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Risk-based crowd massing early warning approach for public places: A case study in China

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ABSTRACT

Beijing municipal government plans to establish a comprehensive real-time monitoring and risk identification technological system basically covering the targeted districts with crowded pedestrian traffic. The system aims to send out alarm in crowded places through analyzing quantitative data from intelligent real-time monitoring devices installed in key locations. An early warning signal is derived from the judgment of current status of the crowd, and this research aims to explain the mechanism of how to judge crowd status. Classically risk is defined as multiplication of impact and probability of occurrence of an event. Here, a 2-D risk matrix is established to judge the crowd status by probability (duration of the pedestrian status) plus consequence (strength of the pedestrian status). After installed intelligent monitoring devices in key locations, the online observations of crowd movement within the targeted district can produce the early warning alarm ahead of time. Such alarm is expected to provide the local administrator 10 min to prevent potential undesired chaos by taking proper controlling actions. This paper is a case study in a specific area in China. This system can be used in many areas such as sporting events and religious gatherings.

1. Introduction

1.1. Background

Recently, the stable development of economy increased the demands for material goods and culture. Urban public places have been acting as the main venues to undertake various business, recreation, cultural, traffic and transportation, sports and religious gathering, etc. The number of public places rise sharply. More activities with massing crowd are taking place in kinds of public places. The crowd stampede has aroused great attention.

Being the high intensity of the crowd, once the stampede occurs, severe casualties will be caused. According to incomplete statistics, thousands of people all over the world died in the emergencies occurred in the massing crowded activities per year (Lee and Hughes, 2006). Now, the crowd safety issue in urban public places is facing severe challenges. These challenges are more prominent in China and mainly summarized as follows.

(1) From 1978 to 2013, the population urbanization rate of China rose from 17.9% to 53.7% (China Statistical Yearbook, 2014). And in the coming years, China's urbanization rate will still be in accelerated development. However, inadequate accommodation, out-of-date facilities and plenty of hazards increase risks of mass crowding in public places.
(2) The self-owned characteristics of urban public places create notable exposure to disaster. It makes the disaster relief system rather weak. And disaster prevention and relief of these public places is also a hard nut in fighting against disasters in cities.
(3) The phase with the per capita *GDP* reaching USD 1000–3000 is called "golden development phase" or "highlighted period". It is also named as social transition period (Huntington, 1991). China is now in this very period. China is facing unbalanced social equality, great polarization between the rich and the poor, increasing prominent disparity between the countryside and cities. And urban public places are featured by highly dense crowd, much social wealth and great social sensitivity. Undoubtedly they become the most preferred target of those criminals.

Crowd stampedes shows the following features compared with ordinary accidents.

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Firstly, the location and time of occurrence is uncertain. All public places are likely to suffer crowd stampede at any time, especially in the entrance and exit, corridor and stairs of buildings or squares, etc. The greater the density of the crowd, the more likely there exists for the occurrence of the stampede.

Secondly, many causes may lead to stampedes. The evacuation resulting from the emergency or a great number of people crowding in exits or entrances, or unexpected riot may arouse stampede without notable reasons.

Thirdly, it happens too hastily to control. Once happened, a great number of people will be endangered within extremely short time period (several seconds to several minutes). The scene is always full of chaos.

Lastly, casualties are always caused which are leading to huge jeopardy.

In response to the disastrous massive crowding stampede, the prediction and early warning based on real-time judgment of the status of crowd flow through measurable parameter of crowd flows is the main technical method to avoid crowd stampede.

1.2. Literature review

Lee and Hughes were the first to conduct the research on crowd stampede accident (Lee and Hughes, 2005). They mainly used open access data, and introduced the pedestrian flow model to made quantitative analysis on the mass crowding and stampede through practical cases.

Helbing made a detailed analysis on the panic of crowd as is the main cause of crowd stampede, and put forward the "Social Force" model, grounded on which the simulative research on various self-organization phenomenon under the crowd panic was made (Helbing et al., 2000; Helbing, 2001). Through simulating the crowd movement by setting different scenarios, he concluded that "the most dangerous thing for mass crowding is the frightened running of the crowd due to panic, the collision and stampede between individuals will always result in huge casualty".

Henei and White made improvement on the "cellular automaton model", and analyzed the crowd behavior during the process of evacuation of computer simulation based on multi-agent technology (Kirchner and Schadschneider, 2002; Henein and White, 2007). In the model presented, they expounded on the fact that death of individuals in the crowd was caused by the interactive force which reached certain thread value, and gave four basic principles that should be abided by acting forces between individuals. Although Henein made a research on the interactive forces among the crowds as the main cause of crowd stampede, but they didn't made a detailed analysis on the categories of acting forces between individuals.

Heigeas mentioned two kinds of crowds. One is the interrelation between individuals (discussion and negotiation between small-sized groups), the other is large-scale crowd, such as flowing and jamming (Heigeas et al., 2003). However, Heigeas' research was mainly about the second type of mass crowding under non-negotiated emergencies. His research was in the purpose of manifesting typical self-organization action of the crowd. He also established a particle simulative system based on physical acting forces.

On the basis of the "Social Force" model raised by Helbing, Kardi Teknomo carried out in-depth analysis on the repulsive force in the acting force between individuals of the crowd and set up relevant microcosmic simulation model (Teknomo, 2002). He mainly collected the data of pedestrians through video and established the aTXY data base. He set up through contrastive analysis of the real data and computer simulation results. Though the crowd stampede accident wasn't mentioned in his paper, the microcosmic model established by him carried out detailed description on the acting force between individuals of the crowd. The acting force was the major cause of the crowd stampede accident and was considered as one of the main reference of the computer simulation model.

The above are literature related to crowd stampede accident, and the earliest research on crowd behavior is from the point of sociology (Valach et al., 2002). The present research on the crowd is mainly focused on crowd dynamics. That is analyzing the crowd behavior especially the evacuation in normal status through establishing relevant macro or micro pedestrian traffic model.

Lu carried out relevant research on the mechanism of crowds based on the wave theory, especially the shock wave theory (Lu, 2006). In her points, she took the moving pedestrian as the continuous medium and any perturbation of the crowded pedestrian (which directly presenting as the density variation) would be propagated among people by pedestrian waves. Meanwhile, because of the difference among individuals, the nonlinear aberration of wave might lead to shock waves, i.e., the stampede accident. In addition, by using the feature value solution and Matlab code, the shock could be predicted as when and where to occur at different initial distribution of density and speed.

In the "Social Force" model, the movement of pedestrians is dominated by the social force. Zhang considered the mutual influence among pedestrians comprehensively and set up the microcosmic dynamical model of mass movement by using the intelligent agent technology (P. Zhang et al., 2005, 2006). Different from the research of Lu, Zhang established the microcosmic simulation model of crowd movement, but she didn't reveal the stampede mechanism.

Liu conducted the research on the quantitative method of crowd retention and crowd safe evacuation (Ren et al., 2005; Q. Zhang, 2006, 2007). He put forward the general approaches for analyzing the crowd stampede accidents. He used the cluster index to represent the parameter of high crowd gathering and obtained the characteristics of the accidents through analysis of the crowd stampede accidents home and abroad. The emphasis on prevention and control of the accidents was also stressed.

Hu and Kou conducted the research on the crowd stampede accidents from the social management point of view (Hu and Ye, 2003; Kou, 2005).

Crowd monitoring is the process of monitoring and controlling large groups of people for their safety and security. It also provides ways to efficiently utilize space and reduce cost involved in maintenance (Rossi and Bozzoli, 1994). The detection methods are broadly classified into two categories.

The first one is obstructive and the second is non-obstructive (Kamel et al., 2004). The first type to detect the number of people requires personal contact, which obstruct the path. Examples of these types are turnstiles and mattype foot switches. The above sensors are suitable for counting a few people and are not adequate for crowd monitoring.

On the other hand, there are non-contact and non-obstruct sensors. From these types, it is a CCTV visual camera. In CCTV based research efforts, individuals are first detected by human models or detectors and then tracked in order to count the number of pedestrians.

Masoud et al. used different images to detect moving blobs. Pedestrians are detected by rectangular patches based on their dynamic behavior (Masoud and Papanikolopoulos, 2001).

Liu et al. proposed a method based on human appearance models to detect pedestrians (Liu et al., 2005). In this method, human models are created using a set of low level image features, and the number of people is counted using these human models. Also, Sidla et al. proposed a model-based method to detect the number of humans in scenes (Sidla et al., 2006). In this method, humans were successfully detected using active shape models (ASM) even if their bodies were partially occluded.

In this research, we proposed a pioneer method to reflect the crowd risk in public places. First, we need human appearance models to detect pedestrians. However, these methods are difficult