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Multi-grid simulation of counter flow pedestrian dynamics with emotion propagation

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ABSTRACT

Much insight into pedestrian flow dynamics has been achieved by conducting simulations and experiments. However, the combination of pedestrian movement and psychological influence in discrete models has not been well investigated. Here we employ a multi-grid model to understand pedestrian dynamics in counter flow, coupled with the effect of emotion propagation in a crowd stampede induced by panic. The time evolution of average speed under conditions with and without emotion propagation is obtained. Though emotion propagation increases the desired speed, it easily leads to congestion because of an increase in competition in counter flow. According to the speed–density relationship, a function of the crowd density and percentage of pedestrians in counter flow is employed to identify the flowability of pedestrians in a long channel. Thus, three regimes, i.e., lane formation, the transition stage and clogging, are presented. This is useful in the organization of safe mass events with respect to crowd density. The force distribution and cumulative distribution of the largest force that pedestrians bear are further analyzed to understand a tragic incident related to crushing such as the Cambodian stampede. These results provide an estimation of the number of injuries from the perspective of force. It is hoped that this research will be helpful in crowd management.

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1. Introduction

Pedestrian flow dynamics concerned with interacting individuals in a many-particle system has been attracting significant attention due to some interesting dynamical phenomena and phase transitions [1], such as self-organizing lane formation in a counter flow system [2], stop-and-go waves in a unidirectional pedestrian flow [3], 'freezing by heating' under extreme conditions [4], 'faster is slower effect' and herding behavior during an evacuation process [5]. Research on pedestrian flow dynamics is helpful in efficient, safe and comfortable operating environment design (e.g. subways, stadiums and cities) and large-scale crowd management.

When the number of individuals in pedestrian flow increases, resulting in a large crowd, both dynamic and psychological characteristics will be of importance to understand motion and inherent dangers of large crowds of pedestrians [6,7]. In a classic escape panic situation (characteristic features in Ref. [5]), psychological elements have a crucial role in stampede events [8], which are always related to mass behavior. Panic is defined as "an acute fear reaction marked by a loss of

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self-control which is followed by nonsocial and nonrational flight behavior, leading to jamming and life-threatening overcrowding" [5,9]. "Mass panic" is a particular form of collective behavior induced by some individuals exposed to a dangerous situation [10–12]. Crowd disasters, especially panic-driven stampedes [8,9,13], have been reported in recent decades. In a separate religious festival in 2005, a stampede over a river bridge in northern Baghdad, Iraq resulted in 965 Shia pilgrims' death. The reason was that rumors of a bombing spread among crowds, and then panic behavior was evoked. An implausible rumor that the bridge would collapse induced mass panic and a stampede on a bridge in Cambodia on 22 November 2010. 399 pedestrians were trampled to death in this accident. In 2013, over 60 persons perished in a stampede in a gymnasium in Abby, Ivory Coast as a result of pedestrian panic ensuing from a bang of fireworks. These crowd disasters remind us the necessity of studying crowd dynamics with psychological rules (e.g. panic-related emotions).

Emotions play an important role in human behaviors, especially in emergency situations [14,15]. Theories of emotions have been proposed from physiological and psychological views. According to Lange and James's [16] physiological theory, emotions were the sentiments that appeared due to physiological changes, such as heart rate and respiration in response to different human experiences. Nevertheless, the cognitive appraisal theory [17] advocated that emotions were triggered by perception. Minh et al. [14] recommended that fear was the emotion that had the greatest impact on pedestrian behavior in an emergency situation. According to the intensity level of the emotion, they distinguished four levels of fear: normal, stress, fear and panic. In spite of various definitions, emotion is catching as a result of interaction between individuals [18], namely emotional contagion (or emotion propagation). Emotional contagion is defined as "the tendency to mimic the verbal, physiological, and/or behavioral aspects of another person's emotional experience/expression, and thus to experience/express the same emotions oneself" [19]. This process is usually spontaneous, unconscious and uncontrolled [20]. Research has demonstrated that emotional contagion may occur in many cases varying from small groups to panicking crowds [12,21–23]. In the case of a serious emergency (e.g. fire or earthquake), individuals' behavior is primarily directed by the emotions they are feeling or received from others [14]. The transformation or contagion theory introduced by Le Bon [24] stated that social contagion resulted in crowds' mental homogeneity. Durupınar [25] simulated the overall behavior of a crowd consisting of various psychological states and spread of emotions following the approach of biological contagion. Hill et al. [26] presented the classic susceptible–infected–susceptible disease model to evaluate the spread of emotional states, and employed data from the Framingham Heart Study to provide formal evidence that emotional states spread across social networks like infectious diseases. Then this model was extended for sentiment contagion in the financial market by Liu et al. [20]. Hu et al. [27] and Zhao et al. [28] adapted the susceptible–infective–removal model to investigate panic propagation during post-disaster evacuation and under subway emergencies, respectively. Mao et al. [15] emphasized that panic propagation in crowd simulation under emergency situations should not be ignored. Many researchers [14,22,29,30] also considered emotion propagation in agent-based evacuation simulations. This rendered simulations more realistic.

Experimental methods [31–34] and a number of models , such as the social force model [5], lattice gas model [35], multi-grid model [36], floor field model [37,38], agent-based model [39,40] and visual hindrance model [41], have been employed to describe behavior with pedestrian flow. However, only a few models involve pedestrian social-psychological behavior, because it is difficult to be quantified and is varying according to different individuals. Since Helbing et al. [5] proposed the social force model to study mechanisms of panic behavior and jamming by uncoordinated motion in crowds, interactions among pedestrians through forces (e.g. attraction, repulsion and friction) have become the focus of renewed attention. Discrete models such as the lattice gas model and multi-grid model, which have simple movement rules and high simulation efficiency, were modified to simulate pedestrian dynamics, given interaction forces between individuals [36,42–44]. Nevertheless, the "nervousness" parameter [5], which is a measure of impatience and may affect pedestrians' desired speed under emergency situations, was usually neglected in these discrete models. As stated above, emotions are important in crowd simulation, and may propagate through crowds, as manifested in social psychological efforts. In this regard, the influence of emotion propagation on pedestrian dynamics should be integrated with discrete models.

In this paper, we use a multi-grid model combined with abnormal emotion propagation to simulate counter flow pedestrian dynamics. This model enables analysis of different walk velocities and the effect of abnormal emotion on pedestrian movement under a crowd condition. Our aim is to examine to which extent this model is available to advance warning of crowd disasters from perspectives of the percentage of pedestrians in counter flow, density and force. This will be of significant benefit to illuminate tragic incidents such as the stampede on a bridge in Cambodia on 22 November 2010.

The remainder of this paper comprises the following. Section 2 describes the multi-grid model integrated with emotion propagation. Simulation rules are presented. In Section 3, we perform simulations of the counter flow scenario. The model is written in C++ language. Simulations are executed on the hardware condition of Intel(R) Core(TM) i7-3770 CPU, PC. The process of emotion propagation is reproduced. Results of the relationship between speed and density, cumulative distribution of force, number of injured persons, etc. are identified. Finally, conclusions are reported in Section 4.

2. Model

Two factors are involved in our model of pedestrian counter flow. One is to simulate pedestrian movement using a multi-grid model of biased random walkers without back steps. The other is to describe emotion propagation through pedestrians.

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