Chapter 16
Swarm Intelligence-Based Systems: A Review

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1 Introduction

Swarm Intelligence: Over the last few years there have been numerous advancements in the field of robotics, automation, artificial intelligence and their uses. Comparatively, swarm intelligence has been in a relatively low focus. Swarm intelligence has its roots in the way in which some social insects interact with the nature in a unique and smart way despite having subordinate capabilities. Figure 1 shows a swarm of auklets that can be depicted into system of swarm robots.

These swarms of insects, fishes or mammals, allocate different tasks amongst themselves in order to construct, collect food, safeguard territory and countless similar tasks, thereby depicting great flexibility and vitality. In these insects or animals, there exists some obscure mechanism which divides the one complex task into simpler tasks for individual to perform and then finally integrate everything demonstrating collective behaviour.

Similarly, this concept can be reproduced to create group of robots adapting the identical behavioural strategies for search and rescue as well as in defence operations.

Although certain tasks might be herculean for an individual to perform single headedly, but swarm of animals manage to do it without any hassle.

This vitally requires a better communication and information interpretation amongst all the elements of the swarm.

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Fig. 1 Swarm of Auklets

This paper concentrates on concepts, design and features that required to build an operative swarm robot.

The synergy between the robots and the interaction of robots with the environment forms the foundations for functioning of swarms.

The intricacy is reduced by using the principle that establishing and following a fixed set of rules at individual level can lead to exhibition of complex behaviours by the swarm [1] (see Fig. 2).

2 Comparison of Swarm Robots with Traditional Robots

Swarm robots are multiple, small sized and unfussy robots apart from the complex, giant and traditional robots. Swarm robots constitute of simple software and hardware as well. Swarm is the channel of distributed robots where each robot has a specific task. They work in a locally communicated environment. And have local sensing. Swarm robots may or may not be self-learning, whereas traditional robots generally have self-learning algorithm embedded in them.

Moreover, traditional robots generally have controlled and centralised system, whereas swarm robots have decentralised and autonomous system which helps in increasing the response time making them more efficient. Thus, the major difference between both lies in population, control, homogeneity, flexibility and functional extension [1].

Fig. 2 Swarm robots following one another in a defined path

There is also the difference of application of both the system: swarms are generally proposed to be used in, defence and health care, whereas traditional robots have diverse uses right from cooking to industrial production.

3 Features of Swarm Robots

The following points describe the main features or characteristic of swarm robots and intelligence.

(i) *Decentralised*: The robots must be decentralised and self-organising. That is, the functions that they perform are not controlled by external agent. The robots must have internal communication and sensing abilities.

(ii) *Size*: The number of robots in a particular artificial swarm must be huge in number. They must be present in a flock. But each robot is expected to have size corresponding too few millimetres.

(iii) *Homogeneous*: The robots in a swarm must be mainly homogeneous. There shall not be many different types of robots. However, some researches demonstrate few swarms of robot having different type of robots designed to carry out different interdependent functions.

(iv) The robots must mainly focus on the task allocated to them but be operational to smart decision-making for task shift with use of automation [2].
(v) Robots in a swarm demonstrate limited area communication and sensing only. It ensures scalability of the robots [2].
(vi) Restricted sensing abilities and communication also ensure reduced price of robot in the swarm environment.
(vii) *Flexibility*: As the swarm can adapt multiple functionality with same hardware and by making only few changes in the software, it ensures the flexibility of the same. By using the advanced technology of machine learning the robots can improve themselves from their past moves [1].
(viii) *Flying*: Previously, flying swarm generally had externally tracking and operation system. But this does not make the swarm feasible. Instead, it can have global positioning system (GPS) to relocate and create its own map in the environment. Laser scanners can be used to detect the robot's pose and motion in a plane.
In [3], they have used robotic sensor network paradigm to get navigated without global information. Robots are of two types: beacons or explorers. Beacons were made to have the aerial view [4], forming nodes in the network. Explorers were made to map the environment and perform necessary operations.
(ix) *Sensors*: Sensors sense information about the surrounding areas. They may able to store the information locally or forward it at the control areas for further analysis as per the requirement. Robots can also use communication to share the information with other robots in the system [5].

4 Architecture of Swarm Robots

Swarm as a whole for performing a particular task rely on the number of member robots rather than the complexity of task the can perform. Thus, a well-defined architecture is necessary for the proper and efficient swarm functioning. Authors have described the basic architecture of swarm as follows: Swarm robotics model is an essential component of cooperative algorithm which controls the behaviours and interactions of all individuals in the swarm. According to the model, the robots must possess some basic functions related to communication, motioned.

On the basis of functionality utilised by the module to perform certain tasks, the model can be divided into three parts namely *data exchange*, *basic behaviour* and *advanced behaviour*.

The *data exchange* module sets up the basic framework on which the entire swarm relies. The individuals in the swarm propagate the information throughout the swarm autonomously producing cooperation amongst the individuals. General model of swarm robotics is shown in Fig. 3. Occasionally, global and centralised commands are set up, and it is ensured that the swarm is still able to complete the task even if the global communication is blocked.

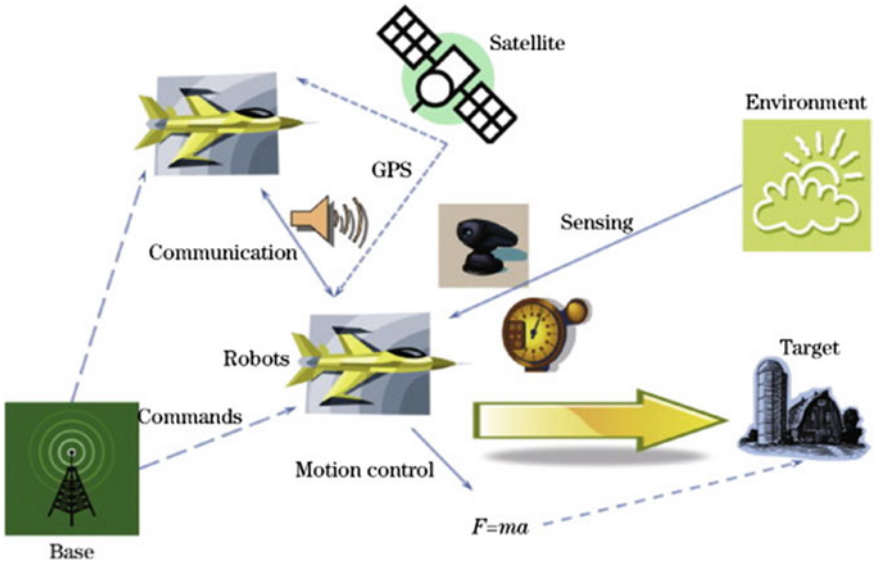

Fig. 3 General model of swarm robotics [1]

The architecture of the swarm is a structure for robotic activities and interactions and determines the topology for information exchange amongst members of the swarm. Thus, it is essential to choose the appropriate architecture of the swarm as the architecture directly affects the performance of swarm.

Locating Global coordinating systems not accessible every time. Therefore, every member of the swarm has to be equipped with a local coordinating system to incorporate the ability to distinguish, identify and locate the nearby robots. Thus, a method for rapidly locating other robots using on-board sensors is very important in swarm robotics [6]. The sensors can sense different waves, including ultrasonic, visible light, infrared ray or sound. However, the relative positioning of swarm robots is more realistic since the abilities of the robots are limited and no global controls exist.

Physical connections: Physical connections are used in the situations that single robot can overcome, such as overpassing large gaps or cooperative transportation. In these tasks, the robots should communicate and dock before they go on to execute their tasks.

Self-organisation and self-assembly: Self-organisation is an ability crucial for building a global module through only local interactions of the basic units. The basic units are not governed by a centralised control or have an external commander, rather the swarm level structure emerges from the synergy between the solitary member robots of the swarm, through already established structures.

Whereas, one method for localisation which also demonstrates the self-organisation and assembly used in the case of swarm of flying robots for indoor navigation with the use of robotic sensor network paradigm [5], where each of the

robot operated in either of the two states: beacon or explorer. The beacon robots formed the nodes in the network and are passively attached to the ceiling maintaining an elevated view and sensing the local environment and communicating it to the explorer robots in the swarm. Thus, requiring the explorers to maintain a beacon to beacon flight and flying under the beacon robots. The area where a no beacon robot is present, an explorer robot switched its state to that of a beacon whilst the previous beacon which was no longer required got converted to an explorer, constantly expanding the network and making it a dynamic system.

5 Application of Swarm Robotics

(a) *Search and rescue*

Swarm robotics has an amazing application in search and rescue.

In [5], they did an experiment in the domain of search and rescue by the use of heterogeneous groups of robots. The experiment aimed of locating immobile humans in a building caught with fire. They used temperature, visibility and toxicity sensing in the system.

(b) *Defence*

There is a lot of speculation about advanced drone and robots bought in work by military and defence purposes.

We also propose a kind of high-speed swarm of robots which can penetrate deep inside the trespasser's body at the military borders so as to destroy the blood vessels eventually leading to death.

(c) *Space Science*

The National Aeronautics and Space Administration (NASA) is also using the advanced system of swarm robots. NASA formerly used swarm robotics to fuel space mining missions. These robots were inspired by the behaviour of ants. NASA started with four robots, but slowly advanced its application [7].

(d) *Medicine*

Robotic technology is improving non-invasive medical processes using clarity, firmness and adroitness. The early experiences of using robots in the medical sciences came from the development of technologies to enhance endoscopic procedures of the intestinal tract [8].

Micro-robots interaction based on the stochastic diffusion search (**SDS**) algorithm is a great tool to identify and detect certain pathological parameters of a human body [9, 10]. Machine learning and artificial intelligence experts predict to have advanced micro-robots that goes deep inside the body and kills all the harmful cell as it enters. Eventually, increasing the life expectancy with an appreciable aggregate. The special feature of micro-robots is that they can penetrate through the blood vessels and carry out many important operations that are not possible currently.

If a group of nanoparticles can be programmed to create a swarm, they can potentially travel to target cancer cells, destroy affected tissue very effectively. Whereas drugs simply diffuse into tissues, swarm nanoparticles would have more intelligence and could more effectively target diseased tissue [11].

6 Conclusion

Swarm is cost effective, miniaturised enough to work in tough inconspicuous spaces (search and rescue operations), adaptive to operate in changing terrains/workplaces. The buzzing VLSI might be furthermore helpful in reducing the size of swarms. Whatsoever, it has numerous individual units, proficiency in connectivity and coordination amongst them elevates their rank on a comparative analysis with standard robots. The most captivating feature of swarms is the ability to relocate themselves with the global positioning system and create its own map environment unlike the standard robots which have external tracking system. Another notable feature is the ability to perform an operation even after partial equipment failure.

Introduction of automated systems in bio-medical instrumentation will increase the surgery precision. As far as the conditions of warfare and security are concerned swarms will reduce the loss of life in such situations to a great extent. Looking at the bigger picture artificial intelligence and machine learning.

Gesture robotics, embedded systems are the quintessential of technology theories on which the twenty-first century would be based upon.

Through this paper, authors tried to introduce basic swarm robotics-based systems and their difference from the traditional robots. Features of swarm intelligence were reflected that are capable of successfully deploying advanced application of swarm intelligence.

In conclusion, using swarm robotics, we can solve complicated time and space consuming problems. This work presents a strategy to build an autonomous, decentralised and self-organising system of swarm robots. Authors have also discussed the architecture of the robots along with their sensor requirements.

Swarm intelligence is a amazing fusion of hardware technology, software technology, biological observances and artificial intelligence.

Authors look forward to experiment upon advanced swarm robotic system in future.

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