Swarm Robots in Education: A Review of Challenges and Opportunities

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ABSTRACT

This study reviews published scientific literature on the use of swarm robots for education purposes in the last ten years. It focuses on user studies involving robotics swarm in order to identify the potential contributions of the incorporation of swarm robots as an educational tool and insight future research. We consider here the appearance of swarm robots, the curriculum of the experimental task and the interaction modalities between learners and robots. The outcomes of the literature review are discussed in terms of their existing challenges and opportunities for guiding researchers, educators, and practitioners.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; • **Applied computing** → **Education**; • **Computer systems organization** → **Robotics**.

KEYWORDS

swarm robots, educational tool, literature review, multi-robot, learning

1 INTRODUCTION

Swarm robotics is an extension of the study of Multi-Robot Systems that exploits concepts of communication, coordination, and collaboration among a large number of robots [9]. Widespread interest in swarm robotics has increased astonishingly in recent years. Dozens of swarm platforms have emerged, focusing on hardware and software system design. There are mainly three different robots-moving on the ground, climbing vertical structures, and flying around the environment. Given their manufacturing cost and versatility, swarms are mainly made up of mobile robots (no legged robots and fewer swarm with drones). By being robust to failure and disturbances, robotics swarms offered new insights for robot research, human-robot interaction, and many other fields such as simulation of biological systems. While much research in swarm robotics focuses on the design of the robot system and its implementation, researchers have also attempted to explore a wide range of possible applications of swarm robotics, from surveillance to entertainment. A novel potential area is education. Many swarm robots have already claimed their design considerations for teaching or learning.In this paper, we present an overview of the recent research in swarm robots and multirobot systems (MRS) for education by doing a review of papers providing empirical evaluations.

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2 METHODOLOGY

Within the context of this paper, we carried out the systematic review search using the Google Scholar database. Searches were restricted to academic papers, written in English, and published between 2010 and 2020. The search string was performed on titles, abstract and keywords for conference and journal articles using: *((swarm) AND (robotic OR robotics OR robot OR robots) AND (education OR educational OR school OR children OR kids))*. We set the following criteria to select papers: (C1) The article should be four pages long or longer since short papers might not contain the necessary information about the empirical evaluation; (C2) The article presents swarm robotics in the children's education context; (C3) Articles were included only when they reported a user study featuring children participants; and (C4) It should involve the use of physical robots. It should be mentioned that the article was outside the scope if it mainly engaged in the design of swarm robots or did not revolve around specific educational activities. The search gave 165 papers, and after applying the set of criteria, there are ten articles left to analyze.

We examine the state of the art aiming to address the following research questions: 1) **Appearance**: How does swarm robots used in education look like? What are their principal features? 2) **Interaction and Outcomes**: What are the interaction modalities between learners and the swarm? What areas of the curriculum have been investigated? How many learners and robots interact together in the presented learning scenario?

3 RESULTS

Our first remark after performing the data collection of papers and the filtering to empirically evaluated learning scenario, is that the field is not so developed. Indeed, although, we found quite an extensive literature describing hardware and software of novel swarm robotics systems that targeted education, very few research actually implemented a user experiment with the goal to test their platform in educational settings and to demonstrate learning outcomes.

3.1 Appearance of the Swarm

From the ten papers selected and presenting an experimental evaluation, all of them feature a swarm composed of mobile robots. They are driven by motors and moving on the limited 2D smooth surface, like tables tops, sheets of paper or on the floor.

Table 1: List of robots found to be used as swarms in educational context. The price and size indicated are per robot. The type indicates if it seems to be a multi-robot system (MRS) with centralized control or a swarm.

Name	Price($)	Size(*mm*)	Interaction Mode	Activity Topic	Type	Number of Robots
Cellulo	136.74	75	Touch, GUI, Visual Force Feedback	Windfield Study [11], Handwriting [1, 4], Shapes [10] Symmetry [8]	MRS MRS	2 or 3 1 to 4
Micromvp	90	$80 \times 50 \times 60$	GUI	Child-Robot Theater [2]	MRS	6
Thymio	39	110	Touch, GUI, Visual	House-Hunting Bees [13]	Swarm	8
Zooids	50	$26 \times 25 \times 21$	GUI, Visual Force Feedback	Physical Game [3]	MRS	8
MSN	N/A	N/A	GUI	Dice-Pushing [6]	Swarm	2/3
Psi	N/A	108	GUI	Programming [5]	Swarm	N/A

In all the selected research work, six various types of swarm robots have been used to explore potential educational use or its performance in different learning activities. Table 1 lists out details. We notice that the number of robots in each scenario is always less than 8. Several reasons can explain this relatively low number of robots: their cost, their size and also the cognitive load and noise that can emerge from having co-located high number of robots in the swarm. In all user studies related to Micromvp, Thymio, Zooids, MSN and Psi, children interacted with swarm robots by controlling their behaviors. Comparably, Cellulo had more types, like in the handwriting activity [1] in which children can have their hand driven by each robot.

3.2 Roles, Tasks and Outcomes

We define two types of educational role for the swarm: symbolic or literal. In the symbolic role, the swarm is used to illustrate concepts not related to swarm robotics (i.e. handwriting [1] or theater [2]). In the literal role, the swarm represents an actual swarm that can be of physical [11] or biological matter [13]. In terms of tasks used by the swarm, researchers have mainly be using collective decision [13], aggregation and coverage [5]. These swarm behaviours are simple to understand and either simulating physics or bio-inspired phenomenon.

In order to demonstrate the worth of using swarm robots for learning to educators, it is crucial to investigate what it is that swarm robots can additionally offer for learners. From the reported results in our paper collection, it is not possible to derive a generic conclusion on the effect of swarm in education. Activities presented in the paper collection target a wide range of curricular fields. Many of these papers target STEAM areas such as biology [13], meteorology [11], arts [2], geometry [8] and programming [3]. Often the learning activity seems to be turn into a game in which the robot agents behave according to certain rules that the students need to understand [3, 11, 13]. Several studies took place in festivals, as extra curricular activity or during open door events. While these events usually gathered more participants (28 to 85 participants) they often don't allow for cognitive evaluation, and authors rely on acceptability questionnaires. Studies included in this review have reported positive outcomes in terms of acceptability but don't demonstrate a positive learning gain against other form of instruction.

4 DISCUSSION AND CONCLUSION

In this paper we presented a short review of empirical evaluation of swarm robots in education. Some limitations should be highlighted: 1) Our definition of swarm robots is broad and include multi-robot systems (MRS) with what it seems to be a centralized controller; 2) Our manual filtering and labeling of papers could have been prone to errors. Having said that, we found some interesting new insights for the investigation of swarm (or MRS) in educational context.

Our review showed that swarm robots used in most above applications are *homogeneous*. Heterogeneous robot systems have rarely been explored, and how to arrange such swarm activities is an open question. Nearly all activities aimed to enhance children's understanding of biological, physical or engineering concepts. Real-time collective behaviors of swarm robots are challenging; in most cases, researchers do not take advantage of the swarm feature, but more of a multi-robot system. Lots of paper used tangible interaction; other modality, such as sound output [13] could further used to enrich the interaction.

Usability and deployability are crucial for acceptability of robots in education [7]. In the case of robotic swarms and MRS, the size of robots should take into account its interactivity, as well as the number of it that can hold in a limited space is really limiting constraint. Another challenge is the unit cost of robots that can refrain the use of a bigger swarm. To tackle these challenges, teachers could be involved in the customization of the curriculum and in guiding children in swarm robots learning activities. Novel user interfaces allowing editing of pedagogical scenarios targeting swarm robots in education would need to be developed [12].Besides, similarly to embodied social agents, swarm in education would have to demonstrate the advantage of embodied interaction for learning outcomes. As the goal of educational swarm robots is to display legible and meaningful actions to convey information, we can imagine that development of research in the field would lead to the design of novel swarm algorithms maximising legibility of global action over task completion time.

To conclude, the field of educational swarm robots is at its infancy. This review highlighted some challenges that will need to be tackled in order to reach a useful impact. These challenges would be both technical and usability regarding the integration of technology in the educators' practice.

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