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A Detailed Review of Swarm Robotics and its Significance

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***Abstract*— Swarm robots are a group of macro robots which are controlled by an actual leader or virtual leader from that group. When the world is moving into the nano technology, its mandatory to upgrade our robotic system into the nano or mini robotic systems. But the nano robots are limited with performing the complex task. To overcome this limitations, group of nano robots are operated in such a way to perform the complex operations. The main discussion in this paper is a small overview on the swarm robotics. Present situations researchers are facing multiple problems and some of them are found some solutions but mostly swarm robotics are having more problems which are needs to be addressed. The main predicament in swarm robotics is that swarm control and unavailability of coordinated algorithm for a particular application. This paper helps the researchers to understand effectively about the swarm robotics.**

Keywords*— Swarm robotics, Beetle swarm optimization algorithm, Behavior and controls of swarm robotics, Nano robots, Robotic technology

I. INTRODUCTION

Swarm is a large group of insects which are moving together in co-ordination. Swarm robotic is influenced by the swarm insects, by the teamwork individual robots are completing the task efficiently. Simple localization and local communications are adapted with the environment to complete the job accurately. Swarm robotic gives more advantages to complete the complex task than single robot [1]. Different types of swarm algorithms are proposed by many researchers to solve the different types of social problems. The progress in swarm has been discussed based on different behaviors of swarm, taxonomy, and few algorithms. Moreover, swarm intelligence algorithm like improved beetle swarm algorithm is mentioned in this article. Combination of Beetle Algorithm Search (BAS) and Particle Swarm Optimization (PSO) gives a new improved beetle swarm algorithm for the better result in the task completion [2].

A. Significance and Characteristics of the Swarm Robotics

The swarm robot is an independent group of robot system that are characterized by the high accessibility of each swarm robots through the effective communication. In swarm robotics, sensing potential is local, and it is restricted with the non-local information access. The collected data is transferred between one robot to another, and all the group of robots are interacted with each other by personally and environmentally [3]. Homogeneous swarm robots and heterogeneous swarm robots are discussed in [4]. Researchers have proposed many swarm algorithms which are working effectively in various applications. But some algorithms are not supporting when it is used as the part of industrial applications [5]. In this survey, in view of real-world applications, it is observed that some rare cases of industry applications only used the term “swarm”, but swarm algorithms are hard to implement for industrial applications. Instead of that entire swarm use of some modules of swarm algorithms and implement them in an industry by using centralized control system is discussed in [6]. The remaining part of this paper is arranged as follows. Section II describes the swarm robotics behaviors-based classification. In Section III few important swarm robotic algorithms are reviewed. Section IV concludes the paper. The structure of the article is shown in Fig. 1.

Fig. 1. Structure of the article

II. CLASSIFICATION BASED ON SWARM ROBOTIC BEHAVIORS

Almost in all the swarm algorithms, the agents are performed individually by their local rules and the behavior of swarm is naturally visible [7]. Translating the natural swarm behavior to the swarm robotics domain, every single robot behavior is depending on the local rule within the given range from the basic simple reactive mapping towards the input and actuator outputs by the complex swarm algorithms [8]. Every single system is interlinked with each other, and they contain some sensory data that can be readable and interpretable [9]. That data is processed to produce the necessary signals to drive the actuators. By the basic behavior and procedure, the collective systems are operating repeatedly to reach the desired state.
Based on the swarm behavior, swarm robotics are classified into different subsequential parts that are discussed below.

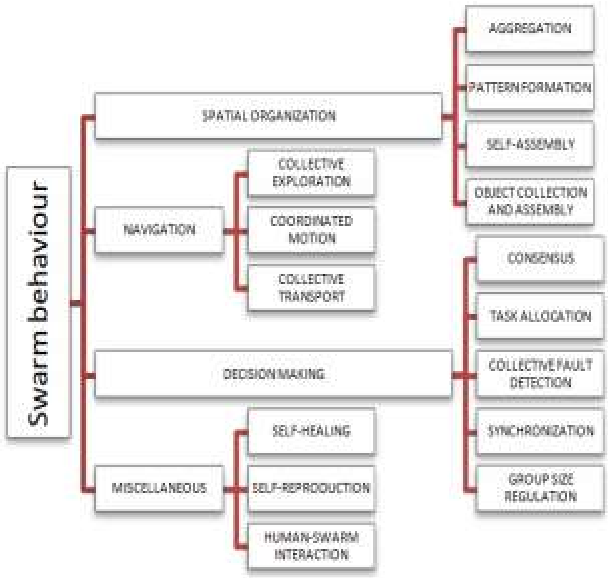

Fig. 2. Behavior of swarm robotics.

The basic taxonomy of swarm behaviors is given in the Fig. 2. The classification is based on the various behaviors of the swarm [11], the overview of a swarm behavior for swarm robots are as follows

A. *Spatial Organization*

Spatial organization behavior makes the robot in a swarm work towards the environment with the focus on organizing themselves without the help from any other external signal. Aggregation is simply defined as making the individual robot to move in a specific region of the given environment. Aggregation makes every swarm robot to move freely and make them close for the future interactions.
Pattern formation organize the whole swarm of robots in required shape. The main important use in the pattern formation as line by swarm of robotics are generally to develop multi-hop communication between two different point.
Self-assembly - In order to obtain special shape for completing the required task, it is required to connect the whole swarm of robots to form a specified structure. The whole swarm of robots are connected physically through the communication links. This self-assembled robot can disassemble and assemble it again based on the requirements of the environment.

Object collection and assembly in swarm of robots are operated with structural design objects. For the construction or formation of various shapes to complete the assigned task the collection and assembly of the objects are more important [12].

B. *Navigation*

Allocating the specified task to the swarm robots need different coordination for performing the allocated task. For exploring the swarm robotics for multiple targets, it needs navigation, and they also need to collect all data through the environment by using the navigation of swarm robotics. Mainly it is used for situational survey, monitor the given surroundings, search for various objects, and establish the communication network between the swarm of robotics.
When a group of robots are working as a team then the whole robot requires some coordination. So that the coordinated motion makes the swarm of robots to move in spatial direction for the formation of the objects.
Collective transport it means the swarm robots are able to move objects which are heavy for single robot to carry that alone [13].

C. *Decision Making*

Decision Making is one of the important behaviors in which swarm of robot's behavior based on the decision made from the computation results or particular inputs. But making decision based on the conditions like where to move, when to move leads to the limitation on applications.

Consensus - every single swarm of robots must agree on one single common decision from the different multiple decisions. Task allocation assigns the task to every robot in a swarm dynamically. Task allocation is the main goal of the swarm robots to maximize the performance of the whole swarm system, but in some cases swarm robots have homogeneous and heterogeneous capabilities. Robots with heterogeneous capabilities makes the task can be separated by their capabilities to increase the system's performances in future.

Collective fault detection -When robots are working on some specified tasks, individual robot can perform their assigned work in that task, but every robot cannot be performing the task perfectly somewhere some robots in a swarm makes some mistakes. Those mistakes are identified by this collective fault detection. Collective fault detection allows the swarm of robots to identify the deviation from the required behavior of the swarm [14].

Collective perception in which the whole collected data from the local environment are sensed by the swarm of robots. Those data are combined into a larger image based on the algorithm. Synchronization is assigned to the swarm of robots through frequency and phase oscillators. Therefore, the system of swarm robots has similar understanding related to time to perform the whole task synchronously.

Group size regulation controls the swarm of robots to form groups with the required size. If the number of robots in the swarm of robots are exceeding the required group size, then it splits into different groups [15].

D. Miscellaneous

Self-healing behavior shows that the swarm robots rectify their faults caused by the hardware and software of every robot in a swarm. The main objective is to minimize the effect of robot failure by the faulty robot then the rest of the swarm robots increases the swarm reliability, robustness, and performance [16].
Self-reproduction behavior makes the swarm robots to either produce the new robots or clone the pattern produced from the whole robots in a swarm. The main objective is to make the swarm robots become autonomous by eliminate the human engineer for creating a new robot and problem solving [17].
Human-swarm interaction allows people to control the swarm robots or to receive information from them. The interaction can be done remotely, for instance, or through a computer terminal [18].

III. Swarm based Robotics Algorithms

There are many algorithms which can supports the swarm robotics operations. Fig. 3 shows the list of swarm-based algorithms. The few widely used algorithms are discussed as follows.

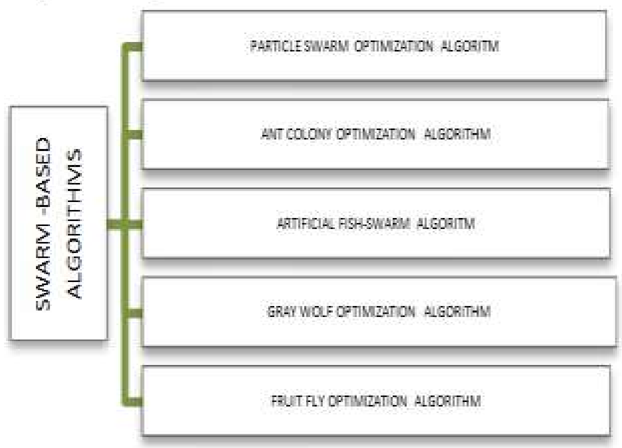

Fig. 3. Swarm based algorithms

A. Multiple Swarm Intelligence Algorithm

Swarm intelligence algorithm is defined as the set of rules to solve the problem. Swarm intelligence algorithm deals with the biological organisms and artificial systems. The few swarm intelligence algorithms are swarm robots search for multiple targets and particle swarm optimization algorithm. Swarm robots search for more than one target is a big challenge faced by researchers [19]. The algorithm used in this search for multiple targets is Robotic Darwinian Particle Swarm Optimization (RDPSO). In this overall study, this review investigates the robotic search for multiple targets related with the real robots, and strengths for experimental applications. For the multi robot search there are two important methods they are communication strategy and task allocation [20].

B. Single Target Search for Swarm Robots

For achieving the desired results, sometimes single robot cannot perform efficiently as compared with the swarm of robots. This area discusses the method for a swarm of mobile robots to search a single target [21]. Particle swarm optimization is a population-related stochastic optimization algorithm influenced by the swarm behavior of bird's flocks and fish schools. By using the basic particle swarm optimization algorithm in some engineering problems, it is very hard to find the solutions for that engineering problems.
By radiating the signal, targets are identified. The target usually can be any source, e.g., light, odor, heat, sound. Mathematical representation gives an optimum in the signals field. Thus, the method of mathematical particle swarm optimization is summarized in Equation. 1[20].

$$\begin{bmatrix} x^{k+1} \\ \dot{x}^{k+1} \end{bmatrix} = \begin{bmatrix} x^{k} \\ \left(I_{3N_P - \Delta t M^{-1}.h^k_{f_3}}\right).\dot{x}^{k} \end{bmatrix} + \Delta t \begin{bmatrix} \dot{x}^{k} \\ \begin{pmatrix} M^{-1}.h^k_{f_1}.\left(x^{best,k}_{self} - x^k\right) + \\ M^{-1}.h^k_{f_2}.\left(x^{best,k}_{nhood} - x^k\right) \end{pmatrix} \end{bmatrix} --(1)$$

X - contains the position and orientation information of all the robots
$\dot{x}$ - velocity of robots
K+1 - calculate the position and velocity of each robot at the next step K+1 by using the current and previous information
$\dot{x}$k - current velocity
Δt - time step
$I3N_P$ - identity matrix
M - mass matrix
Three scaling factors $h^k_{f_i}$ (i=1,2,3) are referred to the inertia, cognitive and social terms
$x^{best,k}_{self}$ - best positions of robots
$x^{best,k}_{nhood}$ - best positions of the robot in certain neighborhoods

Here Np is the number of robots, similarly velocity of robot is denoted by x˙ and M is a generalized mass matrix. The particle swarm optimization is expanded for swarm mobile robots to search a target cooperatively, the robots will be operated by this search planner [22].

C. Searching for Multiple Targets by Swarm Robots

This method of swarm robots search is used for the multiple targets. It is the most difficult task since the complexities are added, e.g., during the rescue times the robots must do different tasks in that swarm of robots, such as, some of them are to find a target, even it may not be assigned earlier. So that this searching for multiple targets is used in that rescue times. The mechanical particle swarm optimization is used to improve the earlier method [23].

Constraint handling, robotic search planner design, task allocation and many are often seen as distinct. In the starting days the mechanical particle swarm algorithm can operate the robots to search a specified mono target in the environment [24]. It defines the search task as a single type of optimization problem by providing the particle swarm algorithm with mechanical properties of robots. The mapping origin in normal particle swarm algorithm is a set of moving particles towards a workable environment to

Table 1. Simulation Platforms in Swarm Robotics

Platforms	Operating System	Level of Simulation	Open Source	Application	Number of Robots	2D/3D	ROS Support
Webots	Linux/Mac/Win	Realistic	Yes	Generic	Limited	3D	Yes
V-rep	Linux/Mac/Win	Realistic	No	Generic	Limited	3D	Yes
USARsim	Linux/Mac/Win	Realistic	Yes	Generic	Limited	2D&3D	Yes
Swarm-sim	Linux/Mac/Win	Abstract	Yes	Swarm	Large	2D&3D	No
Stage	Linux/Mac	Realistic	Yes	Swarm	Large	2D	No
SCRIMMAGE	Linux/Mac	Realistic	Yes	Generic	Large	3D	Yes
PyCX	Linux/Win	Abstract	Yes	Generic	Large	2D	No
OpenHRP	Linux/Win	Realistic	Yes	Generic	Limited	3D	Yes
Netlogo	Linux/Win	Abstract	Yes	Generic	Large	2D	No
Gazebo	Linux/Mac/Win	Realistic	Yes	Generic	Limited	3D	Yes
ARGoS	Linux/Mac	Realistic	Yes	Generic	Limited	2D&3D	Yes

locate a global optimum [25]. In optimizing the objective functions, it requires many cases to find the equal quality solutions [26]. For the real swarm robot applications, the signal scattering may be multi peaked, multimodal because of the multiple signal sources or

the uncooperative natural environment. Optimization a multimodal objective function [27-28], exact equal quality global optima are physically hardly existed, and usually every local minimum is a useful solution although it is necessary to investigate the same quality with global optima. In multimodal optimization, trapping is in local high point. The multiple search targets usually handled by the connected simple sensors for disjunction [29].

D. Improved Beetle Swarm Optimization Algorithm

The results of the beetle swarm algorithm have a great bonding with the initial state of the beetle. Initial position affects the efficiency and affects the optimization level. Particle swarm algorithm uses the birds flock swarm for designing swarm particles[30]. Each swarm particle gives a great solution to the problem, and each swarm particle communicate to the fitness value set on by fitness function.

Table 2. Beetle Swarm Optimization Algorithm

Input:	Swarm needs to be initialized with xi (I =1,2…...,n),u,δ ,k , range of velocity is vlarge and vsmall
Output:	XOPTIM, YOPTIM
Step 1	for each search agent
Step 2	While (k < K)
Step3	fix the inertia weight ω taken from (24)
Step 4	for every single search agent
Step 5	Calculate f (X_{rs}) and f (X_{Is}) taken from (23)
Step 6	After that incremental function ξ has to be updated
Step 7	Speed formula V need to be updated, taken (21)
Step 8	the current search agent position needs to be updated taken from
Step 9	end for
Step 10	for every single search agent f (x) fitness needs to be calculated
Step 11	note down and save the location of each and every single search agent
Step 12	for each search agent
Step 13	if f (x) <fp_{OPTIM} then
Step 14	fp_{OPTIM} ← f (x)
Step 15	end if
Step 16	if f (x) <fg_{OPTIM} then
Step 17	fg_{OPTIM}t ← f (x)
Step 18	end if
Step 19	end for
Step 20	Update x* if there is an improved solution
Step 21	Update step factor δ taken from (18) and (19)
Step 22	end while
Step 23	Return X_{OPTIM}, Y_{OPTIM}

In swam robots the shape formed by the robots depends on the task given and the ranging of the robots so that there may not be any communication delay. Effective completion of task depends on shortening the distance of work. By the motivation of particle swarm algorithm, the BAS algorithm is later developed upon to evolve every single agent into groups, that is where the beetle swarm optimization algorithm is introduced [31]. The basic principle of the algorithm is to replace the particles in the particle swarm algorithm with the beetle, that is, to use BAS optimization to replace the compared individual optimal values by computing Plural Acceptable Solutions (PAS) [32].

$X_I = (x_{i1}, x_{i2} \ldots x_{is})$ s-dimensional vector represents the beetle position attributes. The various attributes of the beetle optimization are calculated by the Equations. 2, 3, 4 and 5.

$$x_{is}^{k+1} = x_{is}^{k} + \lambda v_{is}^{k} + (1-\lambda)\xi_{is}^{k} \qquad \text{----- (2)}$$

$$v_{is}^{k+1} = \omega v_{is}^{k} + c_1 r_1 \left(p_{is}^{k} - x_{is}^{k}\right) + c_2 r_2 \left(p_{gs}^{k} - x_{gs}^{k}\right) \text{-----(3)}$$

$$\xi_{is}^{k+1} = \delta^{k} * v_{is}^{k} * sign(f(x_{rs}^{k}) - f(x_{is}^{k})) \text{-----(4)}$$

$$x_{rs}^{k+1} = x_{rs}^{k} + v_{rs}^{k} * \frac{d}{2}; x_{is}^{k+2} = x_{is}^{k} - v_{is}^{k} * \frac{d}{2} \text{-----(5)}$$

Where s = 1, 2……, n; I = 1,2, 3……n; and k is the number of iterations.

V_{is} expressed as the velocity of the beetle, and ξ_{is} represents the increasing beetle position movements [33-34]. The various simulation platform comparison table is shown in Table 1. From the comparison table researchers can easily identify the platform based on their required number of swarm robots and the applications.

To improve the adaptive factor in the BAS algorithm, the combination of both the BAS and PSO algorithm produces the IBSO algorithm. The Beetle swarm optimization algorithm steps are shown in Table 2. To improve the algorithm with more stability, the beetle search developed with accurate population optimization [35-36].

By the help of mechanical particle swarm optimization, the swarm robots are search for multiple targets. for the real swarm robot applications, the signal scattering may be multi peaked, multimodal because of the multiple signal sources or the uncooperative natural environment.

In [36] Robotic Darwin in a Particle Swarm Optimization (RDPSO) is used as the multiple swarm intelligence algorithm. Implementation of particle swarm optimization is based on meta heuristic.

Synchronization is assigned to swarm of robots by using the RFID (Radio Frequency Identification) tags. It's one of the wireless technologies and it tracks the object and it identify the unique information.

In human swarm interaction human acts as an operator whose take the feedback from the swarm robots. Fig. 4 shows the connections of objects and machine learning methods. Interface is the medium of communication for both human and swarm robot. Through the interface the operator receiving the feedback data and send the input data to the robots.

Fig. 4. Behavior of swarm robotics.

The overall efficiency of the swarm optimization algorithm depends upon various parameters. For the robotic system object collection is done by the sensors and the sensors send the data to machine learning methods that make the robotic systems to detect objects in effective way. For successful rate different object detection methods are used they are Boosted cascade classifiers, Dictionary based object detection algorithms, Partial object handling, Convolutional Neural Networks (CNN) and Structured algorithms.

IV. CONCLUSION

In the near future, many complex works are to be completed by the group of robots. Land based swarm and aerial swarm are playing a major role in swarm robotics applications. This review discussed the preliminaries in swarm along with the classifications of swarm robotics. Beetle based swarm optimization algorithm are discussed to give the important steps required for the swarm algorithm. Outline of the various swarm algorithm helps the upcoming swarm researchers. The various simulation platform comparison table helps to choose the right platform based on the number of robots.

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