Physica A 440 (2015) 200–209

Contents lists available at ScienceDirect

Physica A

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

Congestion detection of pedestrians using the velocity entropy: A case study of Love Parade 2010 disaster

Lida Huang, Tao Chen *, Yan Wang, Hongyong Yuan

Institute of Public Safety Research/Department of Engineering Physics, Tsinghua University, Beijing, 100084, China

HIGHLIGHTS

- We propose velocity entropy as an indicator to detect the crowd congestion.
- The velocity entropy denotes the dispersion of velocity distribution on magnitude and directions.
- This method has been applied to the simulation data from AnyLogic and the video recordings of the Love Parade disaster.
- The method is robust and efficient in detecting the congestion.

ARTICLE INFO

Article history:
Received 31 March 2015
Received in revised form 24 July 2015
Available online 20 August 2015

Keywords:
Congestion detection
Crowd analysis
Video surveillance
Velocity entropy
Love Parade disaster

ABSTRACT

Gatherings of large human crowds often result in crowd disasters such as the Love Parade Disaster in Duisburg, Germany on July 24, 2010. To avoid these tragedies, video surveillance and early warning are becoming more and more significant. In this paper, the velocity entropy is first defined as the criterion for congestion detection, which represents the motion magnitude distribution and the motion direction distribution simultaneously. Then the detection method is verified by the simulation data based on AnyLogic software. To test the generalization performance of this method, video recordings of a real-world case, the Love Parade disaster, are also used in the experiments. The velocity histograms of the foreground object in the videos are extracted by the Gaussian Mixture Model (GMM) and optical flow computation. With a sequential change-point detection algorithm, the velocity entropy can be applied to detect congestions of the Love Parade festival. It turned out that without recognizing and tracking individual pedestrian, our method can detect abnormal crowd behaviors in real-time.

1. Introduction

With the rapid development of urbanization and the increase of population density in the city, more and more mass events, including festival parades, religious processions, marathon races and so on, have been conducted in recent years. At the same time, panic stampedes are more and more frequent and horrible, which have killed thousands of people all over the world according to incomplete statistics [1]. Typical examples of these stampedes include the catastrophe in Mina, Saudi Arabia in January 2006 which killed 363 people, the accident at Love Parade in July 2010 in Duisburg, Germany and the recent disaster in Shanghai Bund, China on December 31, 2014. The high frequency and huge casualties of these accidents emphasize the urgent need to detect the abnormal behavior of pedestrians in real-time and improve the emergency planning process.

* Corresponding author. Tel.: +86 10 62796323.
E-mail address: chentao.a@tsinghua.edu.cn (T. Chen).

http://dx.doi.org/10.1016/j.physa.2015.08.013

In recent years, there are many researches focusing on the study of pedestrian behavior based on the video analyzing technology. Some studies explored the crowd movement features by experimental study. For example, Tobias Kretz et al. designed an experiment to illustrate the relationship between the width of the bottleneck and the movement features including evacuation times, specific fluxes and time gaps [2]. Armin Seyfried et al. illustrated the fundamental diagrams for the single-file movement of pedestrians under normal circumstance [3] and through bottlenecks [4], from which they also explored how the way of flow measurement influences the resulting outcomes. Using high precision motion capture technology, Asja Jelić et al. explored the relation between instantaneous velocity and spatial headway (the distance to the predecessor) for an unidirectional pedestrian flow [5,6]. Liu Xuan analyzed the microscopic characteristics of pedestrian dynamics, including velocity, density, and lateral oscillation of the trajectory for a single-file pedestrian movement with a digital image processing method based on a mean-shift algorithm [7]. In the same way, Wei Tian analyzed the distribution of time headways (the time between two pedestrians) in corridors with different widths [8]. The other common kind is the empirical study, which uses videos from real crowd disasters to complement the experimental data base and reveal the special phenomena in high density crowds. For example, Helbing et al. analyzed video recordings of the crowd disaster in Mina/Makkah during the Muslim pilgrimage on January 12, 2006, revealing the state transitions of crowd as the pedestrian density increased, which is from laminar to stop-and-go and turbulent flows [9,10]. They also analyzed the Love Parade disaster in Duisburg, Germany on July 24, 2010, summarized the causes of the disaster, and gave recommendations to help prevent future crowd disasters [11]. Ma Jian further analyzed the trajectories of pedestrian crowds in Love Parade 2010, quantified the crowd pressure [12] and summarized the special pedestrian movement features for the crowd quakes [13], from which they proposed a heterogeneous contact model to simulate the crowd quake [14]. Zhang Xiaole et al. analyzed the video recordings of a real mass event in Foshan, China, re-verified the transition from laminar to stop-and-go flows [15], obtained the fundamental diagrams and provided a way to estimate the street capacity [16].

Understanding the characteristics of crowd behavior, researchers could improve pedestrian dynamic models and devise evacuation strategies, from which they can identify potential dangers. For example, Helbing's study of the Muslim pilgrimage resulted in structural change of the site and re-organization of the pilgrimage [9], after which there has not been major trample disaster. Since it has been proved that the amplitude of lateral oscillation increases as the velocity of the pedestrian decreases [17], Barbara Krausz adopted the sway amplitude as a criterion to detect dangerous pedestrian flow mode of the Love Parade disaster [18], while this method only applies to the unidirectional or bidirectional pedestrian flow. As under densely packed situations, local body contacts may induce forces, resulting in pedestrian clusters [12], Ma Jian et al. proposed an automatically clustering method for detecting abnormal flow pattern [19]. However, their approach needs to track the pedestrian, which is difficult in high density conditions. Since the crowd congestion is very dangerous in people-intensive places, and there is no general method to detect it, this paper focuses on providing a propagable system which can detect the crowd congestion automatically.

In high-density situations, different movements of pedestrians could happen. On one hand, people may stand still and are not able to move forward, where velocities of pedestrians equal zero. On the other hand, if people stay long time in jam (or for some other reasons like fear caused by sudden events or discomfort caused by cramped spaces), they could start to push each other and manage to move; and if the size of the crowd is high enough, cohesive movements are observable. Our study focuses on the second case which is more dangerous.

The remaining part of this paper is structured as follows: In Section 2, the proposed velocity entropy, used as the indicator for congestion detection, is introduced. In Section 3, the detection method is tested by the simulation data based on AnyLogic software. In Section 4, we apply this method to a real-world case, the Love Parade disaster. Finally, we conclude this paper in Section 5.

2. Proposed velocity entropy

2.1. Overview of entropy

Entropy, which is a measure of the disorder or randomness of a closed system, has been widely used and made remarkable achievements in statistical mechanics, thermodynamics, sociology, information theory, control theory and number theory. It has different definitions in different theory. In statistical mechanics, entropy is the level of order of a system; the greater the entropy, the more disordered the system [20]. In thermodynamics, entropy can be considered as a variable describing the state of matter, which measures the disorder degree of a large number of microscopic particles [21]. In sociology, entropy means the chaos degree of social living condition and social values. In information theory, entropy (also called Shannon entropy) is a measure of uncertainty [22]. Shannon entropy E_S is defined as the sum of expectations of a set of probabilities:

$$E_S = p\left(x_1\right) \log_2 \frac{1}{p\left(x_1\right)} + p\left(x_2\right) \log_2 \frac{1}{p\left(x_2\right)} + \cdots + p\left(x_n\right) \log_2 \frac{1}{p\left(x_n\right)} = -\sum_{i=1}^{n} p\left(x_i\right) \log_2 \frac{1}{p\left(x_i\right)}$$

where p is the posterior probability of a random variable.

In recent years, entropy has also been used in the study of abnormal crowd behavior detection. For example, Xiong et al. defined the crowd entropy to represent the spatial distribution of crowds [23]. Haidar et al. proposed the modified entropy considering the velocity distribution and location distribution to characterize anomalies [24]. Gu et al. used particle entropy