“Nudging” crowds: When it works, when it doesn’t and why

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Abstract In recent years, there has been a substantial technological improvement in pedestrian detection and numerical modeling. Yet, crowd steering is still based on constructional changes or on-site guidance with little automation. In this work, we investigate the possibility of using environmental stimuli to modify (collective) behavior or people. Three different scenarios are considered where steering method, interaction time (with the surrounding environment) and crowd density are changed. Results show that simple changes in land- and soundscape are not sufficient to modify human route choice in a familiar environment such when entering an office building. However, using supervised experiments we showed that when crowd density is sufficiently high, interaction time long enough and the context “neutral”, it is possible to “nudge” people into a more efficient motion. The outcomes of this work may help in the development of steering systems to be used in sparse crowds with minimal constructional intervention at the scope to reduce congestion and delay the occurrence of dangerous situations.

Keywords: crowd steering, nudging, collective interactions, crowd control, guidance

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1 Introduction

In recent years, considerable advances have been made in the detection, analysis and modeling of crowd dynamics and behavior [8]. Images obtained from cameras are now commonly analyzed using machine learning and computer vision techniques to extract information such as the number of people, but also trajectories and, in some cases, even their identities [1]. In addition, mobility data can be collected by exploiting the connectivity of mobile phones over multiple scales, ranging from the building level (BLE or WiFi may be used for this purpose) up to a city level (carriers know the total number of devices connected to a specific antenna). Similarly, crowd simulation has improved both in accuracy and performance. Pedestrian models are getting overly accurate and can reproduce with sufficient detail an increasing number of supervised experiments [14, 16]. Also, commercial simulators are being increasingly used by practitioners and their computing speed is increasing due to better algorithms and more powerful computers.

However, attempts aimed at influencing crowd motion are still mostly focused on constructional modifications or staff guidance. But constructional changes are costly and generally intended for final fixed layouts. Hence, such an approach is suitable in case crowd motion is consistently judged as risky in a specific area or there are enough resources to proceed with this strategy. On the other hand, staff guidance relies on the capability of the people and the organization involved in it and, ultimately, whether it is implemented or not. Whenever there is an organization managing a facility or organizing an event usually guidance is provided and effective. However, public spaces having no clearly-defined supervising authority are often left unguided, putting crowds at risk should an unexpected situation occur.

Considering the technological means available nowadays and the limitations in current steering practices, it would be therefore necessary to develop methods to steer crowds dynamically by making use of (real-time) collected data. This is already done by using automated audio messaging adapting to crowd conditions, but, in this work, we wish to focus on a non-invasive approach potentially influencing collective behavior without substantial intervention. Clearly, such an approach will not work in critical conditions (specifically for very dense crowds) where enforced instructions can only work, but it can nonetheless be effective in smoothing pedestrian motion in low-density situations, thus preventing or delaying the occurrence of congestion.

Specifically, we will study whether a modification of the environment may trigger a change in human behavior and under which conditions it can achieve the highest efficacy.

[1] Obtaining the *personal* identity is typically restricted by privacy regulations, but an *anonymous* identity may be used, for example, to track a person continuously through multiple cameras.

2 Related works

Although research on non-invasive crowd steering is an emerging topic and only few studies can be found in the literature, there are nonetheless existing attempts to tackle the subject and some related works are worth being reviewed.

Light has been known to affect people's behavior in public spaces. Ingi et al. [11] note that people's route choice during daytime is different from nighttime. Also, human mobility is affected by lighting conditions, in particular walking speed, gait characteristics and use of the walkway space. Corbetta et al. [2] employed an "arrow-like stimulus" to affect route choice of pedestrians combining light and visual information. They found that people are more likely to walk in the direction indicated by an arrow, even when there is no specific instruction in doing so.

In our previous works, we also studied how people's decision making can be affected by information provided in different forms and depending on the degree of compliance [9, 5]. However, our investigation was performed through supervised experiments or using simulation, making contextualization of the outcomes limited to laboratory conditions.

Sound has been also commonly employed to influence walking behavior of pedestrians. Yanagisawa et al. [15] showed that rhythm can help increase walking speed under crowded conditions, although their experiment was limited to single file movement and performed in a supervised setting. The effect of music was investigated in an ecological context by Meng et al. [12] showing that people walk faster when no music is played. Finally, sound was actively used by Senan et al. [13] to influence the motion of people. The authors observed that people prefer to walk in quiet areas moving away from sounds which the authors used in an attempt to steer pedestrians.

In contrast to light and sound, the effect of color is however little or not investigated in the frame of crowd and pedestrian motion. Nonetheless, the work by Costa et al. [3] may help understand about the role it plays on humans over long time periods. The authors compared the perception of people living in a facility with rooms of different colors. They found that students living in a blue environment found it easier to study, especially compared to those living in a red environment. Green and yellow achieved similar and intermediate performance in regard to study activity. Costa et al. also found that people would eventually adapt to the environment thus minimizing potential effects on their perception.

Finally, Furukawa et al. [10] employed an "optical illusion" to influence walking direction of individuals. When walking over the "optical sheet" developed by the authors, as one moves forward, stripes appear to be moving from left to right thus influencing people to steer right. In their study, Furukawa et al. showed that people indeed tend to move toward the right helping to reduce frontal collisions that would occur without the use of their optical sheet. However, the sheet was only tested using individuals in low-density conditions, making it questionable whether the same effect could be achieved in denser crowds when visibility of the floor is drastically reduced.

3 Experiments and results

To study how the environment affects people's behavior and whether it can be used to steer them, three different experiments are considered. Below, each experiment is described and results briefly presented. In the following section(s), the three experiments will be compared to discuss potential and limitations of the non-invasive steering approach studied here.

3.1 Transit door

In the first experiment, we tried to steer people toward a particular door in a building where two are available to enter/leave, as illustrated in Fig. 1. Different combinations of ground colors were changed, particular sounds were played upon entrance/exit using directional speakers, light intensity was modified in one location and LED displays were employed to guide people toward a particular door.

LiDAR sensors were installed to count the number of people transiting through both doors in and out. Baseline condition (without steering) was collected over 53 days. Experiments using color, sound, light and LED display were performed for a duration of 32, 41, 37 and 39 days respectively [2].

Results (presented in Fig. 2) indicate that no solution was particularly effective in changing people's behavior in regard to door selection (or use). This could be explained considering that people are routine users of the facility (a university

Fig. 1 Location used to test the effect of environmental changes in regard to entrance selection. The picture was taken when the LED display was tested trying to move people to the right door. When testing colors, mat color was changed from the default green seen in the picture to black (left) and red (right). For acoustic steering, directional speakers (one seen on top-right) were used to play a sound when people transited through the left door (a different sound was used for entry and exit). Lighting intensity was increased on the right side to test the effect of illumination. Intuitively all methods should steer people to the right (with the possible exception of color).

[2] Data were collected during working days since doors are locked on holidays and entrance is only possible on the right using an identification card.

building). According to the "place script" theory [4] people follow a specific script, i.e., coded behavioral rules associated with a specific place which are hard to change (even in case of disasters). Thus, changing behavior of individuals in a familiar context is a very difficult task.

3.2 Crosswalk-type motion

In the second type of experiment, we observed two groups of 27 people passing in a mock-up corridor from opposite directions (a situation similar to a crosswalk). Starting density for each group was slightly less than 1 person per m^2 (thus the density reached in the middle would be around 2 people/m^2). To influence people's behavior, a special optical sheet was set on the ground (see Fig. 3).

When walking over the sheet, as one moves forward, stripes appear to be moving from left to right, potentially nudging both groups to move to the right and help in the formation of lanes. The experiment was repeated five times and collective motion of the crowd was compared with the baseline condition without an optical sheet. Several quantities helpful in the analysis of bidirectional flows were used [7], but the preliminary analysis showed no clear steering efficacy when using the optical sheet. This result can be explained considering the short interaction time (less than 10 seconds), limiting the capability to influence overall behavior.

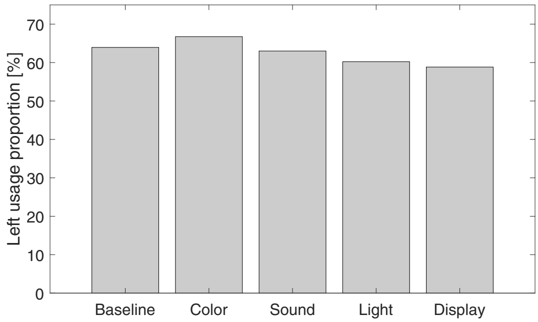

Fig. 2 Percentage of people using the left entrance depending on the steering method. Methods are provided in order of execution, showing a slowly decreasing trend. As a term of comparison, it should be noted that even without steering stimuli, the usage ratio fluctuates by around 5–10% over one month (the period of data collection).

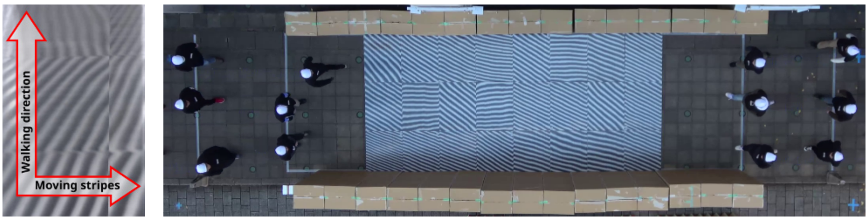

Fig. 3 Left: Working principle of the optical sheet, aiming to induce a turn to the right side. Right: Experimental setup used to check capabilities of the optical sheet in improving the smoothness in a bidirectional flow.

3.3 Continuous bidirectional motion

The third experiment is conceptually similar to what presented earlier but lasted longer in time, thus allowing us to verify whether time is indeed a limitation as speculated above. Specifically, an oval course which included two straight sections was created so that people could continuously walk in a bidirectional configuration (see Fig. 4). The straight sections, 9 m in length, were designed to allow people moving horizontally and minimizing the turning effect. The optical sheet was evenly divided into both straight sections, thus creating a "steering" area of around 4 m on each side.

Half of the people had to walk in the clockwise direction and half in the opposite sense. Each trial lasted about two minutes and three repetitions were performed for the condition with and without an optical sheet (the latter representing the baseline). The analysis focused on the straight sections where speed and density were computed. This time, the optical sheet was found effective in making the crowd faster and facilitating self-organization. More importantly, as shown in Fig. 4, the effect was stronger at higher densities, showing the importance of collective interactions.

4 Summary and discussion

In this section, we would like to compare the results from the experiments presented above and discuss the implications in regard to crowd steering. Table 1 briefly summarizes experimental conditions, steering methods and efficacy in modifying the (collective) behavior of people.

As already discussed, only the experiments in which people moved under medium densities for a comparatively long time were effective in achieving a steering effect. Similar results were also found in experiments with animals, somehow confirming the importance of in-swarm (in-group) interactions in strengthening the effect of external stimuli [6]. In this sense, we should stress on the non-linear nature of collective behavior, i.e. the capability to affect crowds is not linear with their size.

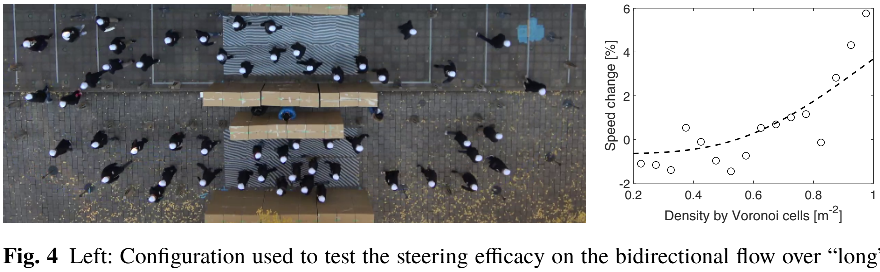

Fig. 4 Left: Configuration used to test the steering efficacy on the bidirectional flow over "long" time periods. Right: Change in average speed against the baseline condition (without optical sheet) for different densities. Only the straight sections are considered in this analysis. Each dot is computed for a density bin of 0.05 m^{-2}.

Table 1 Schematic comparison of the experiments considered in this work

Experiment	Transit door	Crosswalk-type motion	Continuous motion
Stimulus time	Very short	Short	Long
Crowd density	Very low (individuals)	Medium to high	Low to medium
Steering method(s)	Several stimuli tested	Optical illusion	Optical illusion
Steering efficacy	Low or negligible	Low or negligible	Moderate

This translates into a smoother motion when conditions are favorable, but could easily worsen when control is missing or inappropriate.

Overall, our work shows that "a sizeable number of people; at a specific location; for a measurable time period; with common goals; and displaying common behaviors" is a condition needed for the "nudge" to be effective; indirectly validating the definition of crowd often employed in psychological studies [1, 8].

5 Conclusions

In this work, we have discussed the possibility of influencing human behavior using environmental interventions aimed at "nudging" people into choosing a particular door or moving in a specific direction. Both steering approach and crowd condition were studied. To identify feasible environmental stimuli we tested whether color, light, sound or visual information could work in getting people to use a specific door when entering a building. But no solution was found particularly effective at the scope, possibly due to the fact that users are familiar with the location and have developed behavioral rules in relation to the place ("place scripts"). On the other side, an optical illusion (the so-called optical sheet) was found effective in making crowds more self-organized, but only in the condition where density was sufficiently high and people could interact with the environment long enough.

Our work shows the challenges and the opportunities related to dynamic crowd steering. From one side we showed that relatively simple methods could have at least some efficacy under favorable conditions. On the other hand, we also showed that, in most of the cases, a "slight" modification of the environment may not be sufficient. But, even if ineffective, environmental stimuli did not worsen collective motion, thus being a valid candidate to help improve crowd motion in low-risk scenarios to reduce the occurrence of dangerous situations or at least delay them to enable a sufficient preparedness.

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