Information Sciences 360 (2016) 112–130

Contents lists available at ScienceDirect

Information Sciences

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

Modeling and simulation of pedestrian dynamical behavior based on a fuzzy logic approach

Min Zhou[a], Hairong Dong[a,*], Fei-Yue Wang[b,c], Qianling Wang[a], Xiaoxia Yang[a]

[a] *State Key Laboratory of Rail Traffic Control and Safety, Beijing Jiaotong University, Beijing 100044, PR China*
[b] *The State Key Laboratory of Management and Control of Complex Systems, Institute of Automation, Chinese Academy of Science, Beijing 100190, PR China*
[c] *Center for Military Computational Experiments and Parallel Systems Technology, National University of Defense Technology, Changsha, Hunan 410073, PR China*

ARTICLE INFO

Article history:
Received 26 August 2015
Revised 9 March 2016
Accepted 6 April 2016
Available online 12 April 2016

Keywords:
Pedestrian dynamical behavior
Modeling
Perceptual information
Fuzzy logic
Model validation

ABSTRACT

This study proposes a fuzzy logic approach to model and simulate pedestrian dynamical behaviors, which takes full advantage of human experience and knowledge and perceptual information obtained from interactions with surrounding environments. First, the radial-based method is adopted to represent the physical space. A pedestrian's visual field, defined as a fan-shaped area with a certain visual distance and visual angle, is divided into five sectors. Then, the motion states of a pedestrian are determined by the integration of recommendations of local obstacle-avoiding behavior, regional path-searching behavior and global goal-seeking behavior with mutable weighting factors at three different scopes. These elementary behaviors and weighting's assignment principle are modeled as fuzzy inference systems with the input information of a pedestrian's perception toward surrounding environments. A pedestrian is guided to avoid the front obstacles and select the lowest negative energy path by local obstacle-avoiding behavior and regional path-searching behavior, respectively. The global goal-seeking behavior makes a pedestrian has a tendency of moving in direction of his/her goal regardless of external environments. The magnitudes of weighting factors are adjusted automatically to coordinate three elementary behaviors and resolve potential conflicts. At last, the effectiveness of the proposed model is validated by simulations of crowd evacuation, unidirectional and bidirectional pedestrian flows. The simulation results are analyzed from both qualitative and quantitative aspects, which indicate that the fuzzy logic based pedestrian model can get true reappearance of self-organization phenomena such as 'arching and clogging', 'faster-is-slower effect' and 'lane formation', and the fundamental diagrams are in matching with a large variety of empirical and experimental data. A further study finds that walking habits have negligible influence on the fundamental diagrams of bidirectional pedestrian flow at least for densities of $\rho < 3\text{p/m}^2$.

* Corresponding author. Tel.: +0086 010 5168 5749; fax: +0086 010 51683682.
E-mail address: hrdong@bjtu.edu.cn (H. Dong).

http://dx.doi.org/10.1016/j.ins.2016.04.018
0020-0255/© 2016 Published by Elsevier Inc.

1. Introduction

The modeling of pedestrian dynamics as an interdisciplinary research direction has attracted a wider interest of researchers and managers. The traffic capacity at the passage, characteristic features of normal and escape panics, and self-organization phenomena of crowds have been taken into account by architects and designers for optimization of limited traffic resources and formulation of urgent evacuation plans.

In order to understand complicated motion features of pedestrians, the important work is to build a suitable model for characterization of pedestrians' behaviors. Many prior studies on pedestrian dynamics have presented various pedestrian (crowd) models. The state of art of the models is mainly based on the following three type of methods: macroscopic, mesoscopic and microscopic model. The first, which treats the crowds as a fluid or continuum, uses gas kinetics and hydrodynamics to describe large crowds [24,25,60]. The second, which doesn't differentiate between individual pedestrians, focuses on describing part of global properties of pedestrians[21,22]. The third, which can analyze and research individual behaviors with the interplay of pedestrians, always treats a pedestrian as a discrete individual driven by force, potential or utility [1,5,20]. In the last years much more attention has been focused on microscopic modeling, where the socio-psychological and complex interactions of individuals and environments are considered in the model. Examples of microscopic models are the social force model [18,20], cellular automata model [5,46], lattice gas model [38,48], discrete choice model [1], agent-based model [41], and game theoretic model [4,29]. As a kind of highly complex living organisms, the behaviors of a pedestrian are jointly determined by personal internal consciousness and external environments. It is difficult to propose a mathematic model describing and predicting a pedestrian's behaviors accurately, especially given the complex interactions with surrounding environments.

The environmental effect is a critical factor in modeling of pedestrian dynamics, and it varies significantly over time and space. Researchers in various disciplines have made tremendous efforts to specify the stimuli of surrounding environments, including pedestrians, groups, obstacles, exits and so on, on pedestrian dynamic behaviors from different perspectives. The level of environmental stimuli is specified as physical force [18,20], floor field [5,46], drift (bias) [38,48], utility [1], and payoff [4,29] for quantitative evaluation of environmental factors in the previous studies. For example, Helbing et al. [18,20] modeled the effects of surrounding pedestrians and walls as interaction forces which shows a negative exponential decline with distances. In mathematical terms, the change of pedestrian's states is given by a classical Newtonian mechanics equation with precise environmental information such as distances, speeds, and directions. Schadschneider et al. [5,46] introduced the concept of a floor field which is modified by the presence of pedestrians and obstacles. This allows the cellular automation model to take interactions between pedestrians and the geometry of the system into account in a unified and simple way. The floor field modifies the transition probabilities in such a way that a motion into the direction of larger fields is preferred. Antonini et al. [1] adopted the concept of 'utility' borrowed from economics to quantify the interactions between the decision maker and the other pedestrians in the scene as well as the dynamic aspects of the decision maker itself. The utility values of alternatives are then transformed into probabilities and each pedestrian's movement is randomly selected according to these probabilities.

From a review of previous work, we noticed that these microscopic models are presented based on the promise that precise values of the complex interactions with surrounding environments such as speeds, directions and distances can be used in real time. The environmental effects on a pedestrian's behaviors are evaluated quantitatively based on these precise environmental data. Actually, the information got from environments is perception-based information rather than measurement-based information in most situation. It is difficult to quantify the size of environmental stimuli in real-life scenarios because a pedestrian's perceptions in a specific environment vary from one individual to another, and they are subjective in nature. Individuals have diverse perceptions when they are confronted with environmental interactions, and they may react subjectively to similar situations [14,23,43,64]. Moreover, the inter-relationship between pedestrian's dynamical behavior and pedestrian's perception toward the surrounding environment is rarely considered in previous studies. The perception-based information is often neglected in this area of researches. As such, the urgency underlying the current study is to develop a useful model which can make full use of perception-based information and capture the relationship between the environmental design and the pedestrian's perception.

To meet these goals, we employ a fuzzy logic approach in this study. The theory of fuzzy logic systems, inspired by the remarkable human capability, possesses the capability of operating on and reasoning with perception-based information [62–64]. Consider the intrinsic limitations of humans' cognitive abilities for distinguishing detail and storing information, pedestrian's perceptions toward surrounding environments are usually represented by natural language, which are inherently vague and imprecise. A fuzzy logic approach, compared with other methods, is highly robust in coping with the uncertainty and imprecision that are inherent in perception information. It also provides a scientific approach for the management of pervasive reality of fuzziness and vagueness in human cognition [63]. In addition, fuzzy logic also has the ability to utilize human experience and knowledge and imitate human thought processes [32]. For example, the near obstacle has a greater impact on the obstacle-avoiding behavior than the far. Using the fuzzy logic framework, the processes of pedestrian's reasoning and decision making can be formulated by a set of simple and intuitive fuzzy rules, coupled with advantages of accessible input information and easily understandable output [62].

The novelty of this study is the proposing of the fuzzy logic based pedestrian model, which can incorporate efficiently human experience and knowledge and pedestrian's perceptions toward surrounding environments into the modeling process. The main contribution of this paper are briefly summarized as follows: (i) A fuzzy logic-based microscopic pedestrian