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Impact of variable body size on pedestrian dynamics by heuristics-based model

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HIGHLIGHTS

- Propose variable body size into the heuristics-based model.
- Reproduce the direction choice of the pedestrian.
- The change between bypass and traverse behavior.

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ABSTRACT

In the real world, pedestrians can arch the shoulders or rotate their bodies actively to across the narrow space. The method is helpful to reduce the effective size of the body. In this paper, the impact of variable body size on the direction choice has been investigated by an improved heuristic-based model. In the model, it is assumed that the cost of adjusting body size is a factor in the process to evaluate the optimal direction. In a typical simulation scenario, the pedestrian reluctant to adjust body size will pass by the blocks. On the contrary, the pedestrian caring little about body size will traverse through the exit. There is a direction-choice change behavior between bypass and traverse considering block width and the initial location of the pedestrian.

1. Introduction

As a common phenomenon in human society, pedestrian flow exhibits variable and complex patterns during the moving process. Understanding the characteristics of pedestrian dynamics is extremely helpful to improve the efficiency of traffic management, and even protect the safety in the emergency situation.

Simulation modeling is one of the effective methods to study pedestrian behaviors. Many macroscopic models [1–3] and microscopic models have been proposed in the last decades. The macroscopic models describe the system by mean values of density and velocity of pedestrian streams. In microscopic models, pedestrians are regarded as discrete individuals, and their movement is treated separately. Based on the characteristics of time and space, two kinds of microscopic models, the cellular automaton [4–8] and the social force model [9–14], are widely utilized.

By the social force model, many self-organized phenomena can be reproduced, such as "faster is slower", "arch" and lane formation. Moussaïd et al. [11] proposed the heuristics-based model to replace repulsive force in social force model.

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Pedestrians choose the route actively, according to the optimal velocity, which is evaluated by the position of other pedestrians and obstacles. In most of the studies, the body of each pedestrian is regarded as a circle [10], a square [15], or a rectangular [16,17] with fixed size. Chraibi and Seyfried [18] set the pedestrian body as the dynamic ellipse. The required space increases with the velocity, and the minimum value is the normal body size. The pedestrian cannot pass through the exit smaller than his/her normal body size. Thompson and Marchant [19] first proposed to model the body shape with a set of three circles. Qu et al. [20] adopted the three-circle shape model to simulate the pedestrian dynamics on stairs. The shape of three-circles is closer to the human body and has some geometrical advantages. However, the pedestrian can only rotate the body passively due to the contact forces. Moreover, the calculation of distance is complicated, and the added moment of force increases computational burden.

In the real world, pedestrians usually choose to arch the shoulders or rotate their bodies actively to cross narrow spaces. The purpose of these behaviors is to form a smaller effective size of the body. Therefore, the size of the pedestrian body is variable. In this paper, we regard the pedestrian body as the single-circle shape with variable radius. The factor is added into the heuristics-based model [11], and the simulation results show the impact of body size on the choice of moving direction.

The remainder of this paper is organized as follows. Section 2 presents the modified model. Section 3 presents simulation results. Section 4 concludes the paper.

2. Model

To make a clear statement, some notations and definitions are given as follows: pedestrian i is assumed as circle with radius $r_i(t)$ at time t, the mass is m_i, the desired speed is v_i^o, the current velocity is v_i, $and\alpha_o$ is the angle of target movement direction. The vision field ranges to the left and to the right by φ with respect to α_o.

For all possible directions α in $[\varphi, \varphi]$, pedestrian evaluates the distance to the first collision $f(\alpha, r)$, considering others' (pedestrians and obstacles) current velocity sizes and his/her own variable size. If no collision occurs in direction α under the body size r, $f(\alpha, r)$ is set to a default maximum value $d_{\max}$. In Moussaïd et al. [11], the cost to directions is

$$d_1(\alpha, r) = d_{\max}^2 + f(\alpha, r)^2 - 2d_{\max} f(\alpha, r)\cos(\alpha_o - \alpha). \tag{1}$$

In our model, the pedestrian can adjust his/her body size in the interval $[r^l, r^u]$. r^l is the smallest body width, and r^u is the normal body width. If pedestrian chooses arching the shoulders or rotating their body actively to obtain radius r, he/she has to pay an extra cost,

$$d_2(r) = c \cdot (r^u - r) \tag{2}$$

where c is the strength parameter.

The total cost is

$$\mathrm{d}(\alpha, r) = p \cdot d_1(\alpha, r) + (1 - p) \cdot d_2(r) \tag{3}$$

where p is the weigh coefficient ($0 \le p \le 1$). Therefore, we have a new term d_2 in the optimized direction choice with weigh coefficient p. With the larger p, the cost of changing body-size will be lower. This will affect the moving direction of pedestrians.

The chosen direction α_{des} and body size r_{des} is obtained through the minimum of the function $d(\alpha, r)$ to the target direction.

$$\alpha_{des}(t) = \arg\min[d(\alpha, r)] \tag{4}$$

$$r_{des}(t) = \arg\min[d(\alpha, r)]. \tag{5}$$

The speed v_{des} is given by

$$v_{des}(t) = \min[v^o, f(\alpha_{des}, r_{des})/\tau] \tag{6}$$

τ is the relaxation time for keeping a safe distance.

Physical interactions between bodies are not determined by heuristics. The physical contact forces are given as [11],

$$\overrightarrow{f_{ij}} = kg(r_{ides} + r_j - d_{ij})\overrightarrow{n_{ij}} \tag{7}$$

where $g(x) = 0$ if pedestrian i and j do not contact and otherwise equals the argument x. $\overrightarrow{n_{ij}}$ is the normalized vector pointing from pedestrian j to i, and d_{ij} is the distance between the mass centers of pedestrians. k is a parameter.

The physical contact force with a wall W is analogous,

$$\overrightarrow{f_{iW}} = kg(r_{ides} - d_{iW})\overrightarrow{n_{iW}} \tag{8}$$

d_{iW} is the distance to the wall and $\overrightarrow{n_{iW}}$ is the direction perpendicular to it.

The resulting acceleration equation is

$$\frac{\mathrm{d}\overrightarrow{v_i}}{\mathrm{d}t} = \frac{\overrightarrow{v_{des}} - \overrightarrow{v_i}}{\tau} + \frac{\sum \overrightarrow{f_{ij}}}{m_i} + \frac{\sum \overrightarrow{f_{iW}}}{m_i}. \tag{9}$$