ASEAN Journal of Science and Engineering

Journal homepage: http://ejournal.upi.edu/index.php/AJSE/

Understanding of Collective Decision-Making in Natural Swarms System, Applications and Challenges

*Muhammad Abu Bakar**

Department of Computer Science, COMSATS University Islamabad, Abbottabad Campus, Pakistan
*Correspondence: E-mail: abubakarhameedch@gmail.com

ABSTRACTS

Swarm robotics is an emergent field that is inspired from biological system. Decentralized control for the achievement of global task. The concept of collective system is used to develop artificial systems that can perform the tasks in a collective manner, with minimum resources. In this paper we have presented group level intelligence to achieve global goals. Optimization strategies for swarm robotics, self-learning of agents by using trial and error, a well know technique of reinforcement learning and how system is designed to minimize the task allocation. We discuss some of the enabling factors at micro and macro-level and how these factors affect the modelling and intelligence of artificial system. Using the modern artificial intelligence, designing new systems to solve the complex research problems. And some of the key challenges in the field of swarm intelligence.

ARTICLE INFO

Article History:
Received 30 Sep 2021
Revised 16 Oct 2021
Accepted 18 Oct 2021
Available online 19 Oct 2021

Keyword:
Applications,
Challenges,
Natural Swarms System.

1. INTRODUCTION

As we know that swarm intelligence, the field reveals instead of a single agent, multiple agents are performing a collective task in order to achieve a global goal. There are some of the categories for task performance, like task that are easily solve able by single agent, so here is no need to use a swarm of agent, designers have to care about the cost in term of resources specifically, some of tasks that are easily solve able by traditionally multi-agents, existing studies show that, the distributed way of performing task is better in terms of, fewer complex agents are used for performing the global goal (O'Bryan *et al*., 2020). Agents must be autonomous so that can be capable of collaborating with other team agents and interacting environment. Designers must keep in mind the control should be distributed, means there is no need for a central planner. And this will reasonably affect the ability of decision making, agents must made decision on basis of mutual interaction. No central planner is directed to make a decision for implementation. And in this manuscript, we will preview task allocation for multi swarm agents. Different modelling techniques, some of the current challenges and the applications of swarm robotics in solving real world problems. As we know that a piece of work is easily performed by team of agents as compared to a single agent. Means two heads are better than a single. Researchers are studying, how a cognitive and performance of team will be increased in order to take full advantage of effective team for collaborative task. Here a term collective intelligence is used, that means instead of a single mind different minds are used collaboratively to perform a certain goal. And for this purpose, some of the common traits must be insured, the most important is the intelligence, the communication and coordination among team members, the collective performance of team members, last but not the least, the traits of individual agents reasonably effect the team performance. But unluckily so far, researcher is failing to meet up a good mechanism that is use to derive team outcome from individual traits and processes that are individually performed by agents (Dudek *et al*., 1996).

2. METHODS

Same like foraging, clustering of objects is also having some of the methods. When the agents are searching for some particular objects in search space, their movement is usually random. And sometimes the agents are unable to deliver the object to its defined state or location, then the way, they follow up is just same as searching for objects. The most important fact is, during clustering the sensing power and range of agents is limited. And secondly it is hard for these agents to remember, at which object they interact in past, in other words we can say that, the agents are using short term memory for clustering of objects.

Every time we talk about decentralization, the deployment is also some time like this, means the agents are capable of deploying themselves in real environment and there is a decentralized way of communication and no central control (**Table 1**).

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6098 e- ISSN 2776-5938

Table 1. Methods.

Methods	Definition	Benefits
Direct communication	The way of communication in which the agents can sense other agents near to them, and share information.	Helpful in such type of tasks that are self-deployed. It also enhances the cooperation.
Stigmergy	If is also a type of communication, new agents get information from previous ones, and move to the area where other agents performed task. It is also like foraging.	This method is helpful for agents not to repeat the actions already performed and secondly prevent agents to explore already explored area.

3. RESULTS AND DISCUSSION

3.1. Swarm Level Intelligence

Krause *et al.* (2011) works on animal intelligence, a swarm of animals can be easily accomplished task like protecting themselves against enemies or catching more prey. In simple words the swarm of animals living together are actually solving the cognitive problem in a more effective and efficient manner, but this solution that is achieved at group level never be accomplished by a single agent (Krause *et al*., 2010). Actually, intelligence is not only bounded to humans, when we trace back, we will be come to know that system level intelligence is derived from biological systems, like a swarm of ants, swarm of birds or fish school.

3.1.1. Colony of Ant performance in Group Members

Ant colony optimization is a well-known biological example that we have ever seen (see **Figure 1**). Ant's exhibit the most interesting behaviour when they are finding their path in search of food. Ants go out for the search of food and bring back to their nest. The study shows if there are two different paths that are going to the food source. Ants follow both the passages and leave a pheromone trails, after some time when they come back to the nest, they follow the shortest path. Meanwhile pheromone is on the both ways. But when on certain path that is short ants move rigorously, there will be more probability that the path is having high intensity level of pheromone. After some time, all the ant colony adopt the shortest path. More interestingly there is no central control for swarm members (Dorigo, 2007).

Figure 1. Colony of Ant Performance in Group Members.

DOI: http://dx.doi.org/10.17509/xxxx.xxxx
p- ISSN 2775-6793 e- ISSN 2775-6815

3.1.2. Flocking in Birds Intelligence

We have noticed when birds fly, they arrange their selves in a pattern forming V shape, to become safe from enemies and increasing the chances for their survival. Let's talk about the protection from enemies. When the flock of birds fly, forming a special pattern is more beneficial when a predator is trying to reach the flock. There is a maximum probability, predator must be seen by more than a single bird in the flock. As compared to a single bird that is flying their own. Then a message generated that will propagate within a short span of time to the flock. And the message is sent by a bird to its adjacent one, likewise this message is received by all flock of birds. This is also efficient in foraging, if a member finds out some food, all other members dive towards the spot. However, flying in flock is more beneficial as compare to flying individually (Dorigo, 2007) (see **Figure 2**).

Figure 2. Flocking in Birds intelligence.

3.1.3. Swarm Intelligence in Fish

Now we talk about swarm of fish, we have ever seen fishes swim in a same direction in a coordinated manner. But we don't go beyond the reason. Actually, the movement in a swarm is helpful for protecting them from predators. When a shark wants to attack the alarm, message generate and it is propagated to all swarm members. All the members are moving in same direction with a constant pace. This type of movement in swarm is also helpful to reduce body friction and secondly low energy consumption (Dorigo, 2007). Actually, these school of fish and other biological system are self but well-organized processes, there is no leader but the swarm perform better, just the way of communication is mutual and local interaction and this is meaningful for decision making process (see **Figure 3**).

Figure 3. Swarm Intelligence in Fish.

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6098 e- ISSN 2776-5938

3.2. Advancement Base Methodologies for Control Systems

Control strategies are actually inspired by the biological systems like ants and bees. These are simple heuristic that works on the rule-based approaches and becomes more complex. In case of task allocation and performance these rules are difficult to adopt. Keeping this thing in mind designers proposed a strategy named deep reinforcement learning strategy for solving the coordination problem in case of multi-agent swarm. Generally, there is a controller, for controlling all the performances of agents and define the cost function for the performance of global task. But in RL, the algorithm automatically set a cost function for the swarm system and define a policy for task performance. Deep RL minimizes reasonably the cost and resources. However, there are two main challenges that are faced by this approach.

(i) Dimensionality Issue. Dimensionality issue, as the size of the swarm increases the issue caused.
(ii) Change in information. Status of the information is changed, as new agents are entered and some are left from swarm, the available information is updated.

Dimensionality issue, as the size of the swarm increases the issue caused. Status of the information is changed, as new agents are entered and some are left from swarm, the available information is updated. As we know that in decentralized approach the information propagates among the swarm member is based on the mutual coordination, and information from one agent is sent to the other one, when some of the extra information is added this leads to dimensionality issue.

3.3. Agents to Perform Task on Basis of Trial and Error

Agents learning algorithms are specifically designed for the agents to perform task on basis of trial and error, and this is purely based on Markov decision process. In case of swarm, it is defined as five tuples (N, A, P, O, R). N, number of agents in a swarm. A prototype for an agent (A). And this prototype is four tuples (S, O, A, Φ). S, a local set of states for agents. O, local observations for different agents. A, action performed by the agents and a Φ control policy, which is the product of local actions and local observations. P is the state transition model, R is global reward function (Bernstein, 2002).

3.3.1. Local Communication Model

After the observation of local information of adjacent agents on interacted graphs, the next step is communication among these adjacent neighbours. Let suppose there are two agents x and y, these are adjacent to each other on interacting graph. Obviously, their operations are also performed on the local graphs. For example, as in swarm different agents are interacting to each other, if it is decided to compute the shortest path by swarm, it must be observed by at last one of the swarm members by using the local protocols for coordination.

3.3.2. State Representation for Swarm

The information that is receive from one agent to another is affected by some of the factors like distance between the agents and angle between senders to receiver of information. In case of more complex and vague information some other factor like velocity are also encounter. If the agents are interacting in the same network the permutation invariance is affected, some of the drawback of this model are, the growth of model is linear along with the number of agents first, secondly the neighbour are in a specific number when interacting with neural network policies (see **Table 2** and **Table 3**).

Table 2. Enabling Factors at Micro-level.

Level	Theme of study	Defining theme	Approaches	Community con-attribution
Microscopic	Collective intelligence	The problems of computational intelligence are solved by using the group intelligence in case of human.	Stimulus response, nonlinguistic problems and problems related to social signaling.	"Collective Intelligence"
Microscopic	Intelligence factor and factor in human groups	Group performance is described on the basis of collective intelligence called c-factor (Woolley *et al.,* 2010).	Cognitive task emerges from correlation (Woolley *et al.,* 2010).	Woolley, A. (2010) " Factor of collective Intelligence and performances"
Microscopic	Dynamic of swarm robots at behave- ioral level	Autonomous robots are used for the purpose of distributed manipulation with reactive controller Martinoli *et al.* (2004).	Non-spatial without defining the trajectories Martinoli *et al.* (2004).	Martinoli *et al.* (2004)" collaborative distribution manipulation"

Table 3. Modelling and Macroscopic.

Level	Theme of study	Defining theme	Approaches	Community con-attribution
Macroscopic	Decision making	Agents Locally interact with each other without central control, decision is made to achieve goal (Prasetyo, 2019).	Different alternative solutions available but swarm has to choose best optimal solution (Prasetyo, 2019).	collective decision making for dynamic environment.
Macroscopic	Wisdom of crowd	Intelligence level and estimation of group is much better as compare to individual agents.	Decision making on basis of intellectual pattern and emergent behaviour (Prasetyo, 2019).	conflicting Opinion and collective intelligence.
Macroscopic	Aggregation	The smaller chunks of information from agents are combine in such a way to derive a collective information.	Independent individuals socially interact with each other, provide solution to cognitive problems (Prasetyo, 2019).	Krause *et al.,* (2011) "swarm intelligence for human"
Macroscopic	Independence	As there is no central control, so it is ensured that agents are independent of each other, decision of one can't affect other.	"social influence effect", "range reduction effect" and "confidence effect" are factors ruins the wisdom of crowd (Prasetyo, 2019).	Lorenz *et al.* (2011) "social in flue nce undermine wisdom of crowd"

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6098 e- ISSN 2776-5938

3.4. Swarm Robotics Challenges in Real World Application

As we know that there is a difference in running robot inside a simulator environment and a real environment. So, there are many factors that are encounter in real world application, but in simulations they are in controlled manner, we are encountering some of the key problem in the field of swarm robotics.

3.4.1. Robotic Consuming More Energy

First of all, we discuss what the energy problem is? And how it caused, and effect the swarm behaviour? As we known that the robotics systems are consuming energy, so it means if there is a swarm of robots that is trying to achieve the global goal, in real world scenario, swarm has a proper energy backup for effectively and efficiently doing the task. If the energy depleted the swarm system becomes fail. As robots are physically designed, when robots are in action there is maximum probability that swarm is consuming more energy. So, to overcome this issue the designers are working on battery consumption, however this is ensured that for performing a specific task the swarm has sufficient energy. And secondly if there is problem for making a sufficient battery, they these batteries must be rechargeable in real scenario. However, this is a tough task to charge the swarm at run time.

3.4.2. Energy Problem and Their Modern Solution

There are some of the different ways that are adopted by designers to overcome the problem of energy depletion in swarm system, the first one is minimizing the robot's weight, this is the very first and a big issue for more energy consumption. Secondly, to overcome the communicating range between swarm, other swarm agents and the interacting environment. Sometimes designers are using undirected links between the swarm agents, the drawback of this approach is swarm explore all the search space that is also a big issue for saving energy, so use of directed links must be ensured (Cortes *et al*., 2004). Power and energy consumption can be resolved by minimizing the distance, oscillatory movements and instead of initiating multiple starting and stopping point, make only one start and stop point (Yang *et al.,* 2007).

3.5. Challenges in the Research Advance in Swarm Robotics

This section is a motivation to young researches, this is a source of information that how much work has been already done, and for solving some of specific problem, which type of approach must be followed.

3.5.1. Gathering

Gathering is a common behaviour that is observed in biological systems like insects and other animals. Now we discuss what aggregation actually is? Aggregation means placement of swarm agents in random place, in the interacting environment. Aggregation is basis for development of many mathematical models, development of various algorithms for both static and as well as dynamic environment.

3.5.2. Structure

Some of the important structure are used for the purpose of controlling swarm movement, controlling swarm agents and many other factors like artificial evolution (**Table 4**).

DOI: http://dx.doi.org/10.17509/xxxx.xxxx
p- ISSN 2775-6793 e- ISSN 2775-6815

Table 4. Methods for Controlling Aggregation in Swarm.

Methods	Definition	Inspiration	Practical implementation	Practical implementation
Artificial physics	By using the virtual forces, the individual behaviour is formed, these forces are like attraction and repulsion.	Biological systems like ants, birds and fishes.	Widely used for dynamic environment with real robots.	Much sensing capability, less cost effective, wide range of viability.
Probabilistic methods	Behaviour of each agent is predicted by interaction and a random manner.	Social insects, like honeybees and cockroaches.	Work on the concept of finite state machine i.e. Walk and wait.	Use with swarm dynamic, find out distance b/w agents and random movement.
Evolutionary methods	Achievement of dynamic aggregation by using controller like neural network (sensory methods for input and output).	Some of the algorithms used like genetic algorithm and q-tournament selection.	Gomes et al proposes novelty search, that do not work on concept of fitness-based evolution and prevents to stick at local maxima (Gomes *et al.*, 2013).	Efficient and effective outputs as compared to domain similarity measures.

3.5.3. Schooling

Schooling is the behaviour that is commonly observed in bird species, in which swarm of birds are moving towards their targeted location in a collective manner. Such type of behaviour are also observed in some other biological species like the fish schooling. Local interaction between agent's resultant in emergence at global level.

3.5.4. Techniques

According to researcher the flocking defines the distance and orientation between the agents. The study of animal flocking by Reynolds reveals that, there are three basic principles that are resultant for the achievement of global behaviour like flocking or any other. These are avoiding the collision, second is matching the velocity between other team agents and third one is flock centring means making a constant distance between all other team agents (Reynolds, 1987).

3.5.6. Design

When agents are foraging means they are doing two types of task, in the first one they bring some of the food item to the nest and second one agent are making cooperation between other team agents. In such a way that their cooperation is based on local interaction that results for enhancement of scalability, some of the approaches used for this purpose are discussed in **Table 5**.

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6098 e- ISSN 2776-5938

Table 5. Design.

Design	Definition	Benefits	Challenges
Share memory	There is a medium known as share memory, all the information Relevant to interaction and communication is broadcasted by using this medium. And every agent can easily read and write its relevant information.	Analysis of information that is shared for the purpose of foraging and evaluating the overall Performances of agents.	This method is not adoptable for ensuring scalability and simplicity between swarm agents.
Communication via environment	The concept is inspired from insect like ants, in which they identify their surrounding ways on basis of a special chemical called pheromone. This is a way of indirect communication.	In case of artificial swarm robots, there is no chemical for predicting the ways for the agents. So here, static gradient is used, that is helpful for marking the nest location, in other words the intensity of gradient is higher when agents come closer to nest.	Pheromone Approach is used in biological and dynamic system; this is called a communication by means of environment but for artificial system such type of communication is define statically.

3.5.7. Interacting Environment

As objects are distributed in the interacting environment, the agents can make a group around the objects, we use term clustering of objects here. Sometimes agents are dealing with similar objects and sometimes there are different types of objects, it means clusters are also of different types.

4. CONCLUSION

We present how system performs in dynamic environment and adding or removing agents from swarm system. Although this paper is not a complete review, we believe that we have review some major steps and techniques that can be used as a base step for further designing of new models and meet up the challenges and overview some of the optimization techniques, discuss issues and applications of real problem identification and solution by using modern swarm robotics. We discussed some of the strength’s weaknesses according to different domains. Still there are many issues and challenges in designing such a system that is consider to be an ideal for solving complex real-world problems. Designers are working on collective behaviour using distributed algorithms, in such a way the agents use local interaction for achievement of global task without a central planner, the concept is inspired from biological system. We present in this paper how previous studies are used to develop some new techniques for local interaction, different methods and models that are used for coordination and communication.

5. AUTHORS’ NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

DOI: http://dx.doi.org/10.17509/xxxx.xxxx
p- ISSN 2775-6793 e- ISSN 2775-6815

6. REFERENCES

Bernstein, D. S., Givan, R., Immerman, N., and Zilberstein, S. (2002). The complexity of decentralized control of Markov decision processes. *Mathematics of operations research, 27*(4), 819-840.

Cortes, J., Martinez, S., Karatas, T., and Bullo, F. (2004). Coverage control for mobile sensing networks*. IEEE Transactions on robotics and Automation, 20*(2), 243-255.

Dorigo, M., Birattari, M., and Stutzle, T. (2006). Ant colony optimization. *IEEE computational intelligence magazine, 1*(4), 28-39.

Dudek, G., Jenkin, M. R., Milios, E., and Wilkes, D. (1996). A taxonomy for multi-agent robotics*. Autonomous Robots, 3*(4), 375-397.

Gomes, J., Urbano, P., and Christensen, A. L. (2013). Evolution of swarm robotics systems with novelty search. *Swarm Intelligence, 7*(2), 115-144.

Krause, J., Ruxton, G. D., and Krause, S. (2010). Swarm intelligence in animals and humans. *Trends in ecology & evolution, 25*(1), 28-34.

Krause, S., James, R., Faria, J. J., Ruxton, G. D., and Krause, J. (2011). Swarm intelligence in humans: Diversity can trump ability. *Animal Behaviour, 81*(5), 941-948.

Lorenz, J., Rauhut, H., Schweitzer, F., & Helbing, D. (2011). How social influence can undermine the wisdom of crowd effect. *Proceedings of the National Academy of Sciences, 108*(22), 9020-9025.

Martinoli, A., Easton, K., and Agassounon, W. (2004). Modeling swarm robotic systems: A case study in collaborative distributed manipulation. *The International Journal of Robotics Research, 23*(4-5), 415-436.

O'Bryan, L., Beier, M., and Salas, E. (2020). How approaches to animal swarm intelligence can improve the study of collective intelligence in human teams. Journal of Intelligence, 8(1), 9.

Prasetyo, J., De Masi, G., and Ferrante, E. (2019). Collective decision making in dynamic environments. *Swarm Intelligence, 13*(3), 217-243.

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., and Malone, T. W. (2010). Evidence for a collective intelligence factor in the performance of human groups. *Science, 330*(6004), 686-688.

Yang, S., Li, M., and Wu, J. (2007). Scan-based movement-assisted sensor deployment methods in wireless sensor networks. *IEEE Transactions on Parallel and Distributed Systems, 18*(8), 1108-1121.

DOI: http://dx.doi.org/10. 17509/xxxx.xxxx
p- ISSN 2776-6098 e- ISSN 2776-5938