# SWARM INTELLIGENCE ALGORITHMS: CONCEPTS, MODELS, APPLICATIONS

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***ABSTRACT****—Swarm intelligence is one of very important concept in artificial intelligence. The essential idea of implementing the swarm intelligence algorithms is to employ many simple agents applying with minimum number of rules which in turn leads to an emergent global behavior. Self-organization is the main theme with limited restrictions from interactions among agents. Many famous examples of swarm intelligence come from the world of animals, such as birds flock, fish school and bugs swarm. The social interactions among individual agent help them to adapt to the environment more efficiently since more information are gathered from the whole swarm. In this paper, we will introduce some of the most famous and effective bio-mimicry algorithms and discuss them with the implementations of these algorithms in various applications based on meta heuristic derived from nature and their applications in problem solving.*

**Keywords**—swarm; intelligence;artificial intelligence; swarm algorithm; swarm intelligence.

## I. INTRODUCTION

The last three decades researchers' interest in Artificial Intelligence has gradually increased to serve the evolution of technologies. The AI field is wide in many different paths. It is where human rely on machines to solve problems depending on certain criteria given based on specific rules and actions.

Many phenomenon's we observe in nature and living organism's behavior are a source for inspiration for scientific research and sometimes a more direct interpretation by abstraction and analysis yields a more tangible results and output. Colonial animals such as bees and ants demonstrate a highly efficient organized behavior that is in abstraction highly resembles how nodes communicates in computer networks and artificial intelligence implementations. While the main objective of these animals is tailored to ensure survival and sustainability as per the evolutionary process, the behavior proven to be highly efficient and not at all random and disruptive, some studies observed the behavior of ants locating food outside the anthill and how they almost always mark and use the shortest paths while utilizing their numbers efficiently. Other were fascinated by bees and wasps as they have classes and specializations to coherently work in an apparent autonomous manner.

Abstracting this behavior, categorizing it and distinguishing key data artifacts results in the creation of highly efficient algorithms. The beginning of the idea started at 1991 by Kennedy and Eberhart. This was an evolutionary progress in AI. The creation of this model has led to an implementation of numerous other SI algorithms. The SI heuristic based not only served the technical part but also helped in the medical and science fields such as genetics. The Particle Swarm Optimization (PSO) for example, simulates the social behavior and behavior of bird and fowl to find shelter, and food sources or another suitable habitat. It's been used in Biomedical, Communication Networks to say the least more emphasis later in this works. Based on [19], PSO comparing to other SI algorithms obtained the highest usage in papers by researchers due to its effectiveness in problem solving with obvious results.

We would also discuss Artificial Bee Colony Algorithm(ABC). This type of algorithms is deduced from the behavior of bees adjusting the number of working bees in the colony according to the available food finding sources with various utilization from traffic systems to robotic navigation and path finding. Another type is Evolutionary Algorithm (EA), where the diversity of the population genetics and how they evolved comes under the spotlight. These algorithms are the main algorithms behind the study of genetics evolution and how it functions. The last one of the main types of swarm intelligence algorithms is Ant Colony Optimization (ACO). In ants, the individual ant worker behavior is embedded into the social interaction behavior like in relocating food and finding shortest paths. This type of algorithms is very popular in pattern recognition and robot vision. These types of algorithms fall under Swarm Intelligence Algorithms.

The main goal of this paper is to discuss the types of Swarm Intelligence Algorithms, covering:

- Particle Swarm Optimization (PSO).
- Artificial Bee Colony Algorithm (ABC).
- Evolutionary Algorithm (EA).
- Ant Colony Optimization (ACO).

In the next few sections we will be going through each one of them and analyzing the efficiency and comprehensiveness of these algorithms for optimum utilization of SI.

## II. LITERATURE REVIEW

The researchers lately are highly interested in using SI algorithms to solve problems and deploy it in their applications based on metaheuristic nature derived as it proved the reliability comparing with traditional algorithms. Attention has been paid to this type because of the diversity and flexibility it offers to adapt and solve many types of problems and complex problems.

Using particle swarm methodology, a nonlinear function optimized to introduce this concept and proposed a nonlinear function optimization and neural network training. It's considered as a medium-level form of biologically derived algorithm. The evolutionary computation has a clear relation with particle swarm optimization. It has been simulated using simplified social model. The simplicity of PSO was effective to improve a lot of functions[22]. The Particle Swarm Optimization presented to properly find the optimal global best particle by group of moving time periods and number of neural networks for future stock investment choices using previous stock data. The proposed method achieved better and reliable results in the investments from the marke. [24]. The Artificial bee colony ABC a new approach proposed by [25]. This meta heuristic algorithm simulates the real honey bees for solving the problems of multidimensional and multimodal. It consists of employed bees, onlookers and scouts. The study based on finding global minimum of three know test functions. The

new proposed model comparing with previous model is simpler and more flexible. The opposition-based concept proposed to enhance the Artificial bee colony algorithm through initialization and jumping in [20]. The initialization was randomly allocated while on jumping is also initialized and applied the same, but then jumps from a position to another until the ideal position is located. By comparing the performance of the new along with original OABC and ABC, the OABC obtained superior results.

In order to optimize the project resources, a new genetic evolutionary algorithm GA proposed to investigate the start-up of non-critical activities by [26]. This algorithm aims to solve the resource optimization issues in projects. The GA proves the capability of solving complex problems in allocating the optimal resources and coping real world projects. The simulation of complex animal arranged tasks in robots require researchers to derive mathematical models and mimic the actual animal behavior such as birds' nests selections and combine them as an algorithm. A distributed algorithm, Grammatical Evolution algorithm for Evolution of Swarm behaviors (GEESE) proposed in [23]. The algorithm benchmarked by GE Grammatical Evolution and Santa Fe Trail and showed promising result by the second one.

In [21]a new approach was proposed with the class of problems that can be applied with. The algorithm called Ant colony optimization ACO metaheuristic-based which is a combination of previous ant systems. The ACO obtained a short overview by Applying to traveling salesman and routing in packet-switching networks.

An ant inspired Ant Colony Algorithm proposed in [27] to solve the problem of the Maximum Edge-Disjoint routes in networks to improve the speed and was compared to a multi-start greedy model. As a result, the new approach showed an optimized result to the quality of service and time.

The PSO and ACO are both studied in [33] to find the optimal placement for distributed generations in networks. By using SI approaches complex problems can be solved easily. The comparison between the two algorithms highlighted the huge difference of how many previous researches have been done on PSO to solve DG deployment problems.

Based on the chemical insect like ants, an approach presented in [28] to coordinate the behavior of numerous small robotics by using virtual pheromone which consist of chemical elements used to transfer signal from one animal to another, it's called symbolic message. In [29] a nature inspired ACO for self-regulation of the level of infrastructure in ad hoc networks for achieving a scalable, dynamic self-organization. The main factor for calculating pheromones used by matchmaking performance. The approach obtained a reliable behavior of the system in managing the resources. In [34] in order to solve the early convergence in robots an enhanced particle swarm algorithm with random factor proposed and in a multi-robot system. The approach tackles the coordination in multi robots in cleanup task as it is critical under a dynamic environment. The modified PSO obtained a significant result and high performance in searching, cleanup tasks and to handle the issue of low convergence. Self-organizing particle swarm optimization algorithm is used on image fusion based on region energy to get the image fusion using the better particle in [35]. The self-organizing particle solved the issue of close values by ideal search method. The preferable fusion results can be gained on both subjective analyses. The self-particle swarm have a higher optimization rate the standard PSO. By [32] a new PSO called Discrete Particle Swarm Optimization DPSO and Intelligent Discrete Particle Swarm Optimization IDPSO that is suitable for any discrete optimization problem. The new model used to schedule the task efficiently in heterogeneous multiprocessor systems. The proposed approach aims to solve the scheduling problem and the obtained results showed its efficiency.

In [39] a new model was proposed for solving optimization problems called cat swarm algorithm CSO. This model defined the coverage intensity for network node based on the cat's behavior. An enhanced parallel EPCSO presented in [36] to balance the power consumption in network sensor nodes to design routing for providing balanced routing paths. The deployment of this model result in an acceptable reduced consumption power rate comparing to other algorithms.

The Benefit from the intelligence of human groups was proposed by comparing the crowd to the swarm in [37]. The study was conducted on a non-equal sample with higher number of crowd's sample. The set of easily verifiable of prediction events the comparison conducted on the predictive ability between swarm and crowd. The swarm amplified the result regardless the difference in the sample. The accuracy amplifying of the prediction is tested in [38] using SI. The group was formed to test the accuracy of swarm with real time and closed-loop swarm. The members together obtained a higher prediction results than when they were alone which proved the accuracy of amplifying the prediction using SI.

The quality of service (QoS) requirements affect the deployment and mapping of components in networks, to overcome the issue a nature based heuristic SI algorithm proposed. The deployment of the components done using Cross Entropy Ant System (CEAS). The process starts by searching the best solution using many agents with consideration to QoS. The results from the model managed to obtain the deployment of components with considered QoS rates [40].

A heterogeneous wireless sensor nodes and channels applied in [41] using binary optimization based on three swarm algorithms. The simulation results on real problems showed a great result for bin PSO comparing with bin ACO and finally bin ABC. In [31] MANETs is when all nodes are at the same level without the need for a central coordinator while they are formed by portable wireless devices that do not require a predefined infrastructure. The routing is highly required in this kind of network. In order to solve the routing issue there are different ways to do that. In this research a metaheuristic routing algorithm proposed based on ACO a hybrid Ant colony algorithm routing (HACOR). The result of the simulation compared to latest routing protocol, that the proposed approach showed a significant performance.

Finally, a comparative evaluation performed at [30] to study the swarm intelligence algorithms in detail for solving combinatorial optimization problems. The traveling salesman used as a benchmark in this study. After a thoroughly investigation of numerous benchmarks, the ABO proved to be the best algorithm for solving combinatorial problems, then the FFA, HBMO, GA, BA, PSO, ASA-GS

and finally the ACO in this order. The reason of the high performance of the first two the African Buffalo and the Firefly Optimization can be as these are a new creation

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### A. *Types of SI Algorithms*

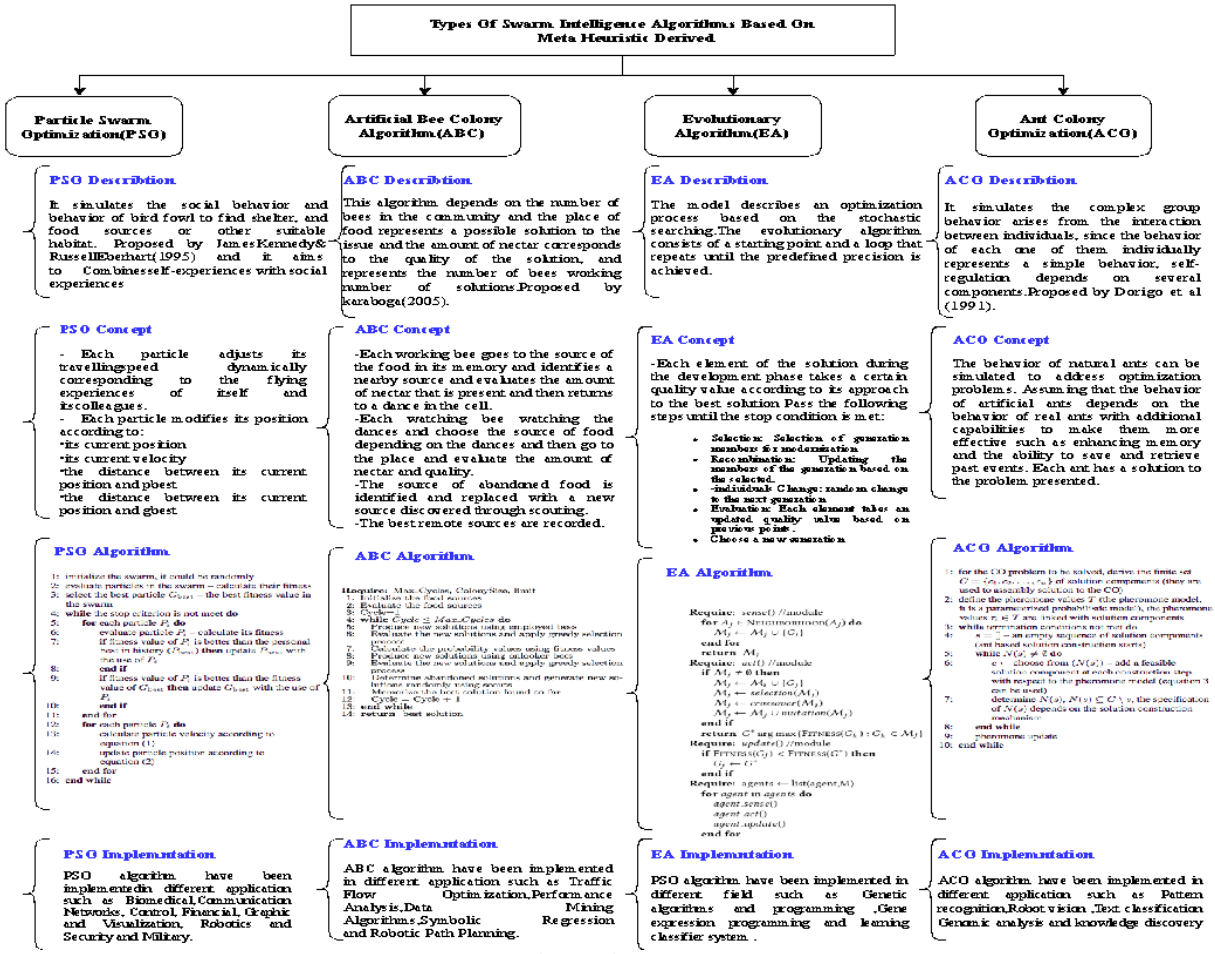


**Fig. 1 Classification for SI Algorithms.**

### B. *Advantages and Disadvantages of SI Algorithms*

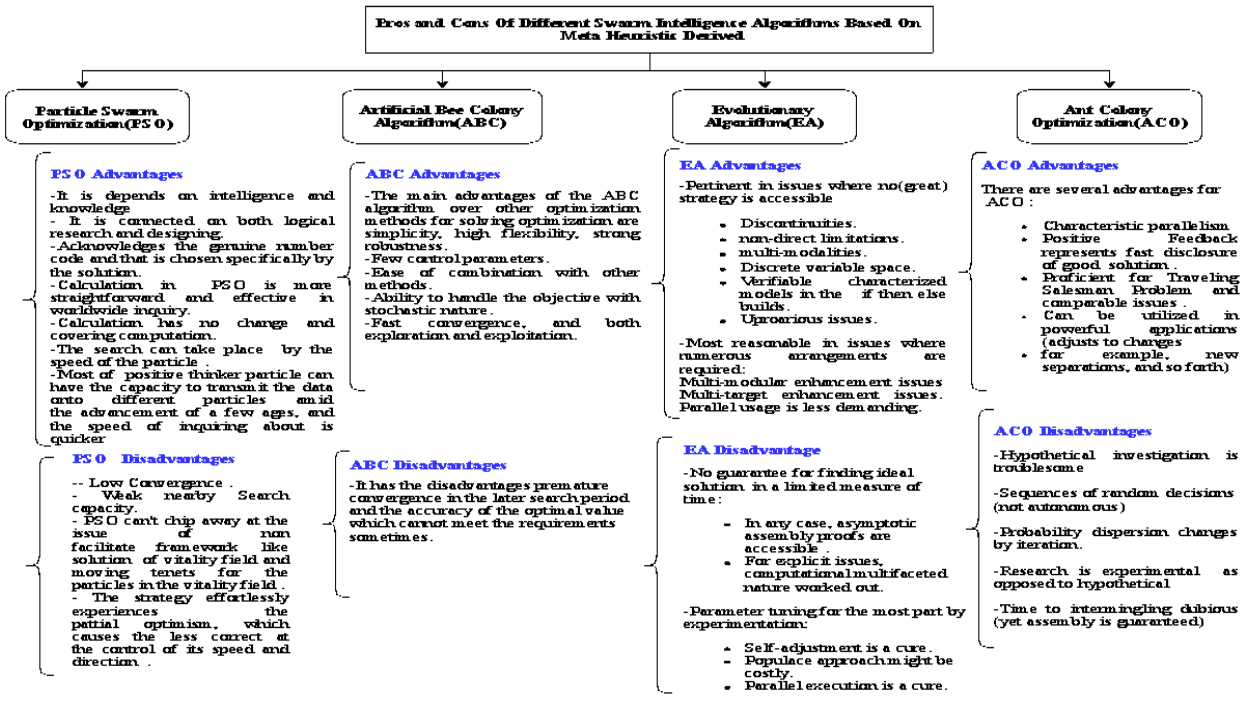


**Fig. 2: Advantages and Disadvantages of PSO, ABC, EA and ACO Algorithms**

## III SWARM APPLICATIONS

Swarm intelligence is a collection of intelligence groups of simple autonomous agents with self-organization. The autonomous agent can be explained as system that can communicate its environment, which may consist of various similar type of contents, but acts independently from all other agents. These agents do not follow the leader's instructions or any swarm's global plan. In Swarm Intelligence various algorithms has been implemented out of these the most important algorithms has been already discussed in last section. This paper will illustrate some of the major applications of swarm intelligence.

### *A. Swarm Robotics*

The coordinated logistics of movement in swarms is a stream of multiple-robotics in which several pre-conditioned robots are deployed and dispersed in a distributed and decentralized fashion. As huge quantity of simple and less complicated robots can perform complex assigned tasks in much better efficient method than a single and complex robot, giving robustness and flexibility to the swarm. The joint collective social behavior of the swarm insects was considered for a significant period of time a astonishing and fringe aspect of biology. The researchers have clearly demonstrated in recent decades that individual identity does not need any specific representation or dedicated sophisticated knowledge to entice such sophisticated behaviors. In social insects, the singular is not even communicated about the social status of the whole colony. no lead exists which is expected to guide all other individuals in order to accomplish their individual goals. The information of the swarm is distributed among all the participants of the colony, where single participant will not be able to complete its specialized contribution without the complement of the collective.

The social swarm operators or the creepy crawlies are proficient to trade the required data and convey for example, correspondence about the area of the nourishment source, a great and secure searching zone or the nearness of adversary or risk to themselves or the mates in the colony. This correspondence and cooperation between the swarm individual's member depends on the idea of area, where there is no other learning about the present and by and large situation is available. This exclusive and implicit communication for the changes occurred in the environment is called strategy. The swarm members can change their social behavior because of the previous modifications made by their swarm members in the swarm social environment. The example of this scenario is the nest development process of termites, where the modification in the behaviors of the workers are determined by the structure of the nest. Organization emerges from the interactions between the individuals the swarm environment. any single individual swarm member. This kind of collective behavior is known as self-organizing behavior. The self-organization theories which are referenced from Science specifically from physics and chemistry domains, can be utilized to demonstrate the complex collective behavior of social insects which inherits from interactions of individuals swarm entity's behaving normally. The self-organization completely depends on the combination of the basic swarm rules i.e. feedback (positive, negative), randomness, and multiple interactions of individuals [3].

### *A. Crowd Control*

The concept of crowd control mainly centralized on creation of sensible smooth and adaptable movement for virtual human by utilization of the computational facilities available in PSO. Specifically, when a uniform conceptual model based on PSO is developed to simulate the movement of the virtual human being in large gathering as per the analogy between a swarm entity and huge number of human populations. A human can be identified as an individual particle, which would like to explore the available solutions and find the best suitable methods. The PSO does contain some features of the crowd's behavior. In PSO the particle is free to move everywhere in the given multidimensional space.

The swarm environment for a crowd may suffer from various issues and hindrances, and the pedestrians existing in the crowd must avoid accidents and collisions. This type of dynamic hindrances is completely unpredictable and may occur at any moment in any circumstances.

### *B. Inverse Heat Conduction Problem*

The backwards warm conduction issue is significantly too hard to determine than the immediate warmth conduction issue in which the fundamental and the restrictions are very much characterized and recognized, the most important factor the temperature which must be taken into the consideration. In Swarm Algorithms the ABC and ACO algorithms can be utilized to decrease the practical representation, which is very crucial content of this approach which leads to resolve the inverse heat conduction issues which consist in heat outflow rebuilding In the problem of reverse conductivity of heat with limited conditions to be analyzed temperature distribution that need to be identified and controlled, the form of heat transfer coefficient is reshaped in the case of limited limits of the third type. The swarm intelligence algorithms are extremely beneficial to resolve this problem. After deploying these algorithms, the outcomes are quite satisfactory for a limited quantity of individuals as well as iterations.

### *B. Implementation of Swarm in Inverse Analysis in Civil Engineering*

In Civil Engineering the applications of identifying the design and contents of Structural building material utilizing various type of Particle Swarm Optimization. Most of the applications of engineering suffered of negligence from various required mechanical parameters. It is specifically required while it is very important to analyze the category of soil necessary to analyses soil contents and behavior. Nevertheless, it is not always suggested to analyze the values of all available parameters soil mechanics [6]. The opposite analyses is an effective and reliable method to achieve those goals. This mechanism has become quite popular due to considerable improvement of computational capabilities. The computational cost has considerable reduced and also allowed to handle the complicated optimization issues through meta-heuristic methods i.e. identification of issues such as the mechanical parameters of any behavioral pattern of a soil to describe the optimal part of the beams forming a truss structure and Consider the environmental influence through the life cycle of the framework [7].

### *C. Applications in Electric Instruments*

The PSO algorithm has possible applications in various

electric motors and machines. The most desired features of PSO can be effectively utilized for maximum optimization optimize of the performance of electric and electronic machinery in various aspects. A field-oriented controller can be designed by implementation of PSO. While designing this method, the two asymmetrical furl inducement motor's speed can control while achieving the maximum performance and motor's efficiency. The PSO choose the best winding flux level at a given working time. The PSO algorithm is an important category of Swarm Intelligence algorithm (SI). The PSO consists of specifically designed speed control strategies i.e. one of them is field-oriented controller (FOC). It is implemented based on mathematically proved experiments. The outcomes of experiments and simulation process has clearly proved that FOC based on PSO algorithm is capable to saves more energy than the any other conventional system. The PSO is also capable to reduce the losses and reducing the operating cost of the induction motor operations. These techniques and strategies are based on PSO and are also known as maximum efficiency and minimum operating cost strategy.

*D. Applications in Software Engineering*

In today's technical and IT world the Software testing plays a key and valuable role in software development life cycle. Due various constraints like time and cost it is highly impossible to conduct manual tests and analyze the software rectify the bugs and defects. Thus, the testing automation process plays a very important role in the software testing. [10] Various Meta-Heuristic algorithms has to be applied to the following fields of software development process: generation of dataset required for software testing, construction of testing module and prediction of cost/effort involved in software development. The generation of dataset involves various activities required to produce the dataset required to satisfy the selected testing criteria [11].

*E. Image Classification and Segmentation*

The image classification and segmentation play a vital role in the image classification and interpretation. The image classification techniques can be categorized in various categories such as edge-based classification, region-based classification, histogram thresholding, and clustering algorithms. The goal of any clustering algorithm is to aggregate the dataset into groups so that the data in each group must share similar type of characteristics while the dataset clusters are totally distinct from each other. Various techniques are developed for optimization and affected by the behavior of natural systems. The outcomes of the experiments clearly demonstrated that swarm intelligence algorithms can be employed as a natural and most effective optimization technique for optimizing both Kmeans and SCL (SIMPLE COMPETITIVE LEARNING) algorithms.

In classification algorithms the K-means algorithm often unable to identify the clusters as it is mainly dependent on the initial cluster groups. The K-means algorithms can be classified as ACO-K-means and PSO-K-means algorithms which provides a larger identification space compared to the K-means algorithm. By implementations of the above mentioned clustering algorithms, the impact of the wrongly chosen initial cluster groups can be eliminated during a number of iterations. Therefore, these algorithms are more effective and the dependency can be reduced on selected initial seeds.

## IV. CONCLUSION

In this paper we have studied various applications deploying the Swarm applications as there is a wide variety of swarm behaviors available in nature, there is a high possibility that more algorithms will be deployed, and more applications and systems will be modeled after studying the social insects and other animal's behavior study. The main challenge in deploying such algorithms and designing such applications are to define the correct rules for the interaction of the individual's seeds, as it is not clearly, and immediately evident which rules will demonstrate the desired behavior of the swarm.

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