shape that evolves through a number of discrete time steps according to a set of rules based on the states of neighbouring cells. CA provides discreteness in two essential variables for pedestrian flow, i.e. space and time. Every pedestrian (or platoon) can be considered as an independent entity, and pedestrian's instantaneous movement at any point of time can be predicted by the route of the journey and the conditions around the pedestrian.

METHODOLOGY AND MODEL FORMULATION

Square CA has been widely used for modelling vehicle traffic. These models are suitable for vehicle traffic, but not much suitable for pedestrian flow as the change in the direction of pedestrian movement is very frequent. Recently hexagonal celluar automata models that provide six possible directions (three each in forward and backward direction) of movements have been developed for pedestrian flow. Hexagonal cells represent the space occupied by the pedestrian more closely (Highway Capacity Manual 2000). The centre of the hexagon represents the centre of the pedestrian body and the area of the hexagon represents his whole body which if shared by other pedestrian's hexagon would be considered as a collision. In this study, we have modified the base cells of the CA from hexagon to triangles. This provides with more freedom of speed as the steps are now smaller than the regular hexagonal CA, hence increasing the number of possible discrete cells. It also improves modelling the collision conditions in a more realistic way as it includes partial space collision as well. This is excellent in modeling highly crowded facility where the level of service is very poor and the pedestrians practically occupy lesser space.

The arrangement of cells and the possible pedestrian movements considered for the present study is shown in Figure 1. Although, backward movements are also possible, we are modelling only forward three movements. Since each pedestrian is represented with a regular hexagon, a unit movement in X-direction will increase the X axis by 1, and a unit movement at an angle of ±60˚ will increase the Y-axis only by $\sqrt{3}/2$. This makes developing rules with absolute coordinates difficult. Thus for modelling purpose, some modifications need to be made in the absolute coordinate system. For algorithm purposes, a virtual integral Y-coordinate (Py) is defined which is equal to $Y*(2/\sqrt{3})$. The absolute coordinates at time t are updated as follows:-

$$X_t = \text{floor}(X_t) + 0.5 * (Py_t \bmod 2) \quad (1)$$

$$Y_t = (\sqrt{3}/2) * Py_t \quad (2)$$

NOTE: The subscript t denotes the time-step; function "floor(x)" returns the largest integer not greater than x; function "x mod y" gives the remainder on division of x by y

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Equation 1 is to determine the X-position on grid of the pedestrian based on Y-position
Equation 2 is to convert the virtual Y-coordinate to absolute Y-coordinate

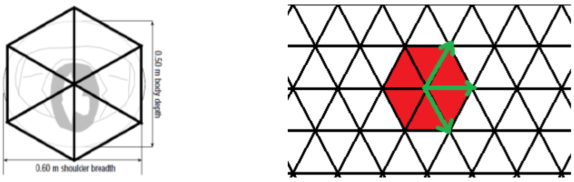

Figure 1. Arrangement of hexagonal cell and possible pedestrian movement

The major parameters affecting the pedestrian flow is the speed distribution and density of pedestrians on the facility. But these parameters depend on various factors such age and gender of pedestrian, time of day, weather conditions, and trip purpose. Thus, every pedestrian has its maximum desirable speed (V_{max}). The instantaneous speed of the pedestrian is greatly determined by his/her immediate surroundings, especially the space (Gap) to move. Since in reality the pedestrian changes its speed randomly, a probabilistic factor (R_t) which depends on speed distribution to randomly affect its speed is required to make the model realistic. At a given time, two kind of possible movements are possible: straight and inclided (direction change). The rules for the through movements are given below:

$$Gap_x = \text{floor}\ (X_t^{leader} – X_t^{ped}) – 2 \tag{3}$$

$$\text{IF}\ (Gap_x < (V_{max}^{ped} + 1))\ \text{THEN}\ Gap_y = \text{abs}\ (Y_t^{leader} – Y_t^{ped}) \tag{4}$$

$$\text{IF}\ (Gap_y < 3)\ \text{THEN}\ (V_t^{ped} = \min \{V_{max}^{ped}, Gap_x\};\ V_t^{ped} = \max \{0, V_t^{ped}\}) \tag{5}$$

$$\text{IF}\ (R_t^{ped} < 10)\ \text{THEN}\ V_t^{ped} = 0 \tag{6}$$

$$\text{IF}\ (10 < R_t^{ped} < 15)\ \text{THEN}\ V_t^{ped} = \min \{V_t^{ped} + V_{t-1}^{leader}, V_{max}^{ped}\} \tag{7}$$

$$\text{IF}\ (15 < R_t^{ped} < 25)\ \text{THEN}\ V_t^{ped} = \max \{V_t^{ped} - 1, 0\} \tag{8}$$

$$X_{t+1}^{ped} = X_t^{ped} + V_t^{ped} \tag{9}$$

NOTE: The superscript ped and leader denotes the concerned pedestrian and immediate leader respectively at time-step t; leader is determined by sorting the pedestrians according to their X-position

Equation (3) determines the Gap in X-direction available between the leader and the pedestrian. The leader is determined by checking the Gap both in X and Y direction in respect to the pedestrian. Equation (4) determines the Gap in Y-direction available between the leader and the pedestrian only if the Gap in X-direction is low such that the leader and the pedestrian can collide. Equation (5) updates the velocity of the pedestrian based on the Gap in X-direction only if the Gap in Y-direction is low such that the pedestrian can collide with the leader. Equation (6), (7) & (8) contributes to the probabilistic movement pattern of the pedestrian which suggests that with 10% probability a pedestrian can come to sudden halt and with 5% chance it can move with the velocity greater than the Gap available depending on the leader's velocity and with 10% probability it can reduce its speed by 1 unit. Equation (9) accounts for updating the X-position of the pedestrian. Similar rules for the inclined movements are being developed which will allow direction changing for pedestrian.

SAMPLE OUTPUT

A program is written in Perl language incorporating the rules for the straight movements. A sample output of the program at a specific time is presented in Figure 2.

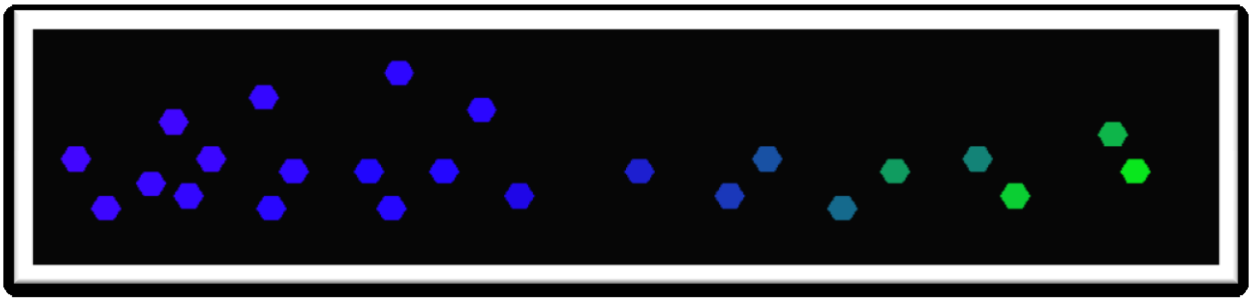

Figure 2. Graphical User Interface of the developed program showing sample output

The movement of pedestrians between two time steps is demonstrated in Figure 3. Consider 3 pedestrians at time step 25. Each pedestrian has a unique ID. The various parameters for each pedestrian at given time considered are {Py, V, X, Y, R}. Using the above rules the various parameters at time 26 based on the parameters at time 25 are given below.

At t = 25 sec,
Ped #12 = {5, 3, 15.5, 4.33, 34.90}
Ped #13 = {2, 0, 15, 1.732, 0.35}
Ped #14 = {2, 3, 10, 1.732, 15.88}

At t = 26 sec,
Ped #12 = {5, 3, 18.5, 4.33, 33.06}
Ped #13 = {2, 0, 15, 1.732, 7.52}
Ped #14 = {2, 0, 13, 1.732, 7.66}

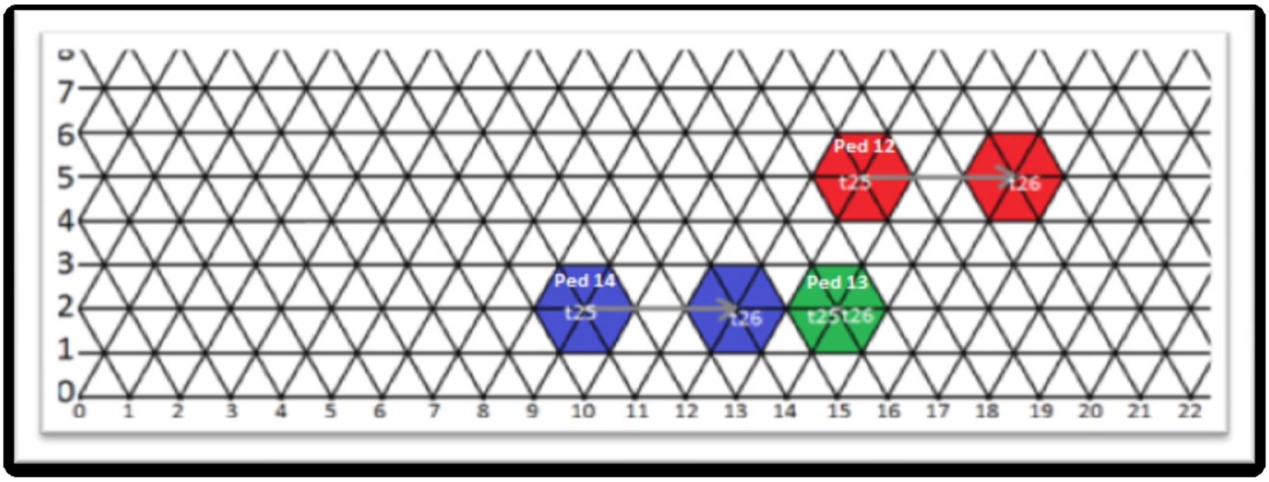

Figure 3. Movement of Pedestrians

NOTE: Random deceleration rule Equation (8) has been neglected just to explain this example; V_{max} is equal for all pedestrians (is equal to 3)

In the above example, Ped #12 and #14 moved 3 steps forward while Ped #13 stayed at its position, Ped #12 was free to move as there is no obstacle (or other pedestrian) in front of him, while Ped #14 is also virtually free to move at t = 25secs as the Gap between him and his leader is greater than 3 which is the maximum movement speed of the pedestrian. Ped #13 did not move even though it has the option to move forward freely because of the random parameter (R_t^{ped}) which is less than 10 and thus its speed is 0 at t = 25secs as per Equation (8).

For the above analysis the pedestrians are moving only straight. As pointed out earlier the hexagonal CA enables modelling direction changing of pedestrian. Extending the work to incorporate direction changing is in progress and will be presented in the full paper.