TOWARDS PRACTICAL APPLICATION OF SWARM ROBOTICS:
OVERVIEW OF SWARM TASKS

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Abstract. Swarm robotics is a relatively new research area inspired from biological systems such as ant or bee colonies. It composes a system consisting of many small robots with simple control mechanisms capable of achieving complex collective behaviours on the swarm level such as aggregation, pattern formation and collective transportation to name a few. However, more research is still required to apply swarm robotics in practice. Within the scope of our knowledge at the moment there are no swarm robotics applications for real-life problems. The current research tends to solve specific tasks in controlled laboratory environments. In this paper we survey the existing works on swarm robotics and their applications and also analyse the potential of their applicability to solve real-life problems.

Keywords: swarm robotics, overview, practical applications, tasks of the swarm.

Introduction

Swarm robotics is a branch of multi-robot systems that embrace the ideas of biological swarms such as insect colonies, flocks of birds and schools of fish. The term “swarm” is used to refer “a large group of locally interacting individuals with common goals” [1]. Swarm robotics systems as well as their biological counterparts consist of many individuals exhibiting simple behaviors. While executing these simple behaviors, individuals are capable of producing complex collective behaviors on the swarm level that no individual is able to achieve alone. Ant colony can be viewed as an example – a single ant has limited sensing capabilities and relies only on local information, but working together the colony is able to perform rather complex foraging, construction and transportation tasks.

Swarm robotics systems are characterized by simplicity of individuals, local sensing and communication capabilities, parallelism in task execution, robustness, scalability, heterogeneousness, flexibility and decentralized control [2]. Some researchers (e.g., in [3]) conclude that even simple passive entities (such as rice) are able to produce interesting behaviors (i.e., form patterns) if stimulated by external force. To analyze potential capabilities of robot swarms, swarm robotics has been studied in the context of producing different collective behaviors to solve tasks such as: aggregation [4], pattern formation [5], self-assembly and morphogenesis [6], object clustering, assembling and construction [7], collective search and exploration [8; 9], coordinated motion [10], collective transportation [11; 12], self-deployment [13], foraging [14] and others.

The analysis of the results of these studies shows that robot swarms are capable to solve these tasks satisfactory in controlled laboratory environments, at the same time there is no evidence of applying swarm robotics to solve real-life problems. The purpose of this paper is to take a step closer to bridging the gap between research in swarm robotics and their practical applications. We analyze the existing approaches in the field of swarm robotics and discuss their result applicability for solving real-life problems by outlining tasks that have been studied in the context of swarm robotics systems and analysing their potential practical applications. We also discuss how the tasks could be combined to achieve desirable practical results.

Tasks of the swarm

The potential applications of swarm robotics range from surveillance operations [15] to mine disarming in hostile environments [16]. We believe it is essential to identify the tasks that can be solved using swarm robotics. According to recent literature reviews [1; 2; 17-19], swarm robotics has been studied in the context of the following tasks:

Aggregation deals with spatially grouping all robots together in a region of the environment. Aggregation is used to get robots in a swarm sufficiently close together and can be used as a starting point for performing some additional tasks, such as communication with limited range. Aggregation near points of interest can be viewed as the first step of more complex tasks, such as collective
transportation where objects of interest need to be transported by several robots. Research in aggregation include [4; 20; 21].

Pattern formation considers robot deployment into environment forming some sort of geometric pattern such as a circle, a square, a line, a star, a lattice, etc. Pattern formation is useful in preserving communication range and helping to overcome environment limitations (e.g., forming a chain to pass a narrow passage). Pattern formation is studied in [5; 22].

In self-assembly robots physically connect to each other to form a particular structure. Self-assembly is used to increase the pulling power of the robots, provide stability to the robot swarm while moving on rough terrains, form a connected structure to guide other swarm robots, assemble structures used to overcome holes that a single robot would fall into and to combine capabilities of heterogeneous robots. Self-assembly is studied in several large-scale research projects such as SWARM-BOTS [4; 5], Symbion [6], Swarmanoid [23] and Replicator [24].

Object clustering and assembling involves picking up objects that are spread across the environment and clustering or assembling them in specific regions. There is no connection among objects in a cluster while objects are physically linked together in assembling tasks. The techniques of clustering and assembling are used in collective construction to produce 2D and 3D structures (such as walls) [25-27].

In swarm-guided navigation robots of the swarm are navigated by other members of the swarm. Robots are not aware of their actual location or the location of the target. Instead, the swarm is guided by directions supplied by previously deployed robots forming a communication relay. Examples include robots forming a chain from a prey to the nest and indicating directions to other robots in a foraging task [28], navigation via exchanging navigation messages [29] and flying robots navigating wheeled robots [30].

Mapping is the process of obtaining a map of the environment using a robot swarm. Determining the position of robots or targets in the environment is called localization. Mapping and localization is usually addressed together since it is essential to know the positions of robots to obtain a map. Mapping has dual purpose. First, it is used to map previously unknown (or even hazardous) environments; second, it assists the navigation of robots reducing the need for beacons and swarm-guided navigation techniques. Mapping and localization is studied in [31-33].

Self-deployment addresses the problem of deploying robots (disperse them) in the environment by covering as much space as possible. This task is also known as area coverage task. The self-deployment problem is known to indirectly solve the mapping problem [18]. Potential applications of self-deployment include surveillance and security. Self-deployment is discussed in [34] and [35].

Coordinated motion task represents moving while preserving formation and is also referred to as flocking. This is useful in applications involving movement groups of robots since preserving formation allows avoiding collisions among robots and serves as a navigation mechanism. Coordinated motion is investigated in [10; 36; 37].

The aim of obstacle avoidance is to prevent robot collisions with environment and with each other. Path planning is used to navigate robots in the environment while avoiding obstacles. The research results dealing with path planning and obstacle avoidance are included in articles [38-41]. Obstacle avoidance is also coupled with coordinated motion in [42; 43].

Collective transportation task involves robot cooperation to collectively transport an object, given that the transportation of single object requires more than one robot. Research in collective transport is divided into pushing [44], grasping [45] and caging [46].

In Consensus achievement and collective decision making robots must agree on a common decision such as which path to take or which target to follow. Agreement is achieved by either direct communication via exchanging messages (e.g., voting) or indirect communication using local sensor information (e.g., follow nearest robot). Consensus achievement is examined in [47-49]. Potential applications include scenarios where a collective decision is necessary to successfully accomplish the task at hand.

In foraging task robots must find preys and bring them to the nest. This type of task is also known as prey retrieval or gathering task. Foraging can be viewed as a subset of object clustering where
robots cluster prey at the nest. Research in foraging is described in [16; 50-52]. The potential applications of foraging in a real-world scenario are search and rescue operations.

In *cooperative hole avoidance* tasks robots must travel through environment while avoiding holes. Hole avoidance for a single robot is viewed as a variant of obstacle avoidance task with holes representing the obstacles. However, robots in a swarm can be connected together while moving in formation, making this problem more difficult to solve. Robots may not only avoid the hole but also assemble into a larger structure and overcome the hole that a single robot would fall into. Hole avoidance is investigated [53; 54].

The objective of *cooperative stick pulling* is to use robots to pull sticks out of the ground. As a single robot cannot pull a stick by itself, there is a need for two or more robots to complete the task. The research results in cooperative stick pulling are published in [55-57].

*Robot soccer* is an experimental test-bed for multi-agent and multi-robot algorithms. To be successful in robot soccer, a team of robots must possess various skills and capabilities, combining existing research and introducing novel algorithms. Example of studies in robot soccer are [58] and [59]. From a practical application point of view robot soccer is interesting in terms of collaboration in competitive scenario. Ideas from robot football could be transferred to other applications such as military defense operations.

The abovementioned tasks are studied together or separately depending on the research conducted. We consider these tasks as basic building blocks to produce a swarm applicable in real-world scenarios. We agree with the authors of [19] in terms that new research should focus more on applications of previous work. The authors of [1] also mention that future swarm research should focus on addressing multiple issues, not just one. Considering the above mentioned we introduce an example of swarm application and analyse how the abovementioned tasks can be used to solve it.

**Practical application of swarm tasks**

We introduce an example of practical application where swarm robotics could be used and analyze which tasks can be applied for the swarm to be successful. The aim is to show how the tasks identified in the previous section fit into solutions for real-world problems and how they can be combined to achieve the desirable result. Consider an example of agriculture – a field that needs to be cultivated. The task is to mow cereals and deposit them at the warehouse. A swarm of robots with the appropriate capabilities (e.g., harvesters and transporters) is sent to complete the task. This is how the tasks contribute to successful completion of the mission.

At the beginning of the mission robots aggregate on the field to achieve the starting point of the mission. To effectively cover the field while performing the mowing operation, robots form patterns, e.g., lines of harvesters. Harvesters *self-assemble* with transporters providing harvester-transporter combo. Ideas from *object clustering and assembling* are used in two phases of the mission. First, mowed cereals are clustered by harvesters in specific points of the field for them to be later picked up by transporters. Second, at the warehouse object clustering and assembling are used to store the goods in an effective way. To overcome drawbacks (or lack of) GPS signals, robots use moving beacons for navigation on the field. A precise map of the field is constructed during the mission and used to overcome environment limitations, e.g., large rocks in the field. After the initial aggregation at the beginning of the mission, robots use techniques from *self-deployment* to cover the field in the most effective way. While mowing, robots sustain a *pattern of harvesters moving in lines* to effectively cover the field. Robots avoid obstacles such as rocks and trees and use planning techniques to construct collision-free paths. Depending on a situation it might be beneficial for a group of transporters to *collectively transport* a large amount of goods at once instead of transporting smaller amounts several times. Harvesters and transporters *collectively decide* upon the most beneficial way to act upon a field. Harvesters either cluster goods at specific regions of the field where transporters pick them up later of self-assemble with transporters to provide harvester-transporter combo. The entire scenario can be abstracted as a *foraging task* where robots go into the field, forage for goods and then return to the warehouse carrying their gain. Robots use techniques from *cooperative hole avoidance* to avoid ditches and ponds. *Cooperative stick pulling* is applied to load the goods into transporters. While there are no real "sticks", the cargo loading operation can be viewed as a stick-pulling task, given that
more than one robot is required to successfully perform the operation. Techniques from robot soccer can indirectly be applied in harvester operation, e.g., ball dribble from the robot soccer can be adapted for movement of goods at short distances. As it can be seen from this example, the potential of practical application of the identified task types of the swarm is rather high. The question is how to fully exploit this potential.

Conclusions

In this paper we have summarized tasks that have been studied in the context of swarm robotics and discussed the practical applicability of these tasks. To take a next step towards practical application of swarm robotics, a research on combining multiple task types should be conducted. The task types studied in the context of swarm robotics can be considered the basic building blocks to produce more complex behaviours with bigger potential of practical applications. We agree with the conclusion of the authors in [19] indicating that new research in swarm robotics should focus more on applications of the previous work. One of the possible steps in this direction is to combine studies in the existing task types to obtain new ones aiming at specific practical applications. For example, by combining the ideas of coordinated motion, obstacle avoidance and cooperative hole avoidance might be possible to produce “safe motion” behaviour. Combining mapping and localization and swarm-guided navigation would produce “safe navigation” behaviour. Combining safe navigation with safe motion would produce a swarm capable of safely travelling through environment while being aware of the position of individual robots. Such swarm has direct application in surveillance and patrolling applications. This is just an example of the possibilities that can be exploited by combining different task types. We believe this research topic is of great potential.

References


