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Correlation dimension of collective versus individual pedestrian movement patterns in crowd-quakes: A case-study

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HIGHLIGHTS

- The fractal analysis is performed on spatial crowd distribution.
- The whole crowd is spatially homogeneously distributed.
- The space patterns of single pedestrians vary from clustered to quasi-homogeneous.

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ABSTRACT

Video recording right before the Love Parade, Duisburg (Germany) crowd-quake, occurred on 24 July 2010, has been analysed in order to investigate the spatial properties of the crowd (collective case) and those of the single pedestrians in the crowd (individual case). The Grassberger–Procaccia correlation dimension, well known to be able to distinguish patterns in spatial point processes, was used. Our results for this case-study reveal that crowd and single pedestrians are characterized by different spatial behaviour: the whole crowd behaves as a quasi-homogeneous spatial point process through time, with an averaged correlation dimension of about 1.92; while the single pedestrians show a quite large variation of correlation dimensions indicating different spatial patterns, ranging from clustered to quasi-homogeneous.

1. Introduction

In recent years, more and more mass events have been taking place all around the world, such as Olympic Games, pilgrimages, music festivals and so on, raising important safety management issues for the organizers and strengthening the need to have more refined models of pedestrian dynamics. The study of pedestrian dynamics has been rapidly developing, not only in terms of pedestrian simulations [1–4], but also in controlled experiments [5–7].

By means of advanced image processing technology [8,9] and devices such as active infrared counters [10,11], detailed crowd disaster analysis has been performed. Johansson et al. [8] developed a software to automatically detect pedestrians' heads in Muslim pilgrimage in Mina/Makkah, Saudi Arabia during the Hajj in 1426H on 12 January 2006. On the basis of

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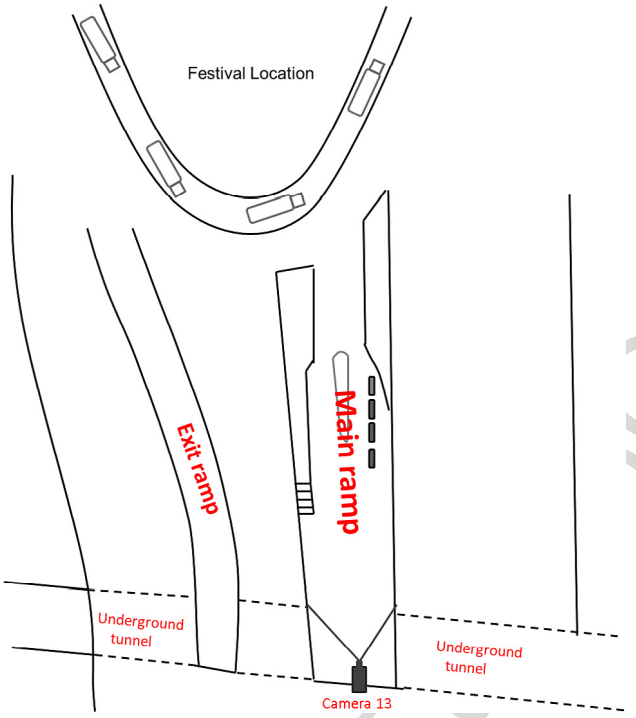

Fig. 1. Location of the Love Parade.

such software, Helbing et al. [12] identified two subsequent sudden transitions of the state of the pilgrimage: from laminar to stop-and-go and "turbulent" flows. Wang et al. [13] re-investigated Mina stampede and extracted the instantaneous velocity field; furthermore, studying the features of stop-and-go wave and turbulence flow, they identified the pressure buffer region.

By improving the repulsive force in social force model at high densities, Yu and Johansson [2] successfully reproduced crowd turbulence. Ma et al. [14] also reproduced crowd turbulence by heterogeneous contact model and found that different contact modes between pedestrians at high densities may be the reason for pressure release. Seyfried et al. [15] analysing congested pedestrian traffic, found that the velocity–density relation shows a coexistence of moving and stopping states that suggests the complex structure of pedestrian movements.

The Love Parade disaster, happened in Duisburg (Germany) on 24 July 2010, represents a well documented stampede and was investigated quite extensively [16]. Ma et al. [17] on the basis of the individual movement information, found that the overall flow field is characterized by vortex and sink structure. Instead of tracking pedestrians, Krausz and Bauckhage [16] used optical flow to extract velocity field in the Love Parade crowd-quake and proposed an early warning system to detect dangerous state in mass events.

In this paper, we analyse the spatial properties of pedestrian dynamics of one case-study of crowd-quake that occurred in the Love Parade festival in Duisburg in 2010. The spatial distribution of the crowd, constituted by 273 pedestrians, was investigated by using the Grassberger–Procaccia fractal method of the correlation integral that is well known for its effectiveness to measure the fractal dimension of small spatial datasets. Our aim is to compare the spatial properties of the whole crowd with those of the each individual pedestrian.

2. Data

The Love Parade took place at the compound of the former freight station of Duisburg, near the city centre. Fig. 1 shows a schematic view of the compound. The festival area was continuously monitored by seven cameras [16]. Thanks to the surveillance camera 13, the chaotic movement of the 273 pedestrians before the disaster was recorded.

On the basis of a mean-shift algorithm [9], each pedestrian's head in each video frame was detected, after the initial position of each pedestrian has been manually marked (see a snapshot of the video in Fig. 2), and its pixel feature defined as input parameter for the software. The duration of the video recording is 25 s, from 16:39:32 to 16:39:57, and a total of 624 time frames were recorded. The pixel resolution is 1280×720, corresponding to an area of approximately 6.4 m $\times$ 3.6 m.

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