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Analysis of repulsion states among pedestrians inflowing into a room

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A R T I C L E I N F O

Article history:
Received 28 March 2018
Received in revised form 28 May 2018
Accepted 31 May 2018
Available online xxxx
Communicated by C.R. Doering

Keywords:
Proxemics
Pedestrians
Inflow
Hurst exponent

A B S T R A C T

One of the characteristics of inflow processes within a room is the changing spatial configuration of people that are in the room due to the entering of new pedestrians. Each entry produces a break of the spatial configuration. Such break can be effectively represented by the proxemics, which describes the repulsion among pedestrians. In this study, we deeply investigate the properties of proxemics defined for pedestrians, who inflow within a room. We analyzed two different cases: when some of the pedestrians are inactive and when no inactive people are present. In both cases the proxemics is characterized by a succession of upward step-like variations superimposed to an initial increasing behavior that tends to stabilize through time. The derivative of the proxemics, which indicates increase of repulsion (if positive) and decrease of repulsion (if negative) among pedestrians, is persistent; however, in case of absence of inactive persons, it increases with the number of moving people, while it remains almost constant when inactive persons obstruct the free movement of the other pedestrians.

1. Introduction

In recent decades, studies have been focused on pedestrian flows as they display various collective behaviors [1–4] and have complex interaction dynamics [5–8]. Pedestrian motion characteristics, such as evacuation time [9–11], pre-movement time [12], stepping behavior [13], density-flow relation [14–16], have been widely studied. Zhang et al. [10] conducted controlled experiments of pedestrian evacuation from a classroom and summarized typical behaviors: variable velocity, dislocable queuing, monopolizing exit, etc. Furthermore, they build a multi-grid model to investigate the effects of the pre-movement time and its distribution on pedestrian evacuation. Armin et al. [17] proposed that the flow had a linear relation with the bottleneck width, and found pedestrian lane width in the bottleneck changed continuously for a small variation of the bottleneck width. Lian et al. [18,19] analyzed spatio-temporal dynamics for pedestrian movement in the Love Parade disaster. Former studies mainly focused on pedestrian outflow process and directional flow, while the study of pedestrian inflow process was rarely investigated. Researchers defined inflow process as pedestrians entering in a confined area, dwelling after finding a comfortable place [20]. Inflow process is common in pedestrian daily life, such as boarding on a bus, subway, elevator and is meaningful for the design of transportation facilities. Inflow process can be displayed through the following phases: perception, decision making for destination, interaction between other pedestrians, stopping, direction change, and adaptation to incoming people [20]. Four dominant factors influenced the decision-making in inflow process: flow avoidance, distance cost, angle cost and boundary preference [21]. Liu et al. [22,23] investigated pedestrian inflow process and found pedestrians were not uniformly distributed in a room. The interaction between the boarding and alighting, i.e. the interaction between inflow and outflow in public transportation facilities, was also investigated [24–26]. It is found that pedestrian traffic management measures had remarkable effects on the passenger service time, passenger density on the platform and vehicle as well as passenger dissatisfaction in metro stations [24]. The effect of the initial ratio of boarding to alighting group size on the average alighting time was studied and a model was built to describe this behavior [25].

In this study we present a deep analysis of a parameter that is commonly used to describe the interaction among pedestrians in inflow processes, the so called proxemics. This parameter, which will be defined later, quantifies the conditions of repulsion among pedestrians, whose movement is confined within a limited space. Up to our knowledge, the properties of inflow processes through the investigation of the proxemics time series has never been performed so far. this condition is crucial to better understand the dynamical properties of inflow processes.

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https://doi.org/10.1016/j.physleta.2018.05.055
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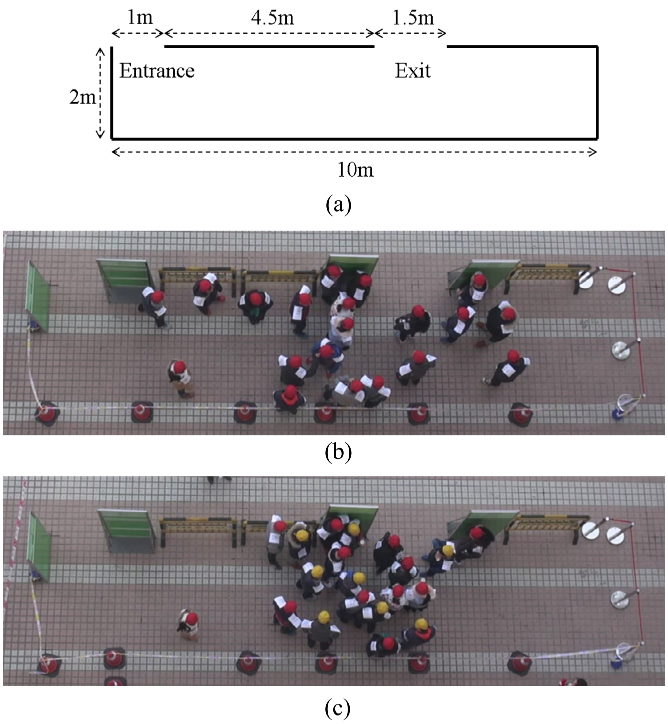

Fig. 1. (a) Geometry of the experiment; (b) snapshot of one experiment without inactive persons; (c) snapshot of one experiment with inactive persons.

2. Experiment arrangement

In order to investigate pedestrian inflow characteristics, a series of controlled experiments in a regular room with the size of 10 m × 2 m was conducted in a school (Fig. 1a). The room had a separate entrance and exit, with width 1 m and 1.5 m respectively. The room has also an exit, because it mimics public transportation like a bus, which has a separate entrance and exit. However, in this study we just focused on the inflow processes. Each experiment was recorded by two cameras, which were fixed in the ceiling. In the experiments, participants were asked to wear red or yellow hats, so that their positions could be automatically extracted by mean-shift algorithm [38] in the recorded videos. Then, the direct linear transformation method [39] was used to convert the positions from image space to real space. The participants were all university students. In order to avoid the bias possibly due to familiarity between students during the experiments, they were divided into several groups, and the sequential participants in the same group were not familiar with each other. Thus, the participant group was rather unacquainted. The participants had been informed to walk as normal, without thinking of emergency situations. Two kinds of experiments were performed: 1) without inactive persons and 2) with inactive persons. In the first case, the participants stood orderly outside the entrance at beginning, and when the voice instruction rang, they started to enter the room and chose somewhere to stop; the participants, however, were allowed to change position if felt uncomfortable when someone else entered the room. In the second case, some participants were told to be inactive, that is after they entered the room and randomly selected a position to stop they were not allowed to move anymore, thus mimicking persons who did not change their place even though they impeded the free movement of other pedestrians, like, for instance, in public transportation vehicles due to laziness, fatigue, etc. In this case, the inactive persons entered the room first. Fig. 1b and Fig. 1c show snapshots of one experiment without inactive persons and one with inactive persons.

3. Data analysis, methods and discussion

We carried out several experiments of pedestrians' inflow in two different conditions: without inactive persons and with inactive persons. Without inactive persons, we considered different numbers of inflowing pedestrians (5, 10, 20, 30 and 40) and carried out three experiments in each case (except when 40 pedestrians were inflowing, for which only two experiments were conducted). With inactive persons, we considered different numbers of inactive persons (2, 4, 6, 8 and 10) and carried out three experiments in each case, but all with 20 inflowing pedestrians.

Fig. 2a shows, as an example, the trajectories in one experiment of 20 people entering the room without inactive persons; while Fig. 2b shows the trajectories in one experiment of 20 people entering the room, but with 8 inactive persons.

The investigation of the spatial relationships among pedestrians occupying the same room is closely linked with the study of human personal behavior and the perception of human personal space. Hall (1963) coined the term "proxemics" to refer to "the study of how men unconsciously structure microspace – the distance between men in the conduct of daily transactions, the organization of space in his houses and buildings and, ultimately the layout of his towns". Furthermore, Hall (1966) defined four interpersonal distances: intimate, personal, social and public. Among these, the personal distance (between 1.5 and 4 feet) is more likely to be used by friends and acquaintances. In this context, Liu et al. [22,23] defined the proxemics as follows.

Indicating with $(x_i,\ y_i)$ the position of pedestrian i, the proxemics of each pedestrian can be calculated by the following equations:

$$P_i = \sum_{j \in N} P_{ij} \tag{1}$$

$$P_{ij} = \begin{cases} 1 & \text{if } d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \le 1\ \text{m} \\ \frac{1}{d_{ij}} & \text{elsewhere} \end{cases} \tag{2}$$

where P_i is the proxemics of pedestrian i. As a consequence, the proxemics of one pedestrian depends on the distance from all the others: if the interdistance between the pedestrian i and j is less or equal to 1 m, the contribution of pedestrian j to the proxemics P_i of pedestrian i is 1, otherwise is smaller than 1; thus, the lower such interdistance, the larger its contribution to the proxemics. If two persons, who are not friends or acquainted, have an interdistance less than 1 m (which represents a sort of spatial limit for the personal distance as defined by Hall, 1966), they very likely would feel uncomfortable and would receive repulsion from each other more than in case the two persons are acquainted. Thus, the proxemics defined in Eqs. (1)–(2) could quantify the repulsion a person suffers from the other persons. The larger the proxemic value is, the more repulsion each person receives [22,23]. Such repulsion decreases as the interdistance increases.

Since the pedestrians enter the room at different times, we considered for each pedestrian's trajectory the time interval between the time in which the pedestrian enters the room and the time in which the last pedestrian that entered the room stops. In this study we analyzed the properties of the time variation of the proxemics as defined in Eqs. (1)–(2).

Fig. 3 shows, as an example, the time variation of two proxemics, one corresponding to a pedestrian in the experiment without inactive persons where 10 persons inflow into the room (Fig. 3a), the other corresponding to a pedestrian in the experiment with 4 inactive persons (Fig. 3b). Both curves are characterized by a succession of upward step-like variations superimposed to an initial increasing behavior. Since the proxemics quantifies the repulsion among pedestrians, such repulsion increases with time

Please cite this article in press as: L. Lian et al., Analysis of repulsion states among pedestrians inflowing into a room, Phys. Lett. A (2018), https://doi.org/10.1016/j.physleta.2018.05.055