RESEARCH ARTICLE OPEN ACCESS

An Introduction to the Collective Behaviour of Swarm Intelligence

Rohan R.[1], Prasad C.N.[2], Jeswin Jose[3],Sadiq Pasha[4]
[1](Department of Computer Applications, St. Joseph's College (Autonomous), Bengaluru, India,)
[2,3,4](St. Joseph's College (Autonomous), Bengaluru, India)

Abstract:
Swarm robotics seems to be the easiest way of understanding robotic architecture and implementing them on a large scale. These consist of multiple robots which are connected together thereby accomplishing a task faster and more efficiently. Inspired by how insects such as bees and ants work together, swarm robotics is a field of multi-working robots which are coordinated and distributed together to perform a task. This paper deals with the working and advancement of swarm robotics in the present AI field using certain algorithms. Here we can understand the nature of these robots, their applications, advantages and the various algorithms on which these robots are based upon.

Keywords ***—ant colony, cuckoo search, swarm robotics, Artificial intelligence (AI).***

I. INTRODUCTION

When we talk about artificial intelligence or robotics the main idea or the unifying theme is that of an intelligent agent. We understand that AI is the study of these agents that procure information from the real world and then perform actions accordingly. We as human beings have learned to perceive, predict and understand the world which is more complicated than ourselves but the field of Artificial Intelligence not only understands the real world but also has the ability to build intelligent entities in it.

To put it simply, swarm intelligence can be described as the collective behaviour of a group of robots to achieve and fulfil a task that is assigned to it. Swarm intelligence has become highly popular in the research community as this is considered to be a prototype to the way actual robotic systems may work.

Each of the robots in the collective system has an individual task to perform and to perform this the major principle of the individual robot is to be self-organized with maximum interaction with others.

The idea was capitalized on the basis of how social insects work together to gather food or build nests. For example, a swarm of bees works together to build a beehive, where each bee has a different task to perform. While worker bees are assigned to build the hive, other bees gather nectar and the queen has the distinct task to lay eggs and reproduce. Finally, as a whole, the bees have to work together to ensure that they survive and multiply[3]. Other examples include a school of fish, flock of birds migrating etc.

For a swarm to function properly, there are certain factors that it has to fulfil:

- **Proximity Factor**: Here, the swarm should function properly while simultaneously relating to its environment. Its response is regarded as the key factor of its computation. Depending on the type of environment involved, the swarm's responses may vary greatly[2].

Quality Factor: The swarm should not just respond depending upon the computation involved, but also should be able to respond qualitatively to the environment.

Diverse Response Factor: The swarms should be designed in such a way that each of the individual agents will be largely resistive to the harshest of conditions. The agents will be protected even in extreme environments.

Adaptability Factor: Swarms are expected to adapt to extreme environmental conditions without being damaged. The swarms should remain stable even in these conditions.

Swarm robotic systems have many advantages while compared to single robots. Firstly a single robot that could accomplish tasks and adapt to different environmental conditions is hard to design[1]. Secondly, to design a robot that could be stable in such environments may incur a lot of cost and labour. Swarm robotics is robust while compared to single robots, they can efficiently inter-depend on each other and complete the task without wasting a lot of time and cost. The main advantage of swarm robotics is that each agent can work on adifferent range of tasks simultaneously but all of these agents aim to accomplish one final task while a single robot system can have the resources to complete one task at a time and only after completing it, can it move to a different task.

II. RESEARCH PROGRESS IN SWARM ROBOTICS

According to Ying Tan and Zhong-yang Zheng[2] "swarm robotics is a combination of swarm intelligence and robotics which shows a great potential in several aspects". Swarm robotics have paved the way for anincrease in the progress of Artificial Intelligence in the current times and therefore can be overwhelmingly important in the coming future.YichenHu[1] states that "the essential idea of swarm intelligence algorithms is to employ many simple agents which in turn leads to an emergent global behaviour". This leads us to the satisfying question of whether swarm intelligence is the next step to solving problems collectively and efficiently rather than individual AI systems. Vito Trianni, ElioTuci, Christos Ampatzis and Marco Dorigo[3] states that "a multi-robot approach can have many advantages over a single-robot system. A monolithic robot that could accomplish various tasks in varying environmental conditions is di□cult to design. Moreover, the single-robot approach su□ers from the problem that even small failures of the robotic unit may prevent the accomplishment of the whole task"[3]. As research progresses, we are therefore moving to a reality where swarm robots can virtually complete any task that is assigned to it without the need for human intervention or help. These robots will learn to incorporate complex structures and themes by using AI and will henceforth implement them on the environment around it.

III. THE BIOLOGICAL INFERENCE

Swarm intelligence techniques and researchers have been inspired by how groups of animals and insects interact with each other in real life. These usually range from a small group of insects to organized colonies that occupy a large area of space and consist of millions of individuals[2]. These individuals interact with each other in order to complete certain tasks such as planning and building of nests, finding food and other related actions.

As it becomes difficult for an individual to complete a set of common tasks alone, insects and animals usually work together in groups to complete these tasks by dividing the work among them. Individual organisms which attempt at completing tasks alone show poor abilities and quality while compared to groups.

A. Fish Schools

Fishes have a distinctive way of swimming together at high speeds without colliding with each other or to objects on the seafloor. The individuals pay a lot of attention to their neighbours while swimming [2]. They have the added advantage of having eyes on the sides of their head and marks on their shoulders to help them steer according to their wish while not breaking the chain. Fish schools also benefit from foraging and avoiding predators.

B. Ant Colonies

Ants communicate with each other using a chemical substance called pheromone. An ant which has found food leaves a fresh trail of pheromone marking the shortest path of its return. This trail is followed by colonies of ants that identify the better and shorter routes[2]. Ants that are successful in finding and gathering food venture out more while compared to other ants that are unsuccessful in their attempts. These ants usually change to other roles which suit them better.

C. Bee Colonies

Bees work on the same principle of collecting food as ants do. Instead of using pheromone a group of bees is sent to forage a food source. Once thefood is located the bees return to the beehive and perform a dance to get the attention of the other bees[7].

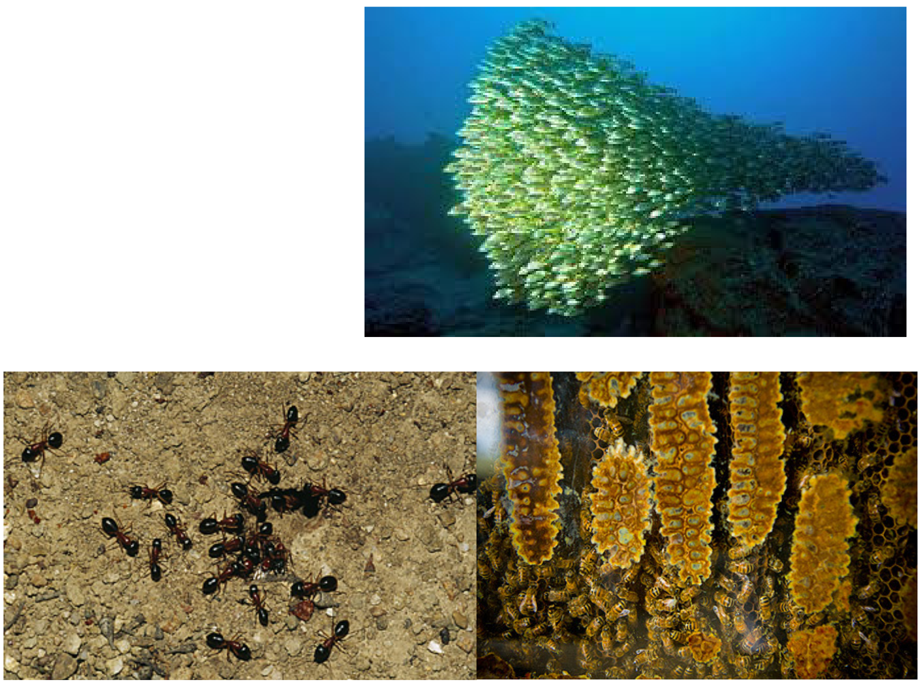

Fig. 1 Nature Swarms

IV. CHARACTERISTICS OF BIOLOGICAL SWARMS

Since swarm intelligence has been mostly been influenced by nature there is a need to understand the characteristics of these swarms to implement them in AI. The research on swarm intelligence started more than a century ago. When research had first begun, researchers thought that in order for swarm intelligence to work, each individual in the swarm must have a unique ID for cooperation and communication([2],[8]). The exchange of information between individuals was controlled by a centralized network. For example, the queen in bee colonies had the distinctive work of assigning tasks to each of the individual workers in the colony.

However, this all changed when researchers found out that human beings who can also relate to nature swarms (social creatures) worked together without having a centralized system. In other words, the system was decentralized i.e. each of the individual agents follows their own local rules without affecting each other. However, the global behaviour which emerges from these rules affect the agents on the basis of exchange of information and the hierarchical structure in the swarm.

A decentralized swarm system not only keeps the swarm robust and flexible but also doesn't impose harsh rules on the individual agents.

V. ADVANTAGES OF SWARM ROBOTICS

The advantages of swarm robotics system can be presented by comparing a single robot to multiple robot systems.

To design a single robot to complete a complicatedtask would incur high cost and design, also there is no certain way to ensure that the robot would be able to complete the task without any problem. A single robot system may become vulnerable when it might break down in turn affecting the entire system[3].

A swarm system, on the other hand, is easy to design and maintain without incurring high cost and labour. They are able to complete the same task easily by interdepending on each other. These systems are self-organized and are therefore suitable for large-scale tasks.

Some of the advantages of swarm robotics are listed below:

Since a swarm consists of millions of individuals, they are able to deal with multiple targets in a single task simultaneously. This enables the swarm to work on multiple targets which are distributed over a large area and therefore would save time in searching for these targets significantly.

The interaction in the swarm is localized, such that the individuals can join or quit the task at any time without disrupting the work of the entire swarm. This feature allows the swarm to re-allocate the task to other agents whenever there is a change in the population[5]. It also indicates that the swarm is adaptable to different sizes of thepopulation without any damage or change to the task that has to be completed.

As said above, the cost of maintaining and designing a swarm is quite economical. A single robot system may require precision while designing it, while a swarm is massively produced where the precision is distributed among multiple members. Also, a swarm system is significantly low in manufacturing even when there are a large number of robots present in it.

Since a swarm system consists of a large number of individuals than a single robot, the cost of energy is more than its counterpart. This means that its lifetime is enlarged while compared to a single robot system. As natural fuels and wired electricity are becoming extinct in modern times, these swarm systems can be useful than traditional single robots.

Thus swarm systems can be used in places where electricity cannot be provided, or to complete problems that involve a large amount of space and time.

VI. SWARM INTELLIGENCE ALGORITHMS

The working of swarm intelligence is based on several different algorithms. In this section, we will talk about the working of two algorithms in particular. These include Ant Colony Optimizationand Cuckoo Search Algorithm. The explanation for these algorithms has been cited from Yichen Hu's research paper "Swarm Intelligence".

A. *Ant Colony Optimization*

This algorithm is derived from how ants forage to gather food using the chemical substance pheromone as mentioned above. Once an ant finds food it returns back to the colony leaving a trail of pheromone along the path[4]. The ants follow the pheromone to the food by devising a short and efficient path. As they move to find the food they leave a trail of pheromone to help the other ants to find the food[6]. This can be shown in the algorithm by using a metaheuristic approach.

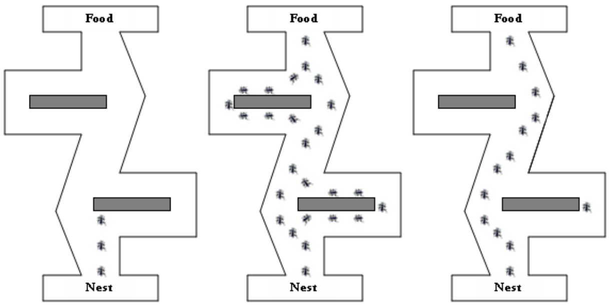

Fig 2. Selecting the shortest path.

- Firstly the problem *P* is defined by *(S,Ω, f)* where *S* is the search space, Ωdenotes the constraints and *f* are the objective functions to be maximized or minimized[1].
- Since ACO uses the concept of pheromone, therefore the approach is split into three phases[1]:

While operation is not terminated then
- *Solution using artificial ants*
- *Search*
- *Use and update the pheromones*

End

- Using artificial ants, *C= {cij}, i = 1...n, j = i...Di* satisfies all the constraints.
- After the solution has been constructed a local search is conducted to improve the solution. However, this is an optional process.
- The process continues with the use of pheromones and updating it for better solutions. The best solutions will consist of the highest concentration of pheromones.

The Ant colony optimization algorithm helps in solving some of the hardest cases of time complexity in computer science. For example, scheduling task and assignment problems require the use of ACO algorithm. However, ACO largely succeeds if a local search is conducted which can be problematic in some situations.

B. *Cuckoo Search Algorithm*

The cuckoo search algorithm was inspired by the brood parasitism behaviour of the cuckoo bird. Here, the cuckoo bird lays its egg in another bird's nest. It conceals the egg in such a way that the host would not doubt that it's another bird's egg. This increases the survival probability of the cuckoo's eggs.

The cuckoo search algorithm works on three basic rules[1]:

- The cuckoo lays its egg and dumps it in a random nest.
- The nests with the highest quality of egg will be brought to the next generation.
- If the host bird discovers the egg was laid by a cuckoo bird then the probability will be pα ∈ (0, 1). It can either throw away the intruding egg or abandon the nest and make a new one.

While operation is not terminated then
- *Get a cuckoo randomly by Levy flights*
- *Calculate its fitness Fi*
- *Choose a nest j randomly:*
  If (Fi<Fj) then replace j with the new solution

End

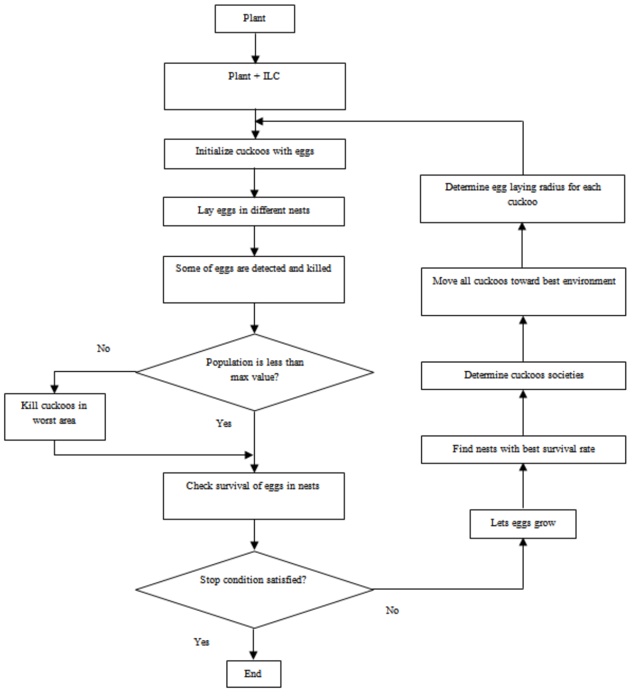

Fig 3. Cuckoo Search Flowchart.

VII. IMPLEMENTATION OF HYBRID ALGORITHM USING TRAVELLING SALESMAN PROBLEM

Both the ant-colony and cuckoo search algorithms are quite efficient in finding the optimized and the shortest path, but although they have their advantages the algorithms have certain drawbacks. The ant-colony optimization has the guaranteed assurance of convergence but the time to convergence is uncertain[1] whereas the cuckoo search algorithm uses an efficientmetaheuristicapproach with lesser parameters than the ant-colony optimization but fails to deliver guaranteed convergence[9].

In order to yield the best results from both the algorithms, a hybrid algorithm can be implemented than using each of them individually. This ensures that the drawbacks of one algorithm are covered by another algorithm. An example where both the algorithms can be used efficiently would be in the travelling salesman problem.

The travelling salesman problem is to find the cheapest way of travelling to all the cities and return to the starting point[9]. The problem must ensure that there isa finite number of cities and each city must be connected to the next one such that the salesman returns to the starting point after visiting the last city.

To solve this problem, we combine the advantages of both the ant-colony optimization and the cuckoo search algorithm. The steps of the hybrid algorithm for the Travelling Salesman Problem is shown below[9]:

- *Initialize the operation*
- *Insert no of nodes*
- *Traverse nodes using Ant-colony and cuckoo search algorithm*
- *Start Ant-colony algorithm, by initializing pheromone trails to each of the ants*
- *Start Cuckoo search by initializing nest*
- *Find the best solution in the nest*
- *If (Fi<Fj) then replace j with the new solution*
- *Choose the next city according to cuckoo search*
- *End Cuckoo Search*
- *Update pheromone trails*
- *If iteration not completed go back to initializing pheromone trails else terminate*
- *If all nodes are traversed then terminate else start process again by inserting nodes*
- *End*

The flowchart below explains the proposed methodology clearly[9]:

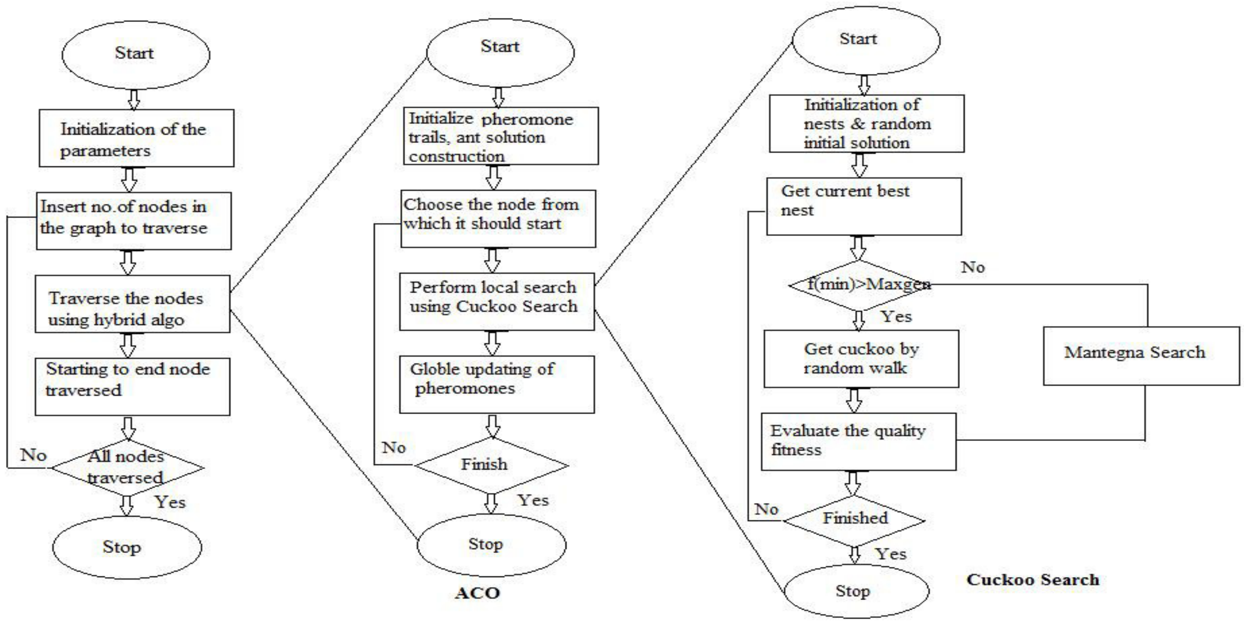

Fig 4. Hybrid Algorithm to solve Travelling Salesman Problem

VIII. APPLICATIONS OF SWARM ROBOTICS

The study of swarm robotics has become preferable for dangerous and inaccessible working areas. These systems have a wide range of applications especially when a target system has to be observed or worked on.

A target system is first located and understood. Swarm systems are then applied to work on the target to get a complete understanding of it. Swarm robotics can be used as prototypes before the actual robotic system can be implemented.
Some of the applications of swarm robotics are listed below:

A swarm system is usually designed to work on tasks that cover a large area. For instance, the robots can be distributed in a large environment such as a factory to detect any chemical leaks. These robots are allowed to patrol the area and raise the alarm when a leak is detected. In intense situations, the robots are also allowed to move to the source of the leak and take immediate actions[5]. This is more suitable than using multi-agent systems as it requires few agents performing the same task with less hardware.

Due to thelow cost required in designing and manufacturing, a swarm system can, therefore, be used in dealing with dangerous tasks preferred to single robots. Since the robots are very cheap they can be used in tasks that can be dangerous to humans. The swarm system may suffer a loss in the number of robots due to the task involved. This is compensable while compared to single robots that are expensive to be used in these tasks. The only requirement for the swarm system to be able to work in these tasks is to be robust and stable during extreme conditions.

Sometimes the robots required for a task may change over time. Therefore the system should reduce or increase the size based on the task involved to increase the efficiency and quality of it. For example, in thecase of an oil leakage the swarm should maintain a high population to clear the leakage but in due course of time, the population should be reduced to take care of the rest of the leakage[5].

Robustness is one of the major features of swarm system but robustness often benefits from redundancy in it. Most tasks that employ swarm systems often require redundancy to be efficient i.e. adding or removal of robots does not create any significant difference. The performance of the system would still remain the same.

IX. CONCLUSION

In this paper, we have learnt the advantages and applications of swarm robotics and how useful it is has become in current time. Swarm-robotics has become a relatively important topic in Artificial Intelligence as swarms are being perceived to help humans in accomplishing dangerous tasks or used during rescue missions. We have also seen a few algorithms that can be used in problem-solving. The different algorithms used here have also helped us in understanding the basics of how these robots work and comply. The ant colony optimization uses a metaheuristic approach to complete a task. The cuckoo search algorithm, on the other hand, is quite an interesting algorithm. It ensures that the undesired solutions are abandoned and only the desired solutions are taken into consideration for a better solution to emerge. A combination of both the algorithms results in a more efficient approach in solving a problem which we have implemented above using a travelling salesman.

For a swarm system to be proposed and utilized in future there are still certain problems that every researcher should ask. How to create a system with low cost and low maintenance? How to make sure that the robots will fully respond to the given tasks without any error? How to predict the nature of these bots both in an individual level and in swarm level? These are all questions that need to be answered and which will be done in due course of time.

REFERENCES

[1] Yichen Hu, *Swarm Intelligence.*

[2]Ying Tan, Zhong-yang Zheng, *Research advance in Swarm Robotics (2013).*

[3]Vito Trianni, ElioTuci, Christo Ampatzis and Marco Dorigo, *Evolutionary Swarm Robotics: a theoretical and methodological itinerary from individual neuro-controllers to collective behaviours.*

[4]Yogeswaran M. and Ponnambalam S. *G, Swarm Robotics: An Extensive Research Review.*

[5]AmritSaggu, PallaviYadav, Monika Roopak*, Applications of Swarm Intelligence.*

[6]M. Dorigo, and T. Sttzle*, Ant Colony Optimization. A Bradford Book, (2004).*

[7]Bonabeau E, Dorigo M, Theraulaz G,*From natural to artificial swarm intelligence. Oxford: Oxford University Press; 1999.*

[8] Reeve HK,GamboaGj,*Queen regulation of worker foraging in paper wasps:asocial feedback control system (polistesfuscatus, Hymenoptera:Vespidae). Behaviour 1987.*

[9] Sandeep KumarJitendraKurmi, Sudhanshu P. Tiwari*, Hybrid Ant Colony Optimization and Cuckoo Search Algorithm for Travelling Salesman Problem.*