Simulation Modelling Practice and Theory 84 (2018) 190–203

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

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

A social force evacuation model driven by video data

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ARTICLE INFO

Article history:
Received 15 May 2017
Revised 11 January 2018
Accepted 11 February 2018

Keywords:
Social force model
Crowd evacuation simulation
Path extraction

ABSTRACT

This paper proposes a video data-driven social force model for simulating crowd evacuation. The initialization of pedestrian position, path navigation, and goal selection in the improved social force model was guided by real video data. To initialize pedestrian position and determine path navigation, the distribution of the pedestrians is set according to the real video. We also extracted the trajectories of pedestrian movement from the videos, and these trajectories were stored into a path set to guide the evacuation of pedestrians. Moreover, a fitness function was defined to model the behavior of a pedestrian goal selection. The fitness function could process the evacuation parameters, which were extracted from the video, and consider the degree and distance of exit congestion. Furthermore, we quantified the relationship values among pedestrians, and a new force called "group force" was added to the primary social force model. Pedestrians with close relationship gathered into one group and walked together. To validate the effectiveness of the proposed method, the video data-driven model was applied to simulate campus halls and roads. Simulation results show that the proposed approach is consistent with real-world situations and can assist in analyzing emergency evacuation scenarios.

1. Introduction

The development of crowd evacuation scenarios has recently become a popular research area [1]. Increasing attention has been paid to determining the safety of people during evacuations. Pedestrian flow in public places, such as supermarkets and subway stations, is mixed, and a small disturbance may cause instability to crowds. Thus, crowd trampling accidents may easily occur. The significance of this issue has been reported [2,3]. A proper evacuation simulation method can predict the danger and save lives during emergencies.

Experiments and simulation modeling are currently the main methods applied to investigate evacuations. Numerous evacuation models, such as social force model (SFM) [4,5], cellular automata models [6,7], fluid dynamic models [8,9], and agent-based models [10], have been established. In most of these models, individuals are treated as autonomous agents, and these individuals can perceive information and decide independently based on their own behavior rules. These models provide a fundamental framework for simulating crowd dynamics. However, finding the correct parameter settings and behavior rules of agents using the traditional models to ensure that the simulation can match the behavior observed in an actual physical system is challenging. Agent behavior rules in agent-based simulations are difficult to derive because the behavior of an agent is affected by his environment and surrounding agents [11].

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https://doi.org/10.1016/j.simpat.2018.02.007
1569-190X/

Recent studies [32–40] showed that introducing real evacuation data into the traditional model is helpful in analyzing pedestrian movements and making the evacuation more realistic. Several of these models are aimed at learning the rules from video data, and these rules are then used to improve pedestrian movements [12–14]. Consequently, the simulation behavior is apparently similar to the video data. Other data-driven models, such as evolutionary algorithms, are aimed at automatically calibrating model parameters. The potential of data-driven approaches in automatic crowd modeling has been demonstrated. However, macroscopic and microscopic factors should be fully considered in the evacuation process. The macroscopic characteristics and social relationship of pedestrians should be considered. In many practical scenarios, considering only the microscopic features is insufficient to generate the desired emergent crowd dynamics. In the macroscopic aspect, path navigation and goal selection are essential parts of a crowd evacuation simulation model. Moreover, the social relationship of pedestrians affects the evacuation. Pedestrians with close relationship gather into a group and walk together. Thus, we combined the traditional models with the data-driven models in this study to integrate their advantages.

This paper proposes a video data-driven SFM to address the aforementioned issues. The main contributions of this paper are as follows:

(1) The initialization of the pedestrian position and path navigation was driven by video data. The distribution of pedestrians was set in accordance with a real video. Crowd motion trajectories were also extracted from the video data. An evacuation path set was built after removing repeated paths, and the trajectories were eventually used to guide the crowd evacuation.
(2) The mechanism of goal selection was driven by video data. A fitness function that considers the degree of congestion and distance of exits was introduced into the original SFM. This fitness function processed parameters, which were extracted from the video; these parameters include the number of pedestrians near the exit and distance to the exits. Then, the fitness of each exit was calculated. Finally, this fitness function modeled the behavior of crowds in goal selection.
(3) We quantified the relationship values among pedestrians and then added a new force called "group force." The results after the improvement showed that pedestrians with close relationship gather into one group and walk together.

The rest of this paper is structured as follows. Related works on crowd evacuation models are discussed in Section 2. The data-driven crowd evacuation model is defined based on the improved SFM in Section 3. The top layer models the goal selection and path navigation of the pedestrians, while the bottom layer models the microscopic collision avoidance and relationship among pedestrians. The simulation experiments in school roads and hall settings are presented in Section 4. Then, the simulation results in goal selection, path navigation, and crowd density distribution are analyzed. Finally, the conclusion and future perspectives are presented in Section 5.

2. Related work

The simulation of pedestrian crowds for normal and evacuation situations has been widely examined. Various approaches exist, and each approach focuses on a specific objective. A possible categorization is to distinguish between macroscopic and microscopic models as proposed in Ref. [2]. The dynamic characteristics of crowd flow for macroscopic models are described by average speed, density, and location [15,16]. The detailed behaviors and interactions of the crowd have been disregarded, although the macroscopic model can describe the overall movement trend of the crowd. The mutual influence of individuals is particularly emphasized in microscopic models contrary to macroscopic models. Cellular automata [6,7] are a discrete dynamic crowd movement system that belongs to a microscopic model with grid-based motion decision. The lattice gas model [8,20] is a special case of cellular automata that are based on probability and statistics. The SFM [4,5,21] is also a microscopic model but in continuous time and space. This model introduces a desired force to describe the inner drive of pedestrians to escape, especially under stressful situations.

These traditional models have been improved and designed to make the model realistic. Several early studies have attempted to model the group phenomena [17–19]. Farina et al. [17] added a heading of pedestrians into the dynamic model and introduced a new force to model the behavior of people that walk together as a single group. The model presented by these authors could reproduce the moving behaviors of pedestrians in open spaces and high-density scenarios. Bandini and co-workers [18] presented a research that focused on group and age-driven pedestrian behaviors in an urban crowded scenario. The result showed that dyads walk 30% slower than singles in irregular flows, while elderlies walk 40% slower than adults. Nishinari and co-workers [19] investigated the role of conflicts in pedestrian traffic. A friction parameter μ was introduced into the cellular automaton model for pedestrian dynamics. The simulation results showed that these conflicts are important for an accurate description of the dynamics. The "group force" that we added in our model is determined by the relationship of pedestrians, unlike the abovementioned methods.

The effects of pedestrian vision field [22] and leading mechanism [23–25] have also been considered. Helbing et al. [22] introduced the vision field by defining a term of the socio-psychological force in the original SFM that could reflect the anisotropic character of pedestrian interaction. Several studies have established route sets [26–31] to help in the evacuation. Hoogendoorn et al. [28,30] presented a summary of factors that influence the decision of an individual on the appropriate route selection and suggested numerous schemes by optimizing several established pedestrian-specific utility functions. Ma and Fukuda [29] proposed a route selection model that incorporates hyper path and the generalized extreme values of a network based on link choice models.