A SURVEY ON THE COLLECTIVE BEHAVIOUR OF SWARM ROBOTICS

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Abstract

In nature many social animals follow a cooperative behaviour for the common good of their colony. Swarm robotics is a method in which a collection of similar or dissimilar robots follow an organized behaviour pattern to perform some specific tasks. The robots interact and follow simple rules to coordinate a large number of robots. Here we focus on the recent developments in swarm robotics as applied to real world problems. Swarm robotics deals with the defining the rules for the cooperative behaviour and designing, modelling, validating, operating and maintaining the robotics system. Swarm robotics can be classified as per the design and analysis or as per the collective behaviour. The limitations and the future research directions for swarm robotics is also discussed.

Keywords: Swarm Robotics, Social behaviour, Collective behaviour, Robots

I. Introduction

Swarm robotics deals with a collection of large number of robots coordinating amongst themselves with a desired collective behaviour [XII]. Many different types of swarm robotics system have been proposed and reported [XII], [III], [VI], [XIII]. Social animals like ants, bees, etc. are the main inspiration for swarm robotics which show such characteristics in nature. Social animals perform seemingly impossible tasks for individuals by working together in groups. Social animals behave in such a way that a unique kind of intelligence is exhibited which is extremely useful for their survival [IV], [VII]. The behavioural aspect of these animals is such that it is flexible, scalable and robust.

The main features of a swarm robotic system are that (i) the robots are autonomous, (ii) it can modify the environment around it, (iii) it can monitor its local environment and communicate among the constituents, (iv) the interaction among the constituents is local and there is no centralized control system and (v) they cooperate to perform a given task. Swarm robotics is the smart application of the behavioural rules that guide the design, operation and maintenance of the system. It is designed
such that it will do complete the given task in a reliable and timely manner. Here we
will focus on application of swarm robotics to real world applications.

II. Methods

Recent research work has focussed on the design and analysis of swarm
robotics. Some of the common methods of design and analysis is presented below.

Design Methods

There are mainly two types design philosophies in swarm robotics, namely
behaviour based design and automatic design. Design could be based on the task to be
performed and the swarm robotics system is planned and developed in such a way
that the given task is completed in a reliable and efficient way.

The most common design in swarm robotics is the behaviour based
design. The characteristics of each individual robot is studied and modified till the
expected collective behaviour is obtained. The design is inspired by the behaviour of
social animals and the models developed to understand the social animals can be used
to implement the design based behaviour method. Automatic design method does not
use the collective behaviour of the robots. It is classified into evolutionary robotics
and multi-robot reinforcement learning.

Behavior-Based Design Methods

In behaviour based design method, the behaviour of the individual robot is
iteratively modified to obtain the expected collective behaviour. Usually this is a trial
and error process. The behaviour based design can be classified into three types,
namely, probabilistic finite state machine design, virtual physics based design and
other design methods.

Probabilistic finite state machine design: The finite state machine is a design
method which takes decision based on the input from the sensors or the memory. In
this design method the robot is not planning the future course of action but takes a
decision based on the immediate input it received from a sensor or memory. Thus it
makes decisions on every finite steps of the process. The transition probability
between states can be kept fixed or it can be changed as per the input parameter. It
dePENDs on the collective behaviour of the entire swarm robotics system [XIV].

Virtual physics based design: As the name suggest this design method is
inspired by physics. Here the concepts of physics are used to design the interactions
and the collective behaviour of the robots. Like the robots can be considered to be
particles which exert force on each other. The advantages in this method are simple
mathematical rules can be used to describe the collective behaviour of the system.
The properties can be described using the theoretical methods developed in physics
[IX].

Other behaviour based design methods: Several behaviour based methods
have been proposed for swarm robotics. A swarm robotics system can be considered
similar to a wireless sensor networks. The algorithms or methods developed for a
wireless sensor network can be used to control the collective behaviour of the robots
in a swarm robotic system. A Scripting language called Protoswarm is developed to
control the collective behaviour of swarm robots [II]. In this method the individual robots are able to do computations and also communicate with the neighbours. By controlling the collective behaviour individual robots behaviour also can be controlled.

A top-down approach to design swarm robotics system is also proposed [V]. Here logical formulas are used to define the system. The logical formulas are tested and modified to obtain the desired collective behaviour. The formulas are tested using real robots to confirm the system is working as per design.

**Automatic Design Methods**

In automatic design methods the intervention of the developer is minimized. It is classified into two types, namely, Reinforcement learning and Evolutionary robotics.

Reinforcement learning is learning method where the robot interacts with the environment in a trial and error method and receiving a reward for a positive outcome. Thus in this method the individual robot is looking to maximize the rewards. The real problem is whether this behaviour of the individual robot is beneficial for the collective behaviour of the swarm. Here for the swarm robotics system the rewards should optimized to achieve the collective objective of the swarm robotics system [II].

Evolutionary robotics (ER) uses evolutionary computation method which is inspired by Darwin’s principle of natural selection and evolution. The ER process is an iterative method. The collective behaviour is assessed at each iteration and adjusted for the best outcome. Initially the individual behaviour is randomly generated, then the collective behaviour is evaluated and the individual behaviour is adjusted for the best outcome of the system [I], [XVI].

**Other Learning and Automatic Design Methods:**

Some research work has been carried out on automatic design methods which are different from the reinforcement learning and evolutionary robotics. Obstacle avoidance task were performed by robots using particle swarm optimization (PSO) algorithm and genetic algorithm. It was that the PSO performed better in completing this task [X]. Ultimately the main purpose of a swarm robotics is to see if the desired collective behaviour is achieved. The next section discusses some of the models for this collective behaviour.

**III. Collective Behaviours**

Collective behaviour of the entire swarm of robots is what is desired to solve real world problems. In a swarm the major behaviours that would be interesting are the spatial movement of the robots, navigational capabilities, decision making and other collective behaviours.

Spatially movement of robots: The physical arrangement of individual robots in a swarm is important in a swarm robotics system. The robots can be arranged in different ways like physically connected robots, chains, aggregates, clusters etc. Aggregation is a type of behaviour which can be useful in certain environments.

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nature many organisms have been seen to show this type of behaviour. In swarm robotics aggregation can be done using probabilistic finite state machines or artificial evolution.

Pattern formation is another way for the spatial arrangement of robots. In this the robots are arranged in a regular and repetitive pattern. In nature this kind of behaviour is found in animals and also in the arrangement of atoms in a solid follow a regular pattern. Virtual physics based design can be used to form such patterns for the swarm robotics. The comprehensive compilation of research work in virtual physics based approach for swarm robotics is carried out by Spears et al. [XV]. Chain formation is another way for the spatial arrangement of robots. This is useful for navigation and surveillance. In nature ants show such a behaviour. Probabilistic finite state machines, artificial evolution or virtual physics based design can be used to achieve this behaviour. The robots can also arrange themselves in self-assembly formation. Such behaviour is seen in animals and even in physical systems at the molecular level in materials. Artificial evolution or probabilistic finite state machine methods can be used to achieve self-assembly in swarm robotics. Clustering and assembling is another way for spatial arrangement of robots. Many social insects exhibit such behaviours in nature. Probabilistic finite state machine approach can be used to achieve this behaviour.

Navigational capabilities: The collective navigational abilities for a coordinated movement of the swarm is studied. The different ways for navigation in swarm robotics are collective exploration, coordinated motion, collective transport, etc.

Collective exploration is a method in which the robots cooperate to explore the environment and navigate. In nature many social animals like ants and bees have been seen to employ such a technique for navigation. Probabilistic finite state machine or virtual physics based designs can be used to achieve this method. Coordinate motion is another method used by swarm robots for navigation. In nature flocks of birds or schools of fish has been observed to exhibit such behaviour. Virtual physics based design can be used to achieve this method. Collective transport is another method used for navigation by swarm robots. Here the robots cooperate to transport a heavy object which cannot be moved by the individual robots. The robots agree to move in a common direction to effectively move the object. Such behaviour is observed in ants in nature. Artificial evolution or probabilistic finite state machine can be used to achieve this method. A collective transport behaviour in which the group of robots agree on a common movement direction by averaging the individual desired direction is shown by Ferrante et al. [VIII].

Decision making: Decision making in swarm robotics is achieved by agreement and specialization between the individual robots. Agreement can be achieved by consensus, by converging on a single decision from other possibilities. Specialization is where the robots take individual tasks to achieve the collective desired outcome.
Consensus is usually achieved by agreeing upon the choice which will give the maximum performance of the system. Many social insects like ants and bees use this approach in nature.

This is achieved by effective communication among the robots and exchanging the information. Task allocation is another decision which the robots have to take. The robots perform a collective behaviour where the robots distribute themselves to perform the different tasks to achieve the desired outcome. Ants and bee colonies exhibit such behaviour in nature.

In ants and bees some individuals have specific tasks like foraging, others are involved in taking care of the larvae, while some are given the task of security. Probabilistic finite state machine can be used to achieve this task.

Other collective behaviours: The other collective behaviour in swarm robotics can involve collective fault detection, group size regulation, Human swarm interaction etc.

IV. Discussion

Swarm robotics is a system where the individual robots cooperate and coordinate amongst themselves to perform a desired task. The aim here is to develop systems that are flexible, scalable and robust. In this paper we analysed the work done by other researchers in swarm robotics and organized the information based on the behavioural patterns of the swarm robotic systems. Despite its potential applications swarm robots have rarely been used in real world applications. Most of the work is focussed towards obtaining the desired collective behaviour and understanding their properties. And these studies have been done on simplified testing systems, whereas in real world application much more complex problems can arise when trying to implement the swarm robotics system. Swarm robotics have been tested in applications like foraging, construction, etc. The possible reasons for swarm robotics not being used widely in real world applications can be due to limitations in the hardware of the available robots. But in the near future a lot of the real world tasks may have to be performed using swarm robots. With an increasing demand for swarm robotics system, there will be a need for further development of the methods that have been described in this paper. The designs, models will have to be further tested, validated and verified for safe and secure application of swarm robotic system in real world applications. The operation and maintenance of the system will also have to be streamlined for efficient use of this system.

V. Conclusion

In this paper we review the state of the art of the swarm robotics system. In future there will be more demand for the swarm robotics systems to be applied to real world problems. Here we have not only presented the important works in this field but also given a categorization of the different behavioural methods used in swarm robotics to achieve the desired collective behaviour to perform the given task. In conclusion the field of swarm robotics will have many more challenges to tackle and lot of work will have to be done to tackle those challenges.

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