Transportation Research Part C 44 (2014) 21–33

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Microscopic modeling of pedestrian movement behavior: Interacting with visual attractors in the environment

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ARTICLE INFO

Article history:
Received 9 March 2014
Received in revised form 12 March 2014
Accepted 12 March 2014

Keywords:
Pedestrian movement behavior
Microscopic modeling
Visual attractors
Impulse stops

ABSTRACT

Goal-directed pedestrian movement behavior is extensively studied by researchers from varied fields, but pedestrian's movement actions such as 'impulse stops' resulting from exploratory movement behavior receive little attention. To understand this, an effective tool that can reveal the attractive interactions between pedestrians and attractors in the environment is needed. This study introduces an agent-based microscopic pedestrian simulation model—CityFlow-U. To determine whether a pedestrian would stop for visual attractors, factors of attractor's attractiveness, distance to the attractor as well as the visibility of the attractor from current location of the agent are considered. By analyzing the parameters in this model, we have successfully revealed different pedestrian movement modes, attractor preferences and movement trajectories in a notional setting. The reliability of the model is then demonstrated with a simulation scenario targeting at a circulation region of a shopping mall in Hong Kong. Observational data is used for model input and the number changes of attracted pedestrians in front of a major attractor are compared between simulation results and empirical video data. Results from the parameter analysis and simulation scenario show that the model is flexible and can benefit in real applications such as shop arrangement as well as street furniture placement.

1. Introduction

Pedestrian dynamics has received increasing attention from various fields including building evacuation (Lo et al., 2004; Shiwakoti and Sarvi, 2013; Zheng et al., 2009), transportation engineering (Davidich et al., 2013; Yuen et al., 2013; Zeng et al., 2014), physics (Helbing and Molnár, 1995), urban design (Yin, 2013), and marketing (Dijkstra et al., 2011). In order to understand collective pedestrian movement patterns through space, different microscopic simulation models have been developed such as Cellular Automaton model (Bandini et al., 2007, 2014; Burstedde et al., 2001), social force model (Helbing and Molnár, 1995; Kwak et al., 2013; Song and Duh, 2010) and agent-based model (Bandini et al., 2011; Dijkstra, 2008; Ma et al., 2013; Schelhorn et al., 1999). With these models, many pedestrian flow phenomena such as lane formation (Hua et al., 2010; Ma et al., 2010), crowd passing through a bottleneck (Dai et al., 2013), and intersecting pedestrian flows (Guo et al., 2010) can be demonstrated. Such self-organized movement patterns of pedestrians could be reproduced to some extent by considering mainly self-driven forces to destinations and repulsive interactions with environment boundaries and other pedestrians. However, pedestrians will visually perceive and response to the environment information (especially

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http://dx.doi.org/10.1016/j.trc.2014.03.009
0968-090X/

attractive objects) in the course of moving along a path (Zacharias, 1997, 2001). In other words, visual perception and attractive interactions with the environmental stimuli are two important issues affecting pedestrian movement behaviors.

In terms of the visual information, it has been directly linked to pedestrian movement model in previous literatures. One common way is the static representation of what pedestrians can see and where they can go within space, such as Visibility Graph Analysis (VGA) (Turner et al., 2001). Turner and Penn (2002) developed an agent simulation to implement pedestrian movement with the aid of an 'exosomatic visual architecture'. But the model experienced obvious limitations in certain environment such as a long thin corridor and large open space, as pedestrian's movement decision greatly depends on the availability of a destination and configurational clues (exit). Another dynamic representation of visual information is the individual fan-shaped vision field (Asano et al., 2010; Moussaïd et al., 2011; Park et al., 2013), which can help implement natural movement of pedestrians. It is usually discretized into limited number of choice sets (directions) to reduce computing costs, and then pedestrian's desired walking direction and desired walking speed is determined by certain rules or mechanisms. However, all these previous models only take the selected goal as the pedestrian's main drive, and all the other objects in the environment, no matter how attractive they are, would be regarded as obstacles.

Pedestrian perceives the environment as they walk, during which they may be influenced by visual attractors such as window displays or street performances. If the object is attractive enough and meets the pedestrians' demands, they would even stop walking and visit it, namely 'impulse stops' (Borgers and Timmermans, 1986; Cobb and Hoyer, 1986). Though it is of great influence on movement behavior, the attractive interactions between pedestrians and visual attractors in the environment received little attention in previous literatures. The STREETS model (Schelhorn et al., 1999) incorporated the concept of 'fixation' to represent the pedestrian behavior that being distracted from their plans, but the mechanisms seemed too random. Chen (2011) introduced the 'attention theory' to pedestrian behavioral model and used an actual street case to simulate the pedestrian movements in urban spaces. However, how pedestrians perceive and interact with environmental attractors in the model was not clear. In a recently published paper, Kwak et al. (2013) extended the social force model by incorporating the attractive interactions between pedestrians and attractions and presented a phase diagram with various collective patterns of pedestrian movements. But it is not practical that only homogeneous properties of pedestrians and attractions were considered in the model.

Although extensive studies have been performed to simulate pedestrian dynamics, limited research works are available in the literatures examining the interactions between pedestrians and environmental attractors based on pedestrian's visual perception. This has motivated our research, the goal of which is to develop a microscopic simulation model that can reveal the realistic pedestrian movement behaviors and explain its mechanism. CityFlow-U is an expanded version of CityFlow which has recently been developed by City University of Hong Kong (Liu et al., in press). A new module named *attention-based exploratory movement module* has been added and analyses on critical parameters have also been provided. This module enables the agent to explore the visual attractors and then decide whether it will be distracted from the pre-defined routes by examining attractor characteristics and agent's internal state of demand. To demonstrate the reliability of the module, a simulation scenario about a circulation region of a shopping mall was presented. Observational data was used for model input and the number changes of attracted pedestrians in front of a major attractor were compared between simulation results and empirical video data. Finally, we drew some conclusions and proposed future researches.

2. Simulation model: CityFlow-U

2.1. Overview of CityFlow-U

The original model was implemented by two modules at three levels: (1) the *route choice and map navigation module* identifies the temporary desired regional target of movement, reflecting strategic, tactical level behavior in macroscopic scope; (2) the *agent-based individual movement module* decides the local movement of the agents based on detailed environmental information at every time step, reflecting operational level behavior in microscopic scope. When the regional target is reached, the second module will convey the message back to the first module and request for the next one until final goal is approached. In CityFlow-U, a new module namely (3) the *attention-based exploratory movement module* has been added which examines characteristics of the external attractors and agent's internal state of demand at operational level in microscopic scope. Once the attractor meets the agent's requirement, the message on changing the regional target will be sent back to the first module, as shown in Fig. 1.

Besides information about the environment, the properties of the agents to be simulated and the demand of the pedestrian system are required as inputs for the model, visual attractor characteristics are new essential data for representing external stimuli in the environment. Specifically, spatial layout of the visual attractor, its type and attractiveness need to be prepared. The building space in the simulation is represented in a network approach by dividing the geometry into 'zones' (including regular space and visual attractors) connected to one another by 'connections'. Fig. 2 shows an example of the space representation. Each zone is defined in a 2D continuous space by lines specifying the geometry boundaries. Zones in the space geometry are connected by 'arcs' which are actually virtual links between zones representing the features of routes, including distance, type and capacity of a route. As some pedestrians may change their plans by visiting visual attractors, these routes are connected by 'dashed arcs'.