Physica A 473 (2017) 319–336

Contents lists available at ScienceDirect

Physica A

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

A grouping method based on grid density and relationship for crowd evacuation simulation

Yan Li [a,b], Hong Liu [a,b,*], Guang-peng Liu [a,b], Liang Li [a,b], Philip Moore [a,b,c], Bin Hu [a,b,c]

[a] School of Information Science and Engineering, Shandong Normal University, Jinan City, China

[b] Shandong Provincial Key Laboratory for Novel Distributed Computer Software Technology, Jinan City, China

[c] School of Information Science and Engineering, Lanzhou University, Lanzhou City, China

HIGHLIGHTS

- It presents an improved social force model which adds the force of group attraction.
- The force of group attraction is the synthesis of two forces.
- A grouping algorithm based on the grid density and relationship is proposed.
- We have tested the appropriate grid partition number and the relationship weight.

ARTICLE INFO

Article history:
Received 21 September 2016
Received in revised form 30 November 2016
Available online 10 January 2017

Keywords:
Crowd evacuation
Social force model
Computer simulation
Grouping algorithm

ABSTRACT

Psychological factors affect the movement of people in the competitive or panic mode of evacuation, in which the density of pedestrians is relatively large and the distance among them is small. In this paper, a crowd is divided into groups according to their social relations to simulate the actual movement of crowd evacuation more realistically and increase the attractiveness of the group based on social force model. The force of group attraction is the synthesis of two forces; one is the attraction of the individuals generated by their social relations to gather, and the other is that of the group leader to the individuals within the group to ensure that the individuals follow the leader. The synthetic force determines the trajectory of individuals. The evacuation process is demonstrated using the improved social force model. In the improved social force model, the individuals with close social relations gradually present a closer and coordinated action while following the leader. In this paper, a grouping algorithm is proposed based on grid density and relationship via computer simulation to illustrate the features of the improved social force model. The definition of the parameters involved in the algorithm is given, and the effect of relational value on the grouping is tested. Reasonable numbers of grids and weights are selected. The effectiveness of the algorithm is shown through simulation experiments. A simulation platform is also established using the proposed grouping algorithm and the improved social force model for crowd evacuation simulation.

* Corresponding author: Hong Liu. Postal address: School of Information Science and Engineering, Shandong Normal University, No. 88, Wenhua East Road, Jinan City, China.

E-mail address: lhsdcn@126.com (H. Liu).

http://dx.doi.org/10.1016/j.physa.2017.01.008
0378-4371/

1. Introduction

The development of the economy and urbanization has resulted in a growing number of large-scale public events that attract large crowds. These events pose significant challenges in respect of crowd management; this has resulted in the growing research interest in simulating crowd behavior in relation to security challenges and evacuation scenarios. Public buildings may be subject to emergency situations, including fires and explosions, which instigate panic situations, in which, for example, stampedes and congestion can be experienced. These problems have historically resulted in large fatalities and personal injuries. Emergency evacuation of large crowds is a complex process.

Crowd evacuation experiments are dedicated to several targets and are rich in data information. However, significant unavoidable challenges, including high cost and staff security, are experienced in attempts to conduct these experiments. Accordingly, computer simulation of crowd dynamics and the evacuation in large-scale public events has gained significant attraction given the implications for security and personal safety. Thus, computer simulations have become the main method for studying emergency evacuation [1–4].

Crowd motion is a complex physical process in the evacuation process. Its dynamic adjustments are directly or indirectly restricted by many factors. Interactions among the crowd and the psychological state of individuals are both important factors that may influence crowd motion. These factors contribute to several typical characteristics in crowd evacuation, including the following:

1. **Clogging phenomenon**: In emergency situations, individuals may react irrationally and move at a higher speed than normal. This feature results in pushing, congestion at egress points, and even crowd stampedes with resultant fatalities.
2. **Mass behavior**: In emergency situations, the panic emotion tends to generate and diffuse more easily than conventional evacuation; thus, "contagion" is higher. This phenomenon contributes to a series of non-adaptive crowd behaviors [5]. When the crowd is significantly large, the dissemination of information is limited by time and space. Individuals make decisions in an instant even with lack of information, which leads to "herding" [6,7], i.e., people tend to do what others do. In the same way, the emotion of people is easily affected by the panic of others.
3. **Grouping behavior**: In evacuating large-scale crowds, individuals tend to form a group with other people, and the group has a social relationship with themselves, such as family members and friends. This grouping sometimes helps in rapidly finding out the exit but does not necessarily accelerate the evacuation speed. Within a group, individuals interact, which demonstrate obvious nonlinear characteristics [8]. Behavioral characteristics [of individuals] in crowds may result in convergence, conflict, and balance and imbalance of various energies, as well as orientation and exclusion of groups [9].

The phenomena described above identify the difficulty in effectively modeling evacuation motion laws for crowds. Thus, establishing a reasonable simulation model for large-scale evacuation in unconventional emergencies is an urgent issue to be addressed. This model should integrate various uncertain factors, such as the psychological state(s), behavioral characteristics, motion laws, and interactions (as discussed in the subsequent sections of this paper).

Significant research interest is given to the emerging application of psychosocial studies with computer simulation, which has been proposed as an effective approach for effective modeling of crowd dynamics in emergency situations [10–12].

Based on the social force model (SFM), an improved SFM (ISFM) is proposed to model crowds effectively, considering psychological factors [13,14]. In this paper, a crowd is divided into groups according to their social relations, and the attractiveness of groups is increased based on SFM. The force of group attraction is the synthesis of two forces; one is the attraction of the individuals generated by their social relations to gather, and the other is that of the group leader to the individuals within the group to ensure that the individuals follow the leader. The synthetic force determines the trajectory of the individuals. The evacuation process is demonstrated using ISFM. In ISFM, the individuals with close social relations gradually present a closer and coordinated action while following the leader.

Based on ISFM, a novel grouping approach predicated on grid density and interpersonal relationships is proposed. In the proposed approach, the "plane space" is initially divided and modeled into a grid of cells. Subsequently, the relative density and relationship information of the non-empty grid cells are calculated. The grouping of data objects is then converted into clusters for grid cell. The proposed approach provides a number of benefits, such as the following:

- The number of grid cells is significantly smaller than the number of data objects; thus, the use of a grid data structure effectively reduces the computational complexity in grouping;
- Based on the selection process in core grid, outliers are effectively separated from the sparse grid and are then grouped with the classified center points of core grid.

The approach used in classification is predicated on the K-medoids method, which is based only on the distance among data points and the relationships that exist among them. In the proposed approach, the grid grouping is reduced to the grouping of data objects. Thus, the proposed approach can effectively improve the accuracy of the grid-based grouping algorithm and is faster than the K-medoids algorithm. Several test cases are used to evaluate and demonstrate the power of the proposed approach.

The remainder of this paper is organized as follows. Section 2 indicates the related works on SFM and clustering algorithms. Section 3 introduces the ISFM and the grouping of attractive force to SFM. In Section 4 a grouping algorithm based on grid density and relationship (GABGDR) is proposed. Section 5 discusses the conducted simulation experiments to show the efficiency of the proposed method. Finally, Section 6 concludes the paper and presents the future research focus.