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研究課題名（和文）Development of a system to steer crowds through imperceptible modifications of the surrounding environment

研究課題名（英文）Development of a system to steer crowds through imperceptible modifications of the surrounding environment

研究代表者

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研究成果の概要（和文）：本研究は、環境刺激を用いて群集の動きに影響を与えることで群集全体を最適に誘導することが可能かどうかを解明することを目的としている。自己組織化が出現するには人と人、また人と環境の間の相互作用を可能にする密度と十分な時間が必要であるため、被験者が慣れ親しんだ環境の中で実証実験をしようと試みたが、十分な結果が得られなかった。一方で動物の群れを使った実験では、制御が機能する条件についていくつかの知見を得ることができた。その測定結果をもとに数値シミュレーションを行い、中程度の密度であれば最適な制御ができることがわかった。さらに過去の群集実験を解析したところ、密度に関して人間でも同様の傾向が確認できた。

研究成果の学術的意義や社会的意義
This research has helped showing that unconventional ways to steer people are viable. In addition, it also showed that by working on areas of research which are different and complementary (human crowds and animal swarms here) can help to create a robust theory and formulate more likely hypotheses.

研究成果の概要（英文）：This research aimed to understand whether it is possible to influence crowd motion by using minor environmental stimuli (light, color, etc.). It has been found that, in a limited extent, such an approach is possible. However, both crowd density and interaction time (with the environment) play an important role. Furthermore, a density which allows interactions between people is needed and time must be long enough to allow the emergence of self-organization.
The conclusions could be obtained through several experiments and by examining old data through intuitions found while working on this research. An experiment unsuccessfully attempted to steer individuals in a familiar environment. But, experiments with animals swarms helped providing some hints on conditions where steering may work. Results showed that at medium densities optimal steering found. By revisiting old experiments it was hinted that, in controlled conditions, interaction between people is needed for an effective steering.

研究分野：complex systems

キーワード：crowd　swarm　collective behavior　emergent behavior　complex systems　environment　nudge

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１．研究開始当初の背景

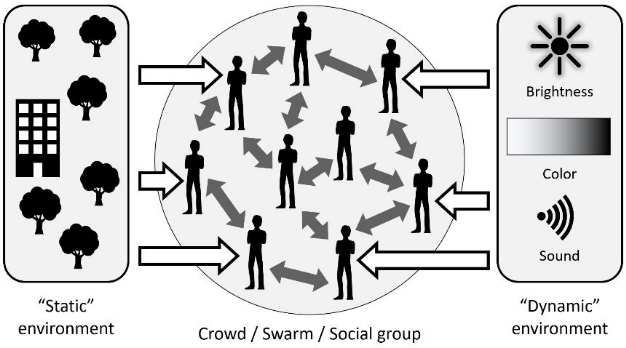

Fig. 1: Schematic representation of interactions with the environment.

People, animals, and any sort of animated things are subject to the effect of the surrounding environment. In the case of social animals (with humans belonging to this category), the interaction is quite complex because individuals get affected by external stimuli and the modification in their behavior is further related to the interaction with others. For example, a single individual may notice some change in the surrounding environment and start behaving differently. But whether other people/animals in the group will start adapting that behavior depends on the internal dynamics within the crowd/swarm.
In general, we are under the influence of two types of environments: a "static" and a "dynamic" one. The static environment can be seen as something not changing or changing very slowly. For example, the landscape or the infrastructure in a city will change over years and behavioral modifications may only appear after long periods. Also, static environment is hard to modify and usually it takes large efforts to perform some changes. The dynamic environment can be seen as something changing in short time, typically seconds to hours. But something changing daily can be also regarded as a dynamic environment depending on the context. Brightness, sound, or color are easy to modify and naturally change from morning to night. For instance, a light could be used to make a dark location brighter or sound can be used to attract people to a shop. Similarly, colors are known to affect our cognition. Blue or green tend to improve concentration and people generally feels more relaxed in an environment with blue or green colors. Red is usually perceived as a sign of warning or may lead to excitation.
The general principles presented in this introductory text are also schematically visualized in Fig. 1 provided above.

２．研究の目的

This research aimed at finding out whether it is possible to modify the dynamic environment to steer social systems, namely crowds of people or animal swarms. Although the main and final aim was to induce specific behaviors in human crowds, I also decided to study animals showing a collective behavior to help identifying viable solutions and outline a theorical foundation which could help understanding human crowds too. In particular, the research aimed to investigate light, color and sounds to determine which solution is the most promising and understand under which condition a specific solution may or may not work.

３．研究の方法

Most of this research was originally intended to be carried out through controlled experiments using human participants and partially by studying the collective behavior of "soldier crabs," a peculiar species of crab moving in large swarms. However, restrictions imposed by the COVID-19 pandemic made the execution of crowd experiments very difficult, especially considering the conditions sought in the frame of this research. Consequently, alternative solutions were considered which ultimately allowed investigating the research questions without the need for controlled experiments with human participants. Long-term data collection in an ecological setting was finally used, with surveys and VR (Virtual Reality) additionally employed as research methods (details on the latter approaches are not discussed here due to the marginal relevance, see list of publications). The collective behavior of crabs was studied by performing laboratory experiments in a facility close to their natural habitat (Iriomote Station, University of the Ryukyus, Okinawa prefecture).

４．研究成果

In the frame of this research, several studies were performed with the aim to elucidate the research questions presented above and reach the goals set at the start. The different studies are presented below with the most important outcomes summarized in each section.

<u>Route selection under the influence of environmental stimuli</u>

To study whether color, light, sound, or visual information can influence decision making in people within a walking environment, a two-years experiment was conducted on campus. The location selected for the experiment was an entrance hall having two doors being completely equal in their function (see Fig. 2). In other words, people could choice to use the door on the right or the one on the left to enter the building. A LiDAR sensor was set on each door to count the number of people passing through each location. The accuracy of the sensor was evaluated in a similar context (but having a much larger number of people transiting) and was assessed as being above 95%.

Fig. 2: Left and right door and environmental stimuli used to influence people in choosing a particular door. In this image all steering approaching are shown together, but in the experiment were tested individually.

Over the two years period during which the experiment was carried out, the appearance of or the sound at each door was changed to check whether people would increase the use of a door instead of the other. Specifically, the mat color was changed from the standard green to gray/red, a sound was played only on one door/direction, a light was used in one location to makes it brighter, and a display was used hinting to a specific door (see also Fig. 2).

Each experiment making use of a specific environmental stimulus lasted around 30 days (only working days are counted since transit is limited to a single door during holidays). The full experiment was divided into five phases. First, a baseline was taken without any steering method in place (baseline 1). Next (test 1), the four steering solutions were tested trying to influence people walking in toward a specific door. After this phase, a new baseline was taken again without steering mechanisms in place (baseline 2). Next (test 2), the experiment was repeated by inversing the steering strategy taken in test 1. For example, if a light was used on the right in test 1, the same light would be used in the left in test 2. Finally, a new baseline was taken once more (baseline 3).

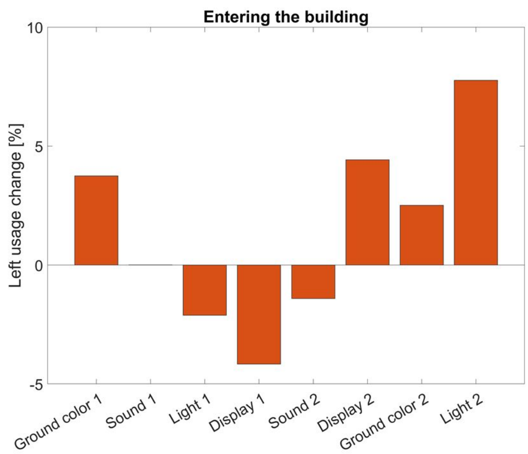

Fig. 3: Change in the use of the left entrance when compared to the baseline. Results for the test phase 1 are compared with baseline 1 and those for test phase 2 with the second baseline.

This methodology allows to make a difference between random fluctuations and effective steering solutions. For example, if light was effective in steering people to the right in test 1 and later managed to move people to the left in test 2, it can be concluded that it is an effective approach. If, however, people get steered in the same direction despite the opposite influence, the efficacy of that solution is questionable.

Because the entrance hall is surrounded by glasses, people moving toward the building may notice the changes in color, lighting, or directions before entering the building. On the other side, door selection when leaving the facility was very likely influenced by the constructional layout and therefore probably biased by limited vision or related aspects. For these reasons, results (presented in Fig. 3) focused on door selection when entering the building. In general, it can be concluded that light is the most effective approach to guide people, partially in line to some evidence in the literature. The high increase shown in test 2 for light may be partially explained considering that the left door being lighted is on a corner location. Therefore, people could notice it from further away compared to the case of the right door. The information display was also found effective, although my research focused on more "non-invasive" intervention and therefore the moving arrow represents a borderline-solution in that regard. Color and sound were however found non-effective. In the case of color, it is possible that the modification was too small to be noticed by people, especially before entering the facility. In the case of sound, it is possible that, because people would hear it only upon entrance, the effect would be limited to frequent users which represent a significant proportion but not the overall usership.

Environmental stimulation to affect the behavior of "dense" crowds

The experiment described above tested the possibility to influence route selection through simple environmental modifications in a context with very low crowd density. Typically, even in the busiest days, only a few hundred people would enter the building. Considering that the aim of this project was to steer people in public facilities like train station, airports, or shopping mall, it is also important to understand whether a similar strategy would work under higher densities.

Although supervised experiments were not possible or very difficult to carry out in the period of this research (due to the restrictions caused by COVID-19), data from preliminary experiments was available for analysis. At the end of 2019 a set of experiments was organized to see whether it was possible to improve lane formation in a corridor-like setup using a special method dubbed "optical sheet". The optical sheet is a special type of flooring showing optical illusions when people walk over it. In detail, people walking over the optical sheet sees stripes moving to the right, thus inducing a deflection in the same direction. Experiments were carried out in 2019 to check whether the optical sheet would work also in crowded conditions and if it would be a viable solution to enhance lane formation and thus reduce congestion in corridors.

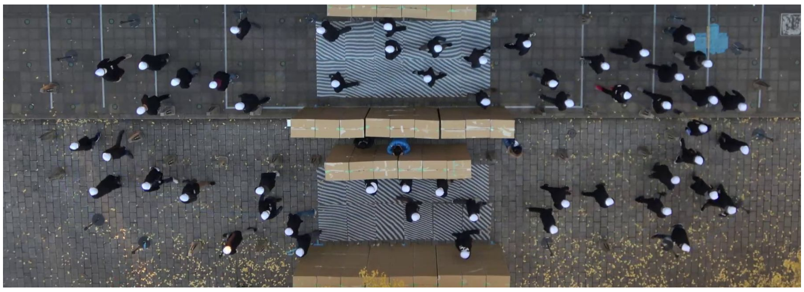

Fig. 4: Experiment designed to test the efficacy of the optical sheet to enhance lane formation and improve pedestrian flow in the frame of a bidirectional flow. The optical sheet is employed in the straight sections.

The layout of the experiments is presented in Fig. 4.: a round course with straight sections was created and people had to walk in opposite directions for two minutes, thus creating lanes moving clockwise and counterclockwise.

The optical illusion created by the optical sheet can be genuinely considered a steering mechanism intended to modify human motion and behavior. For this reason, the data collected from the experiments were analyzed to judge whether results like what obtained in sparse crowds could be obtained under higher densities. The density and the speed of pedestrians in the straight sections was analyzed using the Voronoi method, which allows to define individual values for both quantities. Speed in the condition with the optical sheet was compared with the condition without it (taken as baseline). The results presented in Fig. 5 shows that the increase in speed brought by the presence of the optical sheet is higher when the density is high. This could be explained considering that collective interactions between people are stronger at higher density and thus even a weak influence may become strong enough to change overall motion.

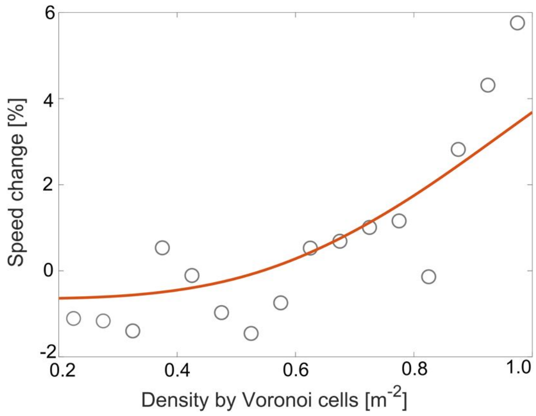

Fig. 5: Speed change when using the optical sheet compared to the baseline condition with the normal floor. Chage in speed is higher at moderate densities.

Influence of moving light in the dynamics of animal swarms

The experiments performed on swarm of crabs allowed to provide further evidence that there is indeed a link between steering effectiveness and density. Of course, care is always needed when comparing results obtained with animals with those obtained for human. But when phenomena occurring in animal swarms are studied considering the mechanisms and from a purely theoretical perspective, it is possible to translate at least some finding to human behavior in crowds. Under this perspective, the experiments performed with crabs should not be seen as a method to validate results obtained for humans, but rather to test some hypotheses and help outlining more solid research directions. Also, the study of animal collective behavior has always been a source of inspiration when developing numerical models to represent crowd motion and the behavior of ants, for example, has inspired some rules employed in crowd simulation which proved to be effective.

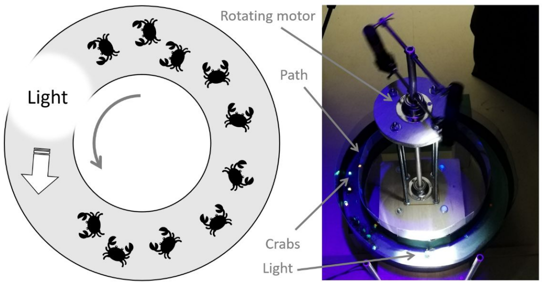

Fig. 6: The experimental equipment used to test how a moving light affect collective motion of soldier crabs. An ultraviolet light and special markers are used to see the motion of crabs in darkness.

Soldier crabs were used to test changes in collective motion under the influence of external stimuli for several reasons. First, soldier crabs are known to form large swarms composed of thousands of individuals and their social structure and individual behavior is rather simple (unlike bees which has a very complex hierarchical structure). Second, the motion of soldier crabs is almost entirely bidimensional unlike school of fishes or swarm of birds which move in a tridimensional space. This characteristic makes them closer to human motion. Third, soldier crabs are easy to catch in large number and several experiments can be performed in a short time using a limited amount of space. In contrast, observation of swarms composed of larger animals is typically limited to drone shooting making the task more complex. Lastly, soldier crabs are known to be reactive to light and therefore it is possible to use this stimulus to affect their (collective) behavior.

The experiment performed on soldier crabs is presented in Fig. 6. A circular course was created which limited crab dynamic to a unidimensional motion (or at least making such an approximation possible, with some limitations). Further, a light was turned around the course to influence crabs in moving in the same direction of the light. Although obtaining a precise value is difficult, it has been estimated that, for individual crabs, the light is effective to induce a movement in a specific direction to an extent of 5%. However, the experiments were performed by varying the number of crabs in the course. The cases with 3, 10, and 30 crabs was tested. In addition, based on empirical observations, a simulation model was also developed to reproduce the motion seen in crabs. Outcomes from the simulation model was compared with experimental results to validate it, showing a generally good agreement. With the validated (and calibrated) simulation model a more detailed investigation was performed on the effect of the external stimulus to the overall behavior of the swarm. Results presented in Fig. 7 shows that the low steering effectiveness observed on single individuals is strengthened as the swarm gets larger and a maximum of around 35% is reached a medium density. At high densities, crabs already synchronize to move in the same direction without the need of an external stimulus and thus the effect becomes negligible.

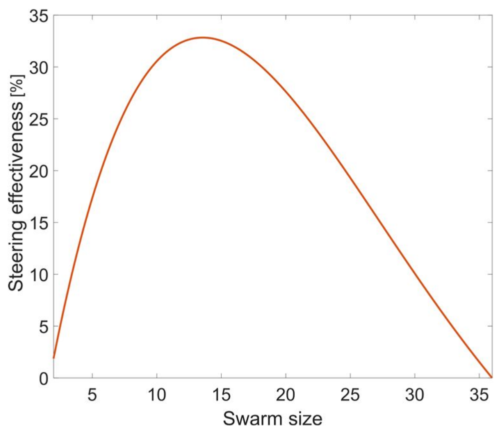

Fig. 7: Steering effectiveness in relation to swarm size. Results were obtained by numerical simulation, but are in line with empirical observations.

This experiment partially explains, at least from a theoretical perspective, the outcomes presented above for human crowds and hint to the fact that a low steering effectiveness is not necessarily an issue since interactions among individuals may contribute in increasing the effect.

５．主な発表論文等

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2．論文標題	**5．発行年**
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3．雑誌名	**6．最初と最後の頁**
Safety Science	105455～105455
掲載論文のDOI（デジタルオブジェクト識別子）	**査読の有無**
10.1016/j.ssci.2021.105455	有
オープンアクセス	**国際共著**
オープンアクセスではない、又はオープンアクセスが困難	該当する

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10.1016/j.physa.2020.125347	有
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3．雑誌名	**6．最初と最後の頁**
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10.1016/j.ssci.2020.105013	有
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3．雑誌名	**6．最初と最後の頁**
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掲載論文のDOI（デジタルオブジェクト識別子）	**査読の有無**
10.1038/s41598-020-72733-w	有
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掲載論文のDOI（デジタルオブジェクト識別子） 10.1098/rsos.201465	査読の有無 有
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掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.ssci.2022.105969	査読の有無 有
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掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.ssci.2023.106174	査読の有無 有
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１．発表者名
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４．発表年 2021年

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関