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An energy based method to measure the crowd safety

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Abstract

How to evaluate crowd safety in crowded areas is a tough, but important, problem. According to accident-causing theory, uncontrolled release of hazardous energy among overcrowded pedestrians is the basic cause of crowd disaster. Therefore, crowd energy is modeled in this paper, which takes both pedestrian kinetic energy, pedestrian potential energy and pedestrian internal energy into consideration. Furthermore, the crowd energy is discussed in an empirical study of subway station based on videos. The result shows that the crowd energy can be used to evaluate crowd safety performance.

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1. Introduction

Large transport stations and large activity venues in particular are the places of frequent and large mass gathering, which sometimes generate extreme crowding in relatively small spaces and short time (Johansson et al. (2012)). And to eliminate the risk of large crowd disaster in such places is a big challenge of crowd management for humans. In past few years, huge efforts are made to solve the problem with development of video monitoring technologies and crowd simulation models. As the first step of crowd management, how to evaluate crowd safety in crowded areas is a tough, but important, problem. Two indicators are proposed and widely used by researchers in previous studies:

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crowd density and crowd pressure. The improved crowd energy conception will be presented in this paper to evaluate the safety state of crowd in extreme crowding areas, especially in massed subway station.

1.1. Related works

Density has been widely adopted as an efficient index to help to improve the decision making process of crowd management. Marana et al. (1997) referred that automatic estimation of crowd density was a part of the problem of automatic monitoring of crowds, and a novel technique was described to estimate crowd density based on texture information of digitized images of the area under monitoring. Rahmalan et al. (2006) pointed that estimating crowd density might be a good solution for maintaining the crowds' safety and could be also used for crowd management and control. In their study, three different techniques were developed for estimating a crowd's density in outdoor scenes. Yaseen et al. (2013) developed a novel sensory fusion model of infrared and visual systems to estimate the real time density in order to provide accurate prognosis in crowd behavior and enhance crowd management and safety. Density indeed can reflect the crowd performance directly. But, it cannot precisely reveal the nature of crowd disaster, while it can't explain why high dense crowd more easily led to injury incidents and why low-density crowd has relatively lower risk of disaster.

Crowd pressure was proposed and spread by Helbing et al. (2002, 2007) and his colleagues, such as Johansson et al. (2008) and Moussaïd et al. (2011). With crowd dynamic models of social force and video-based empirical studies of mass events, crowd pressure was developed and has been found effective in the prediction of potential crowd hazards or disaster. It can be defined as local density times the local velocity variance, and reveals areas with a high risk of falling, indicating the likelihood of a crowd disaster. It can be defined as follows.

$$P(\vec{r}, t) = \rho(\vec{r}, t) \text{Var}_{\vec{r}, t}(\vec{V}) \quad (1)$$

Where $\rho(\vec{r}, t)$ indicates the density at location \vec{r} , $\text{Var}(\vec{V}) = [V(\vec{r}, t) - V(\vec{r})]$ is the velocity variance, and $V(\vec{r}, t) = \sum_i \|\vec{v}_i\| f(d_{i, \vec{r}}) / \sum_i f(d_{i, \vec{r}})$. Previous study has proved that the transition to "turbulent" when the "pressure" exceeds the value $0.02/s^2$. The crowd accident began when the "pressure" reached its peak. $d_{i, \vec{r}}$ is distance of location r and pedestrian i , and $f(d_{i, \vec{r}}) = (1 / \pi R^2) \exp(-d^2 / R^2)$, where R is a measurement parameter. The value $R = 0.7$ m provides a reasonably precise evaluation of the local speed. And these studies light a valuable idea for our proposed crowd internal energy.

Crowd energy has been a hot topic in recent years. Zhong et al. (2007) presented the crowd energy to describe the crowdedness of the scene by using the conception of kinetic energy, which just took velocity into consideration. Inspired by this idea, Xiong et al. (2012) established the image potential energy model, which is a kind of energy related to position or distance from camera to overcome the shortcomings of the initial model. The above models are all applied in practical video-based crowd surveillance. But the energy in their studies is only limited to describe just one side of crowd energy. For instance, kinetic energy proposed by Zhong et al. (2007) cannot distinguish the risk of crowd disaster in these two situations: one is crowd with low density, velocity v_0 and people count N_0 ; the other is crowd with high density, but the same velocity v_0 and people count N_0 . So, further studies should be pushed on.

1.2. Accident Causation Theory based on Energy

Energy is a crucial element to injuries accidents. Haddon (1970) proposed the idea that many accidents and injuries involve the transfer of energy. The energy transfer theory suggests that quantities of energy, means of energy transfer and rates of transfer are related to kind and severity of injuries. Later, in 1972, Haddon proposed a matrix (Called Haddon's matrix) to combine factors and phases in the injury process. Energy release theory is also proposed by researchers alone. According to this theory, an accident is caused by a lack of engineering control. This lack of control results in energy that is out of control which puts cause stress limits to be violated, whether on a person, machinery, or environment. Therefore, accidents can be prevented by instilling a proper engineering control to divert the energy, which is the source of the hazards. This theory has been not introduced in the analysis of the crowd injury incidents.

According to the accident-causing theory above, it's convinced that uncontrolled release of hazardous energy among overcrowded pedestrians is the basic cause of crowd disaster. This kind of energy generates from crowd, but influences on crowd in return. According to this view, preventing the marshalling process, reducing the amount and preventing the release of crowd energy are the main measures of crowd management to prevent crowd disaster. While crowd energy is a difficult to quantify, the simple but scientific calculation methods are focused on in this article.

1.3 Goal and Outline

As referred above, a brand-new crowd energy is modeled in this paper to evaluate the crowd safety in crowding areas. Both pedestrian kinetic energy, pedestrian potential energy and pedestrian internal energy are taken into consideration. The remaining parts are organized as follows: section 2 introduces the basic concept of crowd energy and the calculation methods. In section 3, an empirical study based on video-based data is implemented. Conclusion is given in section 4.

2. Crowd Energy

2.1. Pedestrian kinetic energy

Pedestrian kinetic energy is to describe the single pedestrian's energy in state of motion. The higher the velocity of pedestrian is, the more the kinetic becomes. According to Newtonian mechanics, pedestrian kinetic energy can be defined as in equation(2). Where $\vec{v}_j(\vec{r}, t)$ is the velocity of pedestrian j at the position \vec{r} and time t .

$$e_j^k = m_j \vec{v}_j^2(\vec{r}, t) \quad (2)$$

2.2. Pedestrian potential energy

Pedestrian potential energy is to describe the single pedestrian's energy considering its position, just like the gravitational potential energy. Pedestrian potential energy can be defined as:

$$e_j^p = m_j g \hat{h}_j(\vec{r}) \quad (3)$$

Where, \hat{h}_j indicates the theoretical height of pedestrian j , just like the h in gravitational potential energy. But it is adjusted according to the distance from edges of platform.

2.3. Pedestrian internal energy

Pedestrian internal energy is used to describe the potential energy generated from body compression among the pedestrians. Inspired by crowd pressure, pedestrian internal energy can be defined as:

Firstly, each pedestrian i is characterized by its current position \vec{x}_i and speed \vec{v}_i , which can be collected by Video based systems. Base on the auto-collected data, body compression force can be calculated:

$$C_j(t) = \sum_i \|\vec{f}_{ij}(t)\| \quad (4)$$

$$\|\vec{f}_{ij}(t)\| = A_j e^{(r_i+r_j-d_{ij})/B_j} \quad (5)$$

Where, $C_j(t)$ is the compression forces of pedestrian j . $\vec{f}_{ij}(t)$ is the contact forces of pedestrian i from pedestrian j . r_i is the radius of private space of pedestrian i . And \vec{n}_{ij} is the direction of $\vec{f}_{ij}(t)$. In equation 6, A_i is the pedestrian impact strength, and B_i indicates the impact scope of pedestrian i . Helbing et al. (2002) recommended that the values of A_i and B_i should be 2000 and 0.08m. But, Taras et al. (2005) suggest that A_i should be some value ranging from 300 to 900, and B_i should be 0.5m. According to an amount of empirical studies, we accept 200 for A_i and 0.3 for B_i .

Secondly, crowd internal energy is established based on body compression force, and the calculation formula and its derivation process are shown as equation 7:

$$e_j^C = \sum_i \int_0^{r_i+r_j-d_{ij}} \vec{f}_{ij}(t) dx_{ij} = \sum_i \int_0^{r_i+r_j-d_{ij}} A_j e^{x_{ij}/B_j} dx_{ij} = \sum_i A_j B_j * (e^{(r_i+r_j-d_{ij})/B_j} - 1) \quad (6)$$

$$\text{That is } e_j^C = \sum_i A_j B_j * (e^{(r_i+r_j-d_{ij})/B_j} - 1) .$$

2.4. Crowd Energy

The final model of crowd energy is an integration of pedestrian kinetic energy, pedestrian potential energy and pedestrian internal energy. The general crowd energy can be defined as:

$$e_j = e_j^k + e_j^p + e_j^C \quad (7)$$

$$CE = \sum_j e_j \quad (8)$$

Bring Equation(2), (3), (6), (7) into equation (8), the final **Global Crowd Energy** formula is as follows:

$$CE^{global} = \sum_j (m_j \vec{v}_j^2 + m_j g \hat{h}_j + \sum_i (A_j B_j * (e^{(r_i+r_j-d_{ij})/B_j} - 1))) \quad (9)$$

Besides, in order to investigate the local risk of crowd disaster, **Local Crowd Energy** is modelled as in Equation (10).

$$e(\vec{r}, t) = \sum_i (e_i * f(d_{i,\vec{r}})) \quad (10)$$

Where $f(d_{i,\vec{r}}) = (1/R) * (R - d_{i,\vec{r}})$, $d_{i,\vec{r}}$ is distance of location r and pedestrian i . R is a measurement parameter, and we adopted $R = 0.7$ m just as Moussaïd et al. did in 2011.

3. Case study

Beijing subway is a massed rail transit system with over 10 million ridership each day. Xizhimen station of Beijing subway line 2 is selected to do the empirical study. Three lines, including line 2, line 4 and line 13, join together at Xizhimen station, and huge transfer passengers contributes an overcrowding situation on platforms. Cameras are installed near each train gate.

Based on the latest image processing technique, a semi-automatic collection system of pedestrian behavior characteristics is developed, to achieve the data extraction of speed, density and trajectory of pedestrian and provide the precise and actual data for our empirical studies of crowd energy. The detailed technical principles are referred to Zheng (2014). The scene of video detection is just limited to the area around the train gate on platform in Xizhimen station, just like in Fig. 1.



Fig. 1. Area of video detection, rectangle area enclosed by the four points P1, P2, P3 and P4.

We investigate changes of *global crowd energy* and *local crowd energy* in the process of pedestrian boarding and alighting near the gate, with semi-automatic image processing technologies. *Global crowd energy* is calculated in each frame, and *local crowd energy* is calculated at every position of each frame, as shown in Fig. 2 and Fig. 3.

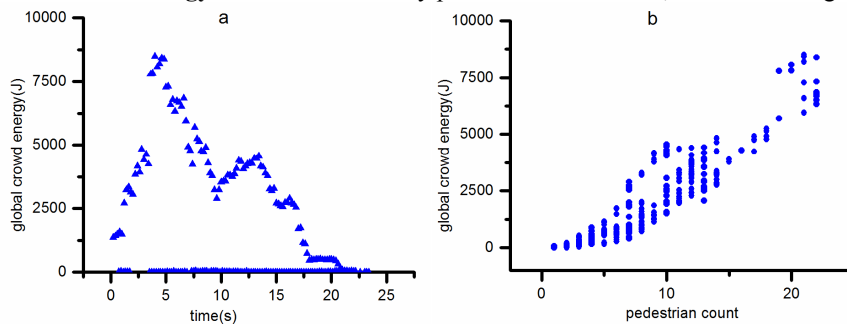


Fig. 2. The global crowd energy varies in process of pedestrian boarding and alighting at the train gate. (a) indicates that once train gate is open, crowd energy becomes high in short time and calm down gradually. (b) indicates that global crowd energy has a positive correlation with the count of pedestrian.

According to accident causation theory of energy transfer and energy release, the higher the crowd energy is, the higher the risk of crowd injury incident is. So it can be found that about 5 seconds after the train gate opens is dangerous time point, while the crowd energy is highest, as shown in Fig. 2. And pedestrians in the red areas in Fig. 3 are suffering a higher risk of crowd injury incidents than the others in yellow, green and blue areas around the red.

4. Conclusion

The Crowd energy model is established, which takes pedestrian kinetic energy, pedestrian potential energy, and pedestrian internal energy into consideration. In order to evaluate different granularity of crowd safety, the global crowd energy model and the local crowd energy model are expanded. The empirical study, based on data extracted from a semi-automatic image processing system of pedestrian behavior characteristics, shows that the crowd energy has a positive correlation with the count of pedestrian and intensity of the collision among pedestrians. The result also shows that the crowd energy can be used to evaluate crowd safety performance.

In our future researches, crowd energy in more different crowded situations will be investigated. And some key parameters in our crowd energy model should be invalidated through amounts of empirical studies.

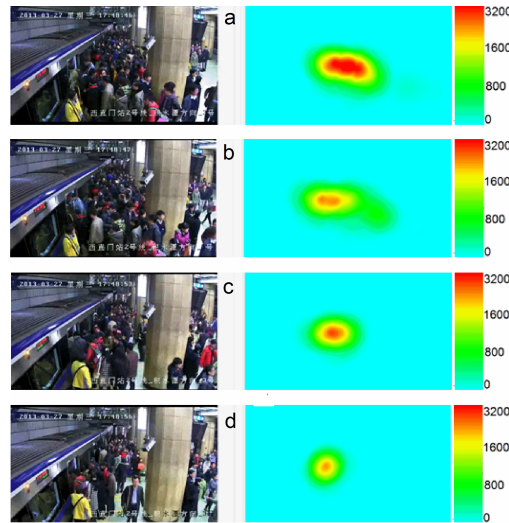


Fig. 3. The local crowd energy varies in process of pedestrian boarding and alighting at one gate. (a) $t=0s$, mix of passengers boarding and alighting are with the high crowd energy, while collision among pedestrians is serious; (b) $t=1s$, passengers nearly finish alighting process, and passengers waiting on platform began to board the train. So the crowd energy spreads out but become smaller than last second; (c) $t=7s$, only passengers aboard the train with relatively smaller but centered crowd energy; (d) $t=10s$, all of passengers nearly finish boarding the train so the crowd energy is small.

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