Being Part of the Swarm: Experiencing Human-Swarm Interaction with VR and Tangible Robots

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ABSTRACT

A swarm is the coherent behavior that emerges ubiquitously from simple interaction rules between self-organized agents. Understanding swarms is of utmost importance in many disciplines and jobs, but hard to teach due to the elusive nature of the phenomenon, which requires to observe events at different scales (i.e., from different perspectives) and to understand the links between them. In this article, we investigate the potential of combining a swarm of tangible, haptic-enabled robots with Virtual Reality, to provide a user with multiple perspectives and interaction modalities on the swarm, ultimately aiming at supporting the learning of emergent behaviours. The framework we developed relies on Cellulo robots and Oculus Quest and was preliminarily evaluated in a user study involving 15 participants. Results suggests that the framework effectively allows users to experience the interaction with the swarm under different perspectives and modalities.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Virtual reality**; **Haptic devices**; **Interaction design**.

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1 INTRODUCTION

A flock of birds winging in the sky or the self-organization of social insects are emergent patterns: "macro" patterns arising from the interaction of "micro" agents. At the intersection of "Swarm Intelligence" and "Learning and Education" lies an active research direction, specifically investigating the difficulty that humans have in understanding and grasping complex dynamic systems [3] known as a "deterministic-centralized mindset" (DC mindset).

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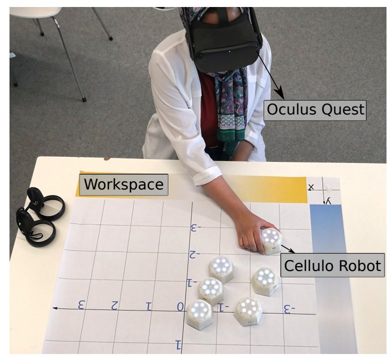

Figure 1: Activity setup

Empirical studies suggest that Agent-Based Models (ABMs) are effective in helping students overcome the "DC mindset" [3]. At the same time, many studies in the field of Robotics for Learning shows that tangible interaction with robots is beneficial for learning, e.g mathematical concepts [2]. Among the robots designed for educational purposes, Cellulo (shown in Figure 1) is one of the few specifically conceived to be used in a swarm [4]. Cellulo robots are low-cost, small-sized tangible mobile robots that can interchangeably move and be moved on printed sheets of paper covered with a dot pattern that enables fast and accurate localization.

Learning activities with robots usually assume that the learner interacts with the robots while keeping an outsider perspective (e.g., as shown in Figure 1), thus losing the possibility of experiencing being a part of the swarm but better grasping the behaviour of the swarm as a whole. Indeed, local perception, i.e. taking the point of view of the agent, provides a highly "immersive" environment, which is one of the design principles for high embodiment in learning environments [1], while global perception leads to apprehending the global emergent behavior.

We postulate that experiencing both perspectives is of utmost importance to gain a solid understanding of emergent behaviours, as one allows the learner to perceive local (micro) effects and the other global (macro) effects. To this end, in this article we propose to combine tangible robot swarms with Virtual Reality (VR), to enable the possibility of observing and interacting with the swarm of robots from multiple perspectives. Concretely, we outline the framework allowing us to investigate how to effectively teach the micro-macro link existing in a swarm system exhibiting an emergent behavior, and preliminarily validate the effects of experiencing the different perspectives in a pilot user study.

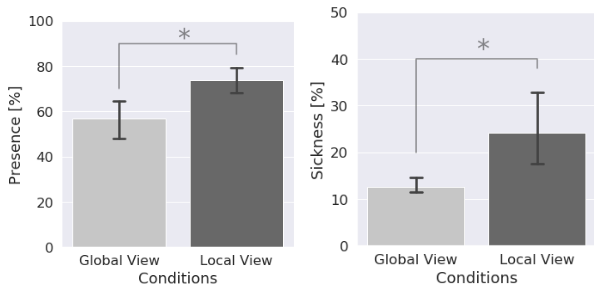

Figure 2: Presence and Sickness percentage results in different VR conditions. * indicates significance at $p < 0.01$.

2 HUMAN SWARM INTERACTION DESIGN

The framework we present relies on the Cellulo robots and the Oculus Quest VR system as its core elements, and allows for a number of settings to provide different experiences to the learner.

The setup, illustrated in Figure 1, includes: *1) The workspace*, consisting of printed sheets of paper "augmented" with a dot pattern [4]; *2) The Cellulo robots*, handheld haptic-enabled mobile robots operating within the workspace; *3) The central controller* (usually a desktop computer or a consumer-grade tablet, and in this case the Oculus Quest) running the application which contains the logic of the activity and coordinates the movements of the robots. The application was developed with the LÖVR framework , using a Lua wrapper to call the native C++ Cellulo API.

Our activity is a flocking activity, implementing the boids algorithm introduced by Reynolds and describing an approach to simulate the natural behaviour of bird-flocks, fish-schools or herds, without hard-coding each individual's path but rather by letting each agent re-arrange its course based on its current surroundings. Each agent only obeys three simple rules: (1) *Separation*: avoid collisions with nearby flock-mates, (2) *Alignment*: attempt to match the velocity of nearby flock-mates, and (3) *Cohesion*: attempt to stay close to nearby flock-mates.

Concretely, whenever the learner tangibly moves a robot, its position is updated in the central controller and used to send appropriate commands to the headset and the other robots. The framework allows for manipulating the following settings:
- *The control method*: The movement of the robot manipulated by the learner can be transposed to the headset through two different methods: (i) *absolute*: the linear movement and orientation change of the camera are the same of the Cellulo robot. In this case the headset is rigidly linked to the robot; (ii) *relative*: the linear and angular velocity of the camera are equal to the offset of the robot relative to its original position (middle of the board, and angle of 0).
- *Haptic Feedback*: The activity relies on the Cellulo robots' haptic feedback API to render force feedback to the learner's hand. The feedback can either be a directional force feedback mimicking interaction with other robots, or provide different types of vibrations.

3 PILOT USER STUDY AND INITIAL RESULTS

The goal of this pilot user study is to verify whether the different perspectives identified as possibly relevant for the activity are perceived as significantly different by the user. A within-subject user study was performed, involving 15 participants aged between 22 and 59 ($M = 29.73, SD = 9.05$; 7 female and 8 male), with average self-reported experience with VR technologies ($M = 3.2, SD = 1.82$ out of seven), mostly positive ($M = 4.38, SD = 1.66$, out of seven). The pilot experiment consists of three conditions: (1) Physical condition: the learner controls one robot with the hand and directly perceives the swarm from a global perspective, without VR headset.
(2) VR top/bird view condition: the learner controls one robot with the hand and perceives a virtual representation of the swarm from a global perspective, through the VR headset.
(3) VR local view condition: the learner embodies the role of a Cellulo robot, controlling its movements with the hand and perceiving the world from its egocentric perspective through the VR headset.

In all conditions, the learner is asked to reach, one after the other, a set of target point on the map. While the target positions are unknown to the user, they are known to the other robots in the swarm, as target migration point. Whenever the user reaches one point, the swarm starts moving to the next one. The user therefore needs to follow the swarm to achieve the task.A haptic feedback force is given to the user as the sum of the forces generated by the three flocking rules (separation, cohesion, and alignment). This force only depends on the interaction between the robots and is thus computed the same way in all conditions.

Participants completed the three conditions in a randomized order. Upon experiencing each condition, they were asked to fill the Slater-Usoh-Steed's (SUS) presence questionnaire, the motion sickness questionnaire, and few custom questions related to the feeling of the haptic feedback. As shown in Figure 2, a Kruskal-Wallis test revealed a significantly higher sense of presence in the VR local view, compared to the VR top view ($H = 7.85, p = 0.005$). At the same time, the VR local view was found to cause significantly higher sickness than the VR top view. No significant difference was observed concerning the perception of haptic feedback.

4 CONCLUSION

We postulate that being able to experience swarm behaviours from multiple perspectives (top/local) is beneficial for learning the micro-macro link of emergent behaviour. We developed a framework allowing learners to tangibly control an agent in the swarm, a Cellulo robot, and experience different perspectives via a VR headset. In a small pilot study we verified that the perspectives we implemented are indeed perceived as different by the learner and all allow for the completion of the task. The proposed framework paves the way into designing richer learning activities, allowing users to switch roles and perspectives, experiencing either the local interaction between agents or observing the resulting emergent global behavior.

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