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Discrete particle simulation for high-density crowd

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Abstract

The present paper describes the discrete particle simulation of the evacuation dynamics. The inter-pedestrian forces are given by the discrete element method (DEM). The composite particle model is proposed to take into account the effect of the non-circular shape of pedestrians on the evacuation behavior. It has been indicated that the pedestrians can evacuate faster when an obstacle is placed at an appropriate position. The effect of the obstacle on the evacuation rate is also examined numerically in the present study. The proposed numerical model represents the positive and negative effects of the obstacle on the evacuation behavior qualitatively.

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Keywords: numerical simulation ; discrete element method ; evacuation ; high-density crowd ; composite particle model ; obstacle

1. Introduction

Pedestrian dynamics has drawn attentions of many researchers in recent years. In addition to the experimental contributions (Hoogendoorn et al. (2003) ; Helbing et al. (2007)), many numerical approaches, such as a cellar automaton (Yanagisawa et al. (2009)), multi-agent simulation (Kaneda, 2005), social force model (Helbing et al. (2000)), and so on, have been applied to the pedestrian flows. DEM (discrete element method), which had been developed in the civil engineering to simulate the motion of soils (Cundall et al. (1979)), has also been applied to the pedestrian flows recently (Tsuji (2003); Gotoh et al. (2012)). DEM is applicable to highly dense situations, since it can conduct the multiple contacts of particles.

The behavior of pedestrians at an exit is one of the most substantial issues, since it is the rate-determining step during the emergency evacuations. The exit is a bottleneck to cause jams of pedestrians. Especially, the arching of

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pedestrians is strongly related to the deterioration in the efficiency of evacuation. It has been suggested that an obstacle placed in front of the exit suppresses the arching to reduce the evacuation time (Nishinari et al, 2008).

In the present paper, the evacuation from an exit is numerically studied by use of DEM. A composite particle model is proposed to take into account the shape of the human body, that is, the shoulder width is wider than the chest depth. The effect of an obstacle placed in front of the exit on the evacuation dynamics is also studied.

Nomenclature

F_C	contact force [N]
F_G	gravitational force [N]
I	moment of inertia [kg m^2]
k	spring constant [N/m]
m	mass [kg]
t	time [s]
T	torque [N m]
v_r	relative surface velocity [m/s]
x	position [m]
δ	deformation [m]
η	damping coefficient [N s/m]
μ_f	coefficient of friction [-]
ω	angular velocity [1/s]
subscript	
n	normal direction
t	tangential direction

2. Model description

A dynamics-based particle model is employed to simulate the pedestrian motion. In highly crowded conditions, a pedestrian may contact with multiple other pedestrians at the same time. Thus, the soft sphere model rather than the hard sphere model is suitable to express the inter-pedestrian forces.

DEM (discrete element method), which is one of the soft sphere models, is adopted to model the inter-pedestrian forces in this study. The contact force model of the DEM is schematically shown in Fig. 1(a). The elastic property of the human body at the compaction in the crowd is expressed by a spring. A damper represents the dissipation of energy during the contact. The elastic and the frictional properties in the tangential direction can be expressed by a spring and a slider.

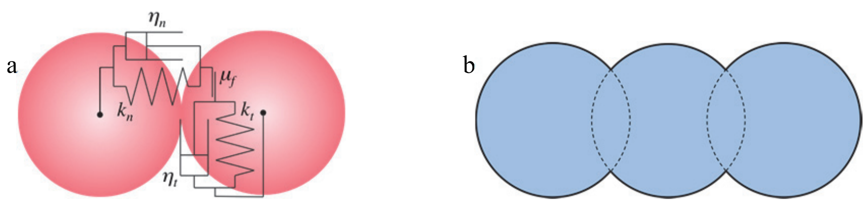

Fig. 1. (a) contact force model of DEM; (b) composite particle model.

The translational and the rotational motion of pedestrians are described by the following Newton's equations of motion.