

## Article info

Received on: 27.10.2023

Accepted on: 27.11.2023

Published on: 30.11.2023

doi: <https://doi.org/10.52688/ASP53217>

## Research Article

# Swarm Intelligence In Swarm Robotics Applications

Shalau Farhad Hussein<sup>1,\*</sup><sup>1</sup> Kirkuk University, Collage of Science, Department of Computer, Kirkuk, Iraq\* [shalaufarhad@uokirkuk.edu.iq](mailto:shalaufarhad@uokirkuk.edu.iq)

## ABSTRACT

This paper provides a comprehensive introduction of the expansive domain of computational swarm intelligence and its various applications within the realm of swarm robotics. Computational swarm intelligence is a theoretical framework that seeks to understand and simulate the collective behavior of animals. Its primary application lies in the field of optimization techniques. The discipline of swarm robotics is a burgeoning area of study that is characterized by its rapid growth and draws inspiration from the concept of swarm intelligence. The utilization of problem-solving techniques observed in social insects, characterized by flexibility, robustness, decentralization, and self-organization, offers an alternative to traditional methodologies in the field of robotics. This study emphasizes the potential avenues for future investigation.

**Keywords:** Swarm Intelligence, Computational Swarm Intelligence, Swarm Robotics

## INTRODUCTION

Researchers have consistently found inspiration in the natural world. It is possible to observe patterns and discern sets of rules that confer logical order upon phenomena that may initially appear chaotic. What are the cognitive processes involved in thinking and memorization? Why does evolution have a significant role in the development of species? How can social insects possess the ability to navigate towards a food source without possessing comprehensive global knowledge? The process of addressing inquiries through artificial intelligence often leads to the emergence of new issues that require further investigation. Computational Intelligence (CI) is a constituent of the wider domain of artificial intelligence (AI) that encompasses several paradigms associated with biological or naturally existing systems. The paradigms under consideration encompass, fuzzy systems (FS), artificial neural networks (ANNs), swarm intelligence (SI), and evolutionary computing (EC). Artificial neural networks (ANNs) are computational models that simulate the functioning of the human brain. One notable attribute of artificial neural networks (ANNs) is their inherent capacity to acquire knowledge from the surrounding environment and effectively retain this information. The aim of this study is to simulate human reasoning by employing imprecise or fuzzy linguistic concepts. One advantage of rule-based expert systems is their ability to manage a wide range of scenarios based on explicit information. However, a limitation of these systems is their inability to effectively address novel situations that are not clearly addressed in their knowledge base. Evolutionary computation (EC), as derived from Darwin's theoretical concepts, pertains to problem-solving systems in computer science that employ computational techniques inspired by evolutionary processes, namely selection, reproduction, and mutation. These core components form the basis of computational systems within the field of EC. The social insect (SI) model is a theoretical framework that explains the social behavior exhibited by several species of insects, fish, and birds. The potential advantages of collaboration among people within a swarm can be substantial in scenarios where there is a lack of comprehensive awareness of the overall environment. Figure 1 displays a model of the CI paradigm that includes hybrid solutions. CI is most often used for optimization issues, while it may be applied to many other types of problems as well.

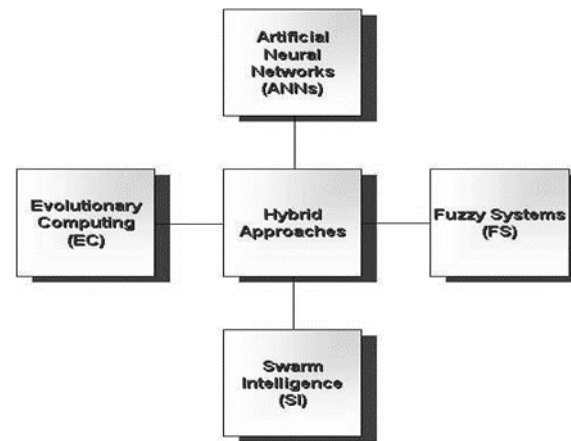
---

**\*Corresponding author**

Hala Husham Nussrat,

Environmental Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq

e-mail: [hala.husham@uomustansiriyah.edu.iq](mailto:hala.husham@uomustansiriyah.edu.iq)



**Figure 1: The topic of discussion pertains to computational intelligence paradigms**

## SWARM INTELLIGENCE

The SI systems exhibit characteristics that are commonly observed in populations consisting of uncomplicated agents that engage in local interactions with both their peers and the surrounding environment. The collective of individuals exhibiting behavior akin to that of a swarm [1]. The term "stigmergy" is employed to describe a sort of communication that is indirect in nature, occurring between individuals within swarms. This communication takes place through the modification of the environment by one individual, which subsequently influences the behavior of other individuals who respond to the altered conditions. Within a given group, individuals engage in interactions by exchanging knowledge that is readily accessible within their immediate surroundings. This collaborative process aims to achieve a solution to a problem or global objective in a more effective manner than what could be accomplished by a single individual. The phenomenon that arises from these interactions, characterized by collective problem-solving activity, is commonly referred to as swarm intelligence. The behavior under consideration is commonly referred to as computational swarm intelligence (CSI) within the realm of algorithmic models. To enhance clarity and facilitate understanding, the term commonly employed is "swarmed intelligence." The self-organization of various facets of social activity in the natural world is evident. Self-organization (SO) refers to a collection of dynamic mechanisms via which patterns emerge at the macroscopic level of a system as a result of interactions among its constituent elements [2]. SO is dependent on four fundamental components.

Recruiting and reinforcing are types of positive feedback (amplification). Some ant species use trail-laying and trail-following for recruitment to a food source, while bees use dances to do the same thing.

- Negative feedback: counteracts positive feedback by either causing tiredness or competitiveness, thereby stabilizing the overall group pattern.
- In many cases, amplifying the randomness introduced by fluctuations is essential for the development of novel solutions.
- Multiple interactions: a critical mass of compatible people is needed to birth a self-organized system.
- The goal of SI is to model simple individual behavior and the local interactions between individuals and their environment and neighbors in order to produce more complex behaviors that may be used to solve difficult issues, most commonly optimization problems. For intelligence to emerge, a certain threshold of people must be present.
- Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) are the most well-known SI algorithms.

## PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization (PSO) was initially motivated by the collective movement patterns observed in avian flocks [3]. In the context of the bird flock analogy, a particle swarm optimizer is comprised of several particles, analogous to birds, who navigate and explore the search space, akin to the sky, in order to identify the optimal position. Individuals engage in communication with each other, either through direct or indirect means, such as the use of search gradients. Each individual particle inside a swarm undergoes a multi-search process, where it samples an objective function at different points. The optimal solution can be represented as a point or surface within the search space. The space is utilized to plot potential solutions, which are then initiated with an initial velocity. The movement of a specific particle is determined by its velocity, which is continuously adjusted to attract it towards its optimal location as well as the optimal positions observed by neighboring particles within the group. The evaluation of each particle's performance is conducted by the utilization of a predetermined fitness function, which

---

### \*Corresponding author

Hala Husham Nussrat,

Environmental Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq

e-mail: [hala.husham@uomustansiriyah.edu.iq](mailto:hala.husham@uomustansiriyah.edu.iq)

encompasses the essential attributes of the optimization problem. Over the course of time, particles exhibit an acceleration towards individuals possessing superior fitness values. The Particle Swarm Optimization (PSO) algorithm is a straightforward yet very effective method for conducting search operations. The implementation of this system involves the adjustment of several parameters, which can be easily executed.

## ANT COLONY OPTIMIZATION

Artificial ant systems are computational models that aim to replicate the social interaction and seemingly intelligent behavior observed in genuine ant colonies. When observing ant colonies, it becomes evident that while the conduct of an individual ant may appear illogical, the collective behavior of the entire colony effectively addresses the challenges faced by the group. Ants employ trail-following behavior as a means of communication, utilizing pheromones to transmit information to their fellow ants through the surrounding environment. The emerging exhibits several behaviors, including as the ability to identify and access optimal food sources, as well as engage in nest construction and maintenance, including the upkeep of burial grounds. The Ant Colony Optimization (ACO) model, as outlined in the cited reference [4], functions as a conceptual framework that captures the communal foraging patterns displayed by ants. Deneubourg et al. (5) have provided evidence that the phenomenon of path selection in the direction of a food supply is subject to the effect of self-organization. The Binary Bridge experiment involves the observation of two ants traversing roads of varying lengths from their nest to a food source. The ant that will return to the nest first is the one that chooses the shorter route. Consequently, the pathway with a higher concentration of pheromones will serve as a magnet for attracting additional ants to follow the same trajectory. The phenomenon of increasing ant participation in response to a larger concentration of pheromones along a trail leads to the establishment of a positive feedback loop, ultimately resulting in the convergence of all ants onto the shortest path. Therefore, the environment is modified by pheromone deposits, leading to indirect social contact and coordination in the context of foraging. The fundamental concept that underlies all ant-based algorithms is the utilization of a positive feedback mechanism. This mechanism draws inspiration from the trail-laying and trail-following behavior exhibited by certain ant species, with the aim of strengthening the solutions. In order to enhance the retention and possible improvement of optimal solutions, a virtual pheromone is employed as a form of reward.

## SWARM INTELLIGENCE APPLICATIONS

Swarm intelligence (SI) techniques refer to a class of population-based stochastic methods that are employed in the domain of combinatorial optimization problems. These strategies leverage the interactions between individuals and their environment to generate functional global patterns, despite the simplicity of the individuals involved. There is no universally optimal optimization strategy applicable to all problems. Each approach possesses distinct merits, and the specific parameters determine the level of excellence exhibited by the solution. There is a growing interest among engineers in the study of swarm behavior due to its potential application in several domains such as optimization in communications systems, robotics, traffic patterns in transportation systems, and military applications. An increasing number of novel applications are emerging as a result of research in the field of social intelligence. The utilization of SI approaches can effectively address any problem application that is fundamentally based on optimization.

## SWARM ROBOTICS

Swarm robotics (SR) pertains to the utilization of swarm intelligence methodologies for examining activities involving physical robotic agents capable of intelligently making decisions and effecting changes in their surroundings. The objective of this methodology is to investigate the architecture of robots, encompassing both their physical structure and control mechanisms, with the aim of eliciting specific collective behaviors. These behaviors are intended to arise from the interactions among the robots themselves, as well as the interactions between the robots and their surrounding environment. While drawing inspiration from the emergent behavior observed in social insects, this approach is not confined solely to such observations. Techniques such as Ant Colony Optimization (ACO) and Particle Swarm Optimization (PSO) can be employed as control algorithms for networked robot swarms [6]. However, it is not necessary for the problem-solving system to possess biological relevance. The notable achievements of social insects in their ability to thrive and establish colonies on Earth can be viewed as a foundation for the development of novel metaphors in the fields of engineering and computer science.

## CRITERIA FOR SWARM ROBOTICS

What makes a system swarm-robotic?

Autonomy- The swarm-robotic system necessitates the inclusion of autonomous robots as its constituent entities. Individuals possess the capability to engage in physical interactions with their surrounding environment, thereby exerting an influence upon it. A significant quantity-A significant quantity of units is necessary in order to facilitate cooperative behavior and swarm intelligence. Defining and justifying the minimum amount poses a challenge. The swarm-robotic system has the capability to form

---

### \*Corresponding author

Hala Husham Nussrat,

Environmental Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq

e-mail: [hala.husham@uomustansiriyah.edu.iq](mailto:hala.husham@uomustansiriyah.edu.iq)

several homogenous groups of robots, each comprising a significant number of units. Robot groups that exhibit a high degree of heterogeneity often do not belong within the realm of swarm robotics.

Restricted capabilities — The individual robots within a swarm should possess limited functionality or exhibit inefficiency while operating independently with regards to the assigned mission.

Scalability and resilience are essential requirements for a swarm-robotic system. The inclusion of more units is expected to enhance the overall performance. Conversely, the removal of certain units is not anticipated to result in catastrophic failure.

Distributed coordination refers to the requirement that robots within a swarm possess only localized and constrained sensing and communication capabilities. The level of coordination among the robots is becoming more widespread. The implementation of a worldwide communication platform for the purpose of coordinating would have an impact on the level of independence exhibited by the individual units.

Although these criteria should not be employed for the purpose of determining the classification of a system as swarm-robotic, they can be utilized to assess the extent to which the term "swarm-robotic" may be applicable.

## SWARM ROBOTICS APPLICATIONS

In terms of application domains, swarm-robotic systems have the potential to be utilized in a wide range of circumstances.

Foraging – The present situation encompasses a wide range of potential uses and necessitates a set of essential abilities from a collective of robots, including but not limited to collective exploration, shortest pathfinding, and efficient work allocation [7]. Additionally, the work encompasses a sub-task that pertains to the developmental aspect of communal transportation [8]. Several examples of applications for foraging situations include toxic waste remediation, search and rescue operations (SAR), and gathering of terrain samples.

The development of a swarm-robotic system enables the adaptation of such systems to domains that involve hazardous operations, hence rendering human involvement in these jobs unnecessary. For example, the task of demining can be efficiently carried out by the utilization of a group of robots [9].

Numerous ongoing projects substantiate the significant level of interest in the topic of SR. The primary aim of the Pheromone Robotics project [10] was to establish a robust and scalable approach to efficiently coordinate the actions of multiple miniature robots, with the goal of achieving notable results across diverse domains including surveillance, reconnaissance, hazard detection, path mapping, payload conveyance, and manipulation on a small scale. The researchers derived inspiration from the chemical markers utilized by insects, namely ants, for the purpose of communication and coordination. The researchers employed a technique known as a "virtual pheromone" by implementing rudimentary beacons and directional sensors on each individual robot.

## ADVANTAGES TO CLASSICAL APPROACHES

Swarm-robotic systems possess several features that render them more attractive in comparison to traditional robotics. Certain tasks may need the execution by a solitary robot. The speed of the solution demonstrates a rise when a substantial quantity of robots is utilized, even in the absence of cooperation. Designing simple robot units for a swarm is a comparatively straightforward task. Social robotics (SR) is presently regarded as one of the most advanced domains within the field of social intelligence (SI). The utilization of Swarm technology offers the potential for improved task performance, increased dependability in the face of faults, reduced complexity at the individual unit level, and decreased overall costs when compared to conventional robotic systems. They possess the capability to complete some jobs that would be unattainable for an individual robot. The study conducted in the domain of swarm robotics demonstrates that a collection of very basic individual behaviors, when supplemented with effective communication, can give rise to a large-scale manifestation of intricate swarm behaviors. Exploration in the context of SR systems pertains to the collaborative actions undertaken by robots to navigate and investigate a given environment with the objective of fulfilling specific tasks, such as monitoring, surveillance, and spatial coverage. In this study, Duarte et al. suggest the utilization of swarm robotics systems for the purpose of conducting maritime environmental monitoring missions, with a specific emphasis on temperature regulation. The researchers undertake a simulation-based assessment of the robot's efficacy in expansive regions and with substantial swarm populations. Furthermore, the researchers successfully executed their proposed methodology in a practical aquatic swarm consisting of eight individual units. The findings indicate that the utilization of swarm systems proves to be advantageous in environmental monitoring endeavors that require extensive coverage of areas.

---

### \*Corresponding author

Hala Husham Nussrat,

Environmental Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq

e-mail: [hala.husham@uomustansiriyah.edu.iq](mailto:hala.husham@uomustansiriyah.edu.iq)

## CONCLUSION

This study provides a comprehensive analysis of the existing body of research on swarm intelligence and its practical implementations in the field of swarm robotics. Swarm robotics presents itself as a compelling alternative to traditional robotics methodologies due to the utilization of problem-solving techniques inspired by social insects. These techniques exhibit qualities such as flexibility, robustness, decentralization, and self-organization. There are various advantages associated with swarm-based robotics. Certain jobs may be designated for execution by a singular robot. The utilization of several robots results in an acceleration in speed, mostly attributable to the enhanced ease of robot design stemming from its inherent simplicity. The swift advancement of hardware technology facilitates novel developments in robot design, hence enabling enhanced levels of reduction. We are already approaching a point in technological advancement when the use of conventional, centralized, hierarchical command and control methods becomes impractical for managing systems that encompass numerous and constantly evolving entities, characterized by diverse communication patterns and heterogeneity. Swarm robotics, along with swarm intelligence as a whole, represents the sole viable approach for effectively managing intricate distributed systems.

## FUTURE WORK

Swarm robotics presents a multitude of topics that can be explored in future lines of research. Insufficient global awareness can result in an impasse, impeding the advancement of the collective of robots. Novel approaches are required to address the issue of stagnation prevention and evasion. The programming of robots is a challenge when the pathways to solutions are not predetermined but instead evolve. When well implemented, self-organization confers onto the swarm the capacity to respond and adjust to unforeseen circumstances. Promising avenues for future research may involve exploring methods to augment indirect communication among robotic entities. The field of swarm robotics, being in its nascent stages, presents ample opportunities for future research.

## REFERENCES

- [1] A.P. Engelbrecht, *Fundamentals of Computational Swarm Intelligence*, John Wiley & Sons, 2006.
- [2] E. Bonabeau, M. Dorigo and G. Theraulaz, *Swarm Intelligence: From Natural to Artificial Systems*, Oxford University Press, Inc., New York, NY, 1999.
- [3] J. Kennedy and R.C. Eberhart, Particle Swarm Optimization, *Proceedings of IEEE International Conference on Neural Networks Vol. IV*, pp. 1942-1948. IEEE service center, Piscataway, NJ, 1995.
- [4] M. Dorigo and T. Stutzle, *Ant Colony Optimization*, MIT Press, Cambridge, 2004.
- [5] J. L. Deneubourg, S. Aron, S. Goss, and J.M. Pasteels, The Self-Organising Exploratory Pattern of the Argentine Ant, *Journal of Insect Behavior*, 3: 159-168, 1990.
- [6] Y. Meng, O. Kazeem and J.C. Muller, A HybridACO/PSO Control Algorithm for Distributed Swarm Robots, *Proceedings of 2007 IEEE Swarm Intelligence Symposium (SIS 2007)*, pp.273-280, April 2007.
- [7] A. Campo and M. Dorigo, Efficient Multi-Foraging in Swarm Robotics, In *Advances in Artificial Life*, *Proceedings of ECAL 2007*, volume LNAI 4648 of *Lecture Notes in Artificial Intelligence*, pages 696-705. Springer-Verlag, Berlin, Germany, 2007
- [8] A. Campo, S. Nouyan, M. Birattari, R. Groß and M. Dorigo, Negotiation of Goal Direction for Cooperative Transport, In M. Dorigo, L. M. Gambardella, M. Birattari, A. Martinoli, R. Poli and T. Stutzle, editors, *Ant Colony Optimization and Swarm Intelligence: 5th International Workshop, ANTS 2006*, volume 4150 of *Lecture Notes in Computer Science*, pages 191- 202. Springer-Verlag, Berlin, Germany, 2006.
- [9] V. Kumar and F. Sahin, Cognitive Maps in Swarm Robots for the Mine Detection Application, *IEEE International Conference on Systems, Man and Cybernetics 2003*, vol.4, pp. 3364-3369, Oct. 2003.
- [10] D. Payton, M. Daily, R. Estkowski, M. Howard and C. Lee, Pheromone robotics. *Autonomous Robots*, 11(3): 319-324, Nov. 2001.

---

### \*Corresponding author

Hala Husham Nussrat,

Environmental Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq

e-mail: [hala.husham@uomustansiriyah.edu.iq](mailto:hala.husham@uomustansiriyah.edu.iq)