Robotic Swarms: Distributed Coordination Without Location

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February 26, 2014

Abstract

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1 Introduction

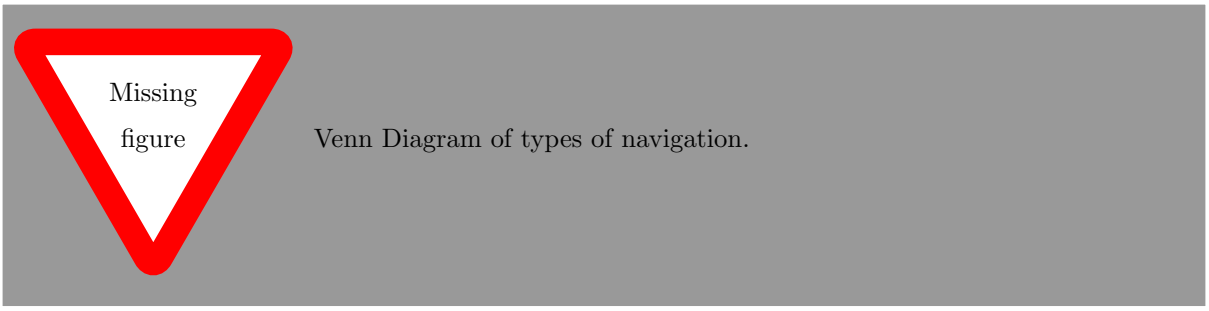
As robots become smaller and easier to produce, interest for robotic swarms is generated. Many possible applications for robotic swarms exist and it is certain many more will follow, indicated by a growing amount of paper written about robotics at for instance the AAMAS (International Conference on Autonomous Agents and Multiagent Systems). [**?**] Many different applications and techniques exist in the field of robotic swarms. This paper aims to deliver a concise review of these applications and techniques.

To avoid confusion, some terminology will be defined. Afterwards, In order to emphasize the importance of the connection between the technology and its applications, a top-down approach is used for this survey. Thus, in this paper we will first review a few different application fields, after which a few examples of applications in these fields will be given. In the second part of the paper we will discuss the most used techniques for these applications and the algorithms behind these techniques.

2 Definitions from Literature

Robotic swarm applications can roughly be characterised by two attributes; they are either *location-based* or *location-free*, or they are either *range-based* and *range-free*. A location-free approach does not exclude a range-free approach and vice-versa; they are two different ways of approaching an application. The definitions of these attributes may be interpreted ambiguously, which is why we will define it here. The definitions are:

- A robotic swarm is *location-free* if the swarm has no knowledge of the boundaries of te location it is in, whether it is provided at the beginning or is actively searched for during the execution of the algorithm.
- A robotic swarm is *location-based* if the swarm has the knowledge of predefined boundaries of the location it operates in, whether provided at the beginning of the execution of the algorithm or if it is actively searched for.
- A robotic swarm is *range-free* if each robot can detect, but does not store or measure the distance, other nearby robots in the swarm or nearby obstacles
- A robotic swarm is *range-based* if each robot in the swarm keeps track of the exact distance between itself and the other robots in the swarm or obstacles.



Venn Diagram of types of navigation.

3 Applications

Robotic swarms can be used for many real-world applications as for example in tasks that cover a region, tasks that are to dangerous for human beings, tasks that scale-up or scale-down in time or tasks that require redundancy [**?**].

3.1 Area Cleaning

Description: *Cleaning a certain area is a common problem which can be solved effectively by using a swarm of autonomous robots. These robots are used to fully explore and clean the area while only being able to see their neighbourhood. In this case the swarm cleans without disconnecting the dirty area.* [**?**]

Techniques: collective, exploration?

3.2 Space Exploration

Description: *Exploration of an unkown environment can be done conveniently using autonomous robotic swarms, even in human impassable areas such as space.* [**?**]

Some of the techniques used in toxic source discovery are: exploration, dispersion.

3.3 Swarm-Assisted Fire Fighting

Description: *Swarm-Assisted Fire Fighting makes interactive use of autonomous robots in fire emergency settings. These swarms of robots are capable of supporting and enhancing fire fighting operations co-operatively with each other and are coordinated by a single human supervisor.*[**?**, **?**]

The techniques required for Swarm-Assisted Fire Fighting include, but are not limited to: *foraging*, *formation*, *mapping* and *exploration.*[**?**, **?**]

Check more sources and verify techniques

The foraging techniques are needed in order to give the swarm the ability to search and locate victims. Formation is required in order for the swarm to navigate optimally and prevent conflicts in exploration. The mapping and exploration service are required to create a well constructed map of the explored area, such that the human and other robots are aware of their surroundings, even if it is impossible to get a visual due to reduced visibility caused by smoke.

3.4 Toxic Emition Source Discovery by Robotic-Swarms

Description: *Due to the ambiguity of this name, there have been many applications which have aimed to achieve this, from nuclear spills and oil spills to fire-origins. Much of this however is theoretical work, due to the fact that the price of these individual robots is still rather high.*

Some of the techniques used in toxic source discovery are: control, communication and distribution.[**?**]

3.5 Collective Transport of Complex Objects

Description: *Transporting objects by robotic swarms has many potential applications in many settings, from agriculture to construction to disaster relief. Especially in dangerous settings like warzones or radioactive areas, robotic swarms can be a powerful tool to safely retrieve many objects. Especially because the robots used for this application are cheap to produce.* For this application to work, each agent only has to know the target direction but does not have to know the object shape, weight, its own position or the position and number of other agents. This makes this application location-free and range-free. An extra invariant is that there must be enough robots to overcome the static friction of the object to be transported. Some of the techniques used in collective transport are: collective intelligence, decentralized strategy, path-finding. [**?**]

3.6 Swarm Surveillance

Description: *Surveillance with a single robot is already a powerful tool, but with a swarm of robots it becomes even more effective. A larger area can be covered, local communication can be handled efficiently and depleted robots can interchanged with other robots. The applications of swarm surveillance are diverse, and are already used in a vast range of applications like agricultural practices, police surveillance, inspecting unreachable locations, patrol missions and reconnaisance tasks.* The application can be implemented in many different ways, but is able to work location-free and range-free, but in some applications the location is already known and in others it can be helpful for a robot to know the exact location of the other robots of the swarm. In some applications the process isn't even completely autonomous; a human user could be in a ground control station. Some of the techniques used in swarm surveillance are: dispersion, localization, distributed communication and exploration. [**?**]

3.7 Overview

Give an overview of real-world applications possible with Robotic Swarms. A list of possible applications:

1. Area Cleaning
2. Space Exploration (swarm of Mars rovers)
3. Rescue Missions
4. Treacherous Radioactive Survey
5. Survey and cleanup of Toxic Spills
6. Surveillance
7. Swarm-Assisted Fire Fighting
8. Collective Transport of Complex Objects

Categories

- Region Covering
- Dangers
- Scaling in time
- Redundancy

4 In-depth review of Techniques

. . . small introduction

4.1 Categorizing Applications and Techniques

List of applications.... idea for table: Orientation Table: LB RB LF RF

	Location-based	Location-free
Range-based	...	
Range-free	...	

4.2 Technique 1

... Introduction to problem 1.

4.2.1 Comparison of Solutions

4.2.2 Remaining Problems

4.3 Technique 2

... Introduction to problem 2.

4.3.1 Comparison of Solutions

4.3.2 Remaining Problems

4.4 Technique 3

... Introduction to problem 3.

4.4.1 Comparison of Solutions

4.4.2 Remaining Problems

4.5 Technique 4

... Introduction to problem 4.

4.5.1 Comparison of Solutions

4.5.2 Remaining Problems

5 Unsolved Problems

6 Discussion