A Review on Swarm Cleverness and Stigmergy: Robotic Operation of Scavenging Performance

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Abstract— **In the present scenario the swarm cleverness or the cleverness has become an important area of research regarding the multi-robot systems. As the researchers got inspired by their biological systems and proposed a variety of robots and applications in the different fields like commercial, military and industrial. To cover the gap between the theory and the application we have focused on the robotic implementation of swarm cleverness or cleverness. Up-till date, some of the demonstrations of swarm cleverness robotics has been successfully done with the help of theoretical research and the computer simulation in this area of robotics systems. In this review paper, a study of intelligent scavenging behaviour by means of their indirect communication between simple individual agents is introduced. Some of the Models regarding scavenging are reviewed and analysed with respect to the system dynamics and dependence on important parameters. The experimental demonstration of cooperative group of their scavenging behaviour without their direct communication is done successfully. To produce the required stigmergic cooperation the Trail-laying and Trail-following are employed. So, the conclusion is that it's experimental result also confirms that's trail-based group scavenging systems can adopt to dynamic environments.**

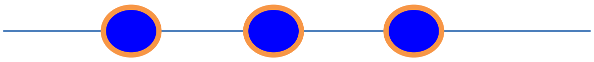
I. Introduction

Presence of special synergism in the swarm, bee and other insects appeal of swarm cleverness .In this paper we will study the combination of: entomology and robotics. From last fifteen years researcher takes help of biological swarm cleverness to solve real world problem instead of taking engineering and artificial cleverness Swarm cleverness is described as the collective behavior of the decentralized and self-organized systems. It is a biological phenomenon which can be applied to solve global problems by creating artificial swarms. These artificial swarms can be formed by grouping multiple agents like swarm robots. The main purpose is to generate a combination between individual from the group that construct an arrangement of steady criticism. Multi robot system of swarm cleverness is categorized into three categories which are cooperative, autonomous and mobile robotics. This research of robotics based on swarm cleverness is used to achieve a task. Some reasons why swarm cleverness is important:-

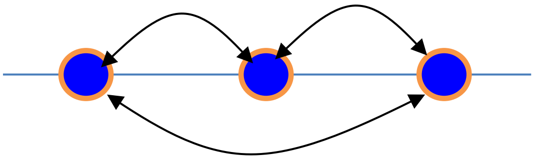
1. Tasks are often inherently too complex for a single robot to accomplish.
2. Several simple robots can be a cheaper and easier solution than one powerful robot.
3. Multi-robot systems are generally more flexible and fault-tolerant than single robots acting alone. .

II. SWARM CLERVERNESS

In Multi-robot systems we can inculcate cleverness to solve a problem using local interactions by forming a swarm It would be a more optimized and efficient method where algorithm's scalability will play a crucial role. One way of acknowledging its structure is to realize that this specific design addressed in this thesis could be considered in the category of cooperative solution domain where each participant agent cooperates with the entire group to solve a specific problem entrusted via its mission.

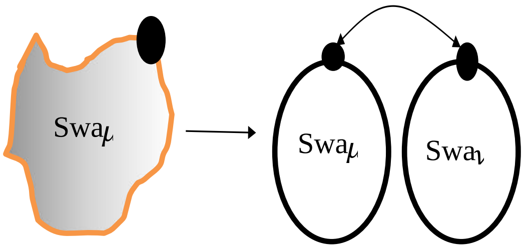


2.1 (a): No interaction



2.1(b): With Interactions

Swarm cleverness claims historical substructures from both biology and engineering. Reviewing the origin and consequent growth of swarm cleverness research hence requires imminent the subject from both biology and robotics. For a problem domain, a multi-agent swarm system may include a single swarm or even a cluster of swarms within a swarm. Since each member of a swarm needs to communicate with one or more of its neighbours regularly using message or signal passing, it may be possible for a swarm to break up in two or more clusters if original neighbourhood fails to remain 'visible' in message passing mode. In other words, the original swarm μ may break up into clusters like μ and ν with their leaders as shown below with their leaders marked in black.

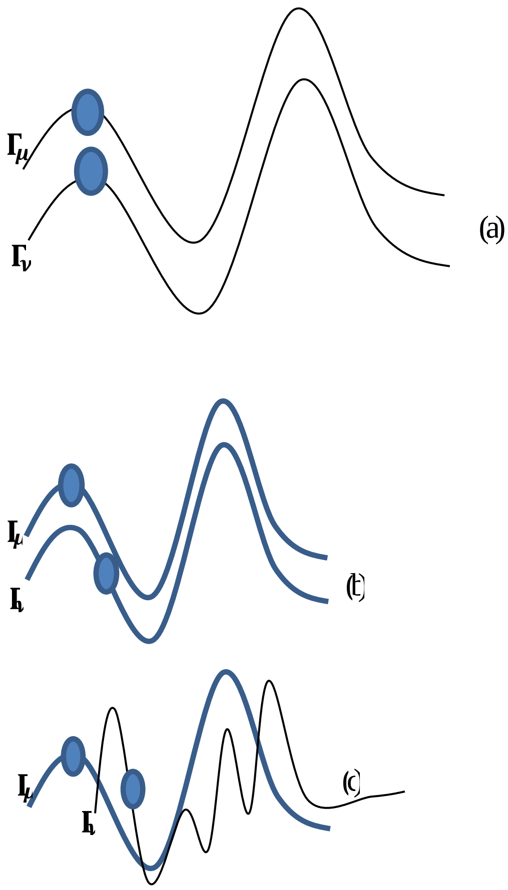


2.1(c): Too Large a swarm 2.1 (d): After split. Two cluster swarms

These leaders of splintered swarm must now communicate with each other on, say, trajectory plans. After split, they may have to pursue their own trajectory Γ toward their destination. In figures E below, we see the two trajectories Γ_μ *and* Γ_ν for the two new swarms $Swarm^\mu$ and $Swarm^\nu$ in different phases. Note that

$$Swarm^\mu\ (new) \cup Swarm^\nu = Swarm^\mu(\text{old})$$

Many planning issues might emerge at this point. What kind of trajectory or path plans might be configured at this point, realizing that a planned trajectory of individual swarms might change during a mission time to cater to, say, more security, for avoidance of external attacks, etc?



2.1 (e) Evaluations in a split swarm

a) Refers to same path trajectory $\Gamma_\mu = \Gamma_\nu$ with both swarms maintaining a phasedifference $\phi = 0$.

b) Same as (a) but the swarms are maintaining a phase difference $\phi \neq 0$ for some strategic reason.

c) Both swarms are on different trajectories $\Gamma_\nu \neq \Gamma_\mu$.rendering the overall system more robust to its mission from security point of view.

Algorithm single-marge {for agent i} **define**
detached: boolean, *safety_clearance: boolean;*
initial *detached* = true;

safety_clearance = false;

do

[] *detached* → *broadcast*(*SOS=“Help me! I’m detached*”);

[] *detached* $\wedge\, recv(ACK, \zeta, SOS, seq = x)$ $\wedge\neg(safety\_clearance)$ → *Identify*(*lastgroup*, *check*(*security*), *seq=y*);

[] *detached* $\wedge\, recv(join, \zeta, safetyclearance, ACK = y, seq = x + 1)$ → *detached = false;*

Safety_clearance = true;
Agent_swarm = ζ; **od**

Both the individual agent and the cluster it would be joining needs to go through a security clearance check to ensure that the individual is genuine and not compromised, and the new group the individual agent would be joining is credible and not compromised. After joining the new group, it has to go through a new security induction process pertinent to its new swarm identity.

Swarm Cleverness is a method required to solve an assigned global problem within a local interactive system [2]. These systems could be artificial or natural.

Swarm Cleverness is described as the collective behavior of the decentralized and self-organized systems [3]. It is a biological phenomenon which can be applied to solve global problems by creating artificial swarms. These artificial swarms can be formed by grouping Multiple agents like swarm robots.

III. Swarm Robotics

Swarm Cleverness is an emerging topic in the scientific world right now. It is a natural phenomenon which can be most commonly observed in Ant Colonies, Bees searching for food, Birds, etc.

Here in the specified applications, timing is crucial. Hence, we can use multiple agents to achieve these scenarios instead of a single agent. The number of agents is inversely proportional to the time required to solve the problem or time required to complete the assigned task. Swarm cleverness applications are mainly classified into two categories, Natural Swarm Intelligent Systems and Artificial Swarm Intelligent Systems.

3.1 Natural swarm cleverness system

Swarm cleverness which can be noticed in the biological system is usually referred as Natural Swarm Intelligent Systems. Best examples of these kinds of systems are Ant Colonies, Bees searching for food and the bird flocking behaviors.

In these systems, Self-organization is the important property. Self-organization is the ability of a swarm to achieve coordination within the system by using local interactions. This coordination is required to complete the task successfully.

3.1.1 *Ant Colonies*

Ant Colonies are most commonly known as visible Swarms. This is the first studied Swarm system. The path which ants follow is taken as the basis to develop many artificial Swarm systems. Usually Ants scavenging will start from their nests in different directions. While travelling they will lay a chemical substance called Pheromone, which can be sensed by other Ant foragers and reach the already found food sources.

Many Ants may find the same food source by following different paths. The probability of the foragers to choose a shortest path is more as the density of the pheromone of longest path will fade. So we can quote that Probability of an ant choosing shortest path is directly proportional to the intensity of the pheromone.

This Ant colony topology is considered as basis for many real world systems like telecommunication networks, Wireless communication systems, for choosing shortest distance between two places and it is also applied to real world problem of the travelling sales man.

Based on the experimental analysis [4] provided an equation which describes the probability of an ant choosing a particular path,

$$P_{n+1} = \frac{(K+A_n)^{\nu}}{(K+A_n)^{\nu}+(K+B_n)^{\nu}} \qquad (3.1)$$

Where,

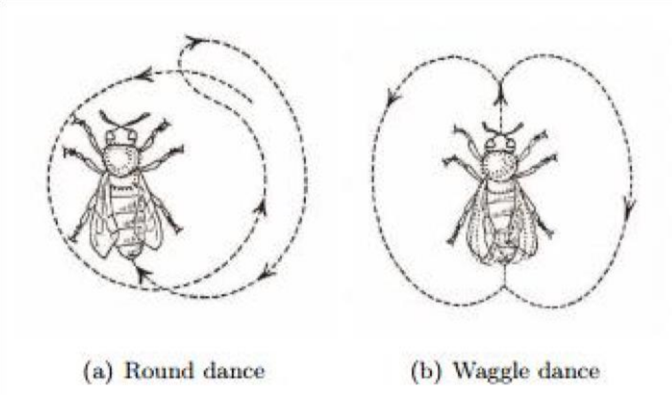
A, B are two particular branches between the source and destination.

An, Bn are the number of ants choosing A and B branches. K is the degree of attraction an unmarked branch ν determines the degree of nonlinearity of the choice function.

The intensity of pheromone makes the K larger. Greater pheromones have larger K value.

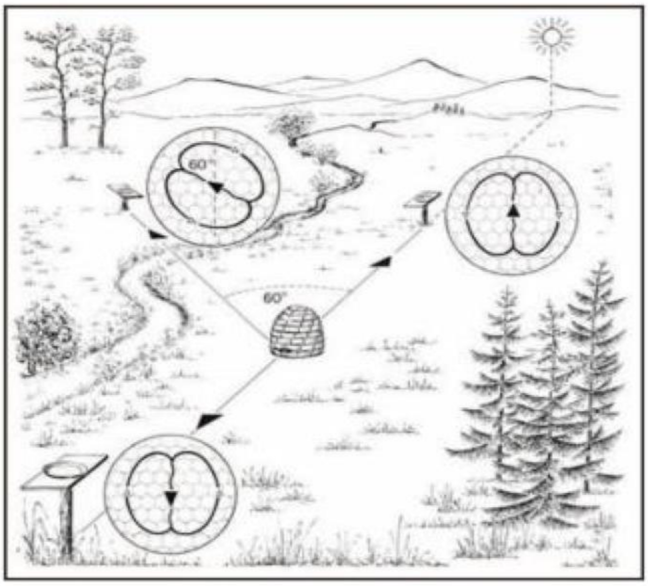
3.1.2 *Bee swarm hunting for food*

Unlike the Ants Bees cannot release pheromones or any chemical substance to indicate the other bees about the found food information. Instead, honey bee dances to indicate the fellow bees about the food information and to recruit them. Wenner and Wells [5] suggested that bees communicate through floral odor upon return from a food source to indicate the found food. But the commonly accepted view is while bees go for the hunt, the recruited bees follow the dance patterns, and in return, they emit the floral odors. They adopt different patterns of dances to indicate other bees the direction and the quantity of food found [6].



3.1 The Design patterns of Bees

When performing a round dance, a forager bee communicates the distance from the food location and the amount of the sustenance accessible to the next selected honey bees. On the other hand, the waggle dance contains the information of both distance and direction of the food location.



3.2 The waggle dance relative to the Sun indicating food location

3.2 Artificial Swarm:

Natural swarms are the inspiration for the researchers to develop the artificial swarms. Artificial Swarms is the multi-agent system formed by applying the swarming behaviour. These artificial swarms can be used in any place where the time taken to respond is critical and where humans cannot reach. It is experimentally verified by many researchers that the multi-agent swarms are more efficient way of completing a task with high performance. However, Task allocation often becomes a problem in multi-agent swarms. Tasks need to be assigned to the agents such that problem will be solved in a more optimized manner.

3.2.1 *Single Agent Swarms*

Single Agent Swarms contains a single agent. This agent adapts to the dynamic changes to the environment and completes the assigned task. If a complicated cultured task arises, then we need to design the single agent with a complex structure to handle such a task results in an expensive design. And it requires high time to complete a single problem as every calculation must be done by itself. Maintenance of such a system is crucial. If at all due to any hardware failure if that single agent malfunction it may lead to catastrophes. This is the main reason for the evolution and popularity of the Swarm robotics.

3.3 Main set of rules:

While implementing artificial swarms we need to consider several things like the issues which may arise during agent's behavior within the swarm. There are few base conditions which need to be maintained to achieve the correct swarming behaviors.

There is artificial swarm program developed by Craig Reynolds [7] in order to simulate the birds flocking behavior, called Boids. This is abbreviation for "bird-oid object" which means bird like objects.

This model is constructed based on a set of simple rules and this can be extended to complex set of rules.

Simple Rules applied to the Boids:

- separation: direct to avoid crowding local flock mates
- alignment: direct towards the average heading of local flock mates
- cohesion: direct to move toward the average position of local flock mates

3.4 Travelling Salesman Problem

In the proposed situation [8], the group of UAVs is sent to fly over a specific number of areas on the ground. This issue can be deciphered as an outstanding NP-hard Optimization issue called the Traveling Salesman Problem (TSP). A general meaning of the TSP is the following. Consider a set N of nodes, speaking to urban areas, also, a set E of arcs completely associating the nodes N. Finding the shortest tour implies sparing time for undertaking execution, and also saving energy needed for the UAVs' flight. The UAVs begin their tour from a base which they always speak with by sending the data of their position and direction of flight (roll, pitch, and yaw). The computation of the tour is performed in the base and sent to the UAVs as a rundown of directions that should be gone by. Every visit begins from the area in the rundown that is nearest to the base. By considering the beginning position of the UAVs, greatest investment funds in time and energy are obtained from the job that needs to be done.

3.5 Algorithm

Distributed Bees Algorithm (DBA)

A robot computes the utilities when it gets data about the targets. The target's correlated cost and quality value are the two features on which the utility depends i.e. just the robot's distance from the target.

Qualities

Precedence or the complexity of the target is signified by the term quality that is a scalar value. Divisions of the aggregate of characteristics of every single available target are utilized to evaluate the Normalized qualities given as:

$$q1= \frac{Q1}{Q1+Q2........+Qr} \quad \textbf{(3.2)}$$

Where Ql denotes the quality of target l. The quality of concerned region is an assessed value that occurs in real-life situations as a consequence of sensor readings or formerly attained information.

Costs

The Euclidean distance between the agent or robot and the target in a plane field gives the cost of a target l for robot n computed as:

$$d_l^n= \sqrt{(y_1-y_n)^2 + (z_1-z_n)^2} \quad (3.3)$$

Where target's and robot's coordinates in the field are represented by (, l y z) and (, n n y z) correspondingly. On the other hand the target's visibility is used to estimate the utility which is the reciprocal value of the distance given as:

1

$$\delta_l^n = \frac{}{\mathbf{d^n_l}} \quad \textbf{(3.4)}$$

Utilities

The utility is determined by both cost and quality of the selected target of a robot and is suggested as (1.1) and is defined as a probability that the robot n is assigned to the target l computed as follows:

$$\sum_{l=1}^{R} p^n_l = \frac{q_1^\alpha \delta_1^\beta}{q_1^\alpha \delta_1^\beta} + \frac{q_2^\alpha \delta_2^\beta}{q_2^\alpha \delta_2^\beta} + \ldots\ldots + \frac{q_R^\alpha \delta_R^\beta}{q_R^\alpha \delta_R^\beta} = 1 \quad (3.5)$$

Decision Making Mechanism

In the decision-making process of the robot for the selection of the target the wheel selection rule is implemented. That is, from a set of available target every target has a concomitant probability with which it is chosen. Once all the probabilities are calculated as in (3.5), the robot will choose a target by considering the quality and location of the target, the one having the closest location and highest quality would be selected as the target. Point to be noted here is that the resulting robots' distribution depends on their initial distribution in the arena, i.e. the distances of robots from each target before the allocation of the target. Therefore, the values of the robots' utilities will differ on the same target if their distances from that target are not same.

3.6 Types of Swarm Robotics:

The swarm robotics systems can be classified into two types Homogeneous systems and Heterogeneous systems.

3.6.1 *Heterogeneous System:*

The robots in the systems which differ in their capabilities and are specialized for a particular task are known to be heterogeneous. The hardware and software used to make a single robot is different from every other robot and hence the performance varies.

3.6.2 *Homogeneous System*

All the robots present in these systems are similar in architecture or the hardware. All the robots are identical when it come to their. The problem discussed in 3.8 corresponds to Homogenous systems.

3.7 Leader in a Swarm

The major issue of a swarm of agents such as of drones differs substantially from the biological swarms we have been inspired to model in non-biological milieu. A swarm leader has to navigate and lead its team towards its destination, goal or sub-goal, but it doesn't need to face a media to justify its past action as a leader, it doesn't need to figure out if the rest of the individual agents in his group are strict "followers" or not.

For our purpose, we see an agent $\alpha_i^{\mu,1}(m_k, l_p, s_t, \theta, t)$ of a swarm group μ as a leader if l=1 instead of 0.

We require that in a swarm only one agent can be identified as a leader at any time. If there are more than one leaders with subscript l = 1, we assume that our election algorithm could be launched again to sort out the confusion and elect a unique leader.

Leader task's set (LTS)

- Compute the latest trajectory $f: (M, \theta, t) \Longrightarrow T_k$ given the current location θ,current time t, current Mission M. Share this planned trajectory incrementally with the sub-leaders.
- A leader must maintain his group or swarm over the mission time unless mitigating circumstances force the leader to shrink, expand or fragment the group.

- For a small group, every member, other than the leader, must follow the leader and a neighbour maintaining a safe distance from the latter. For a large group where everybody may not be 'visible', following a leader may be difficult. In that case every member must follow k nearest neighbours.

- Avoid collisions with any local stationary and mobile object. If necessary, perturb the current trajectory $Tk$to $\delta(Tk)$, and return to Tk

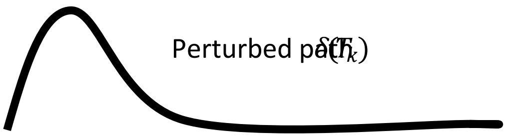
within a small time interval Δ as shown below to avoid collisions

Computed path T_k

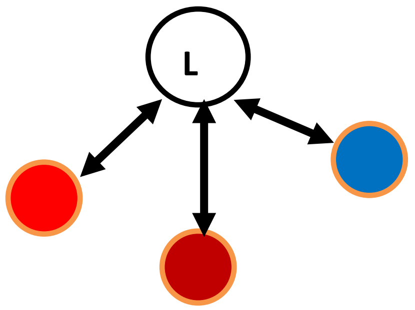
3.3Agent path in case of Obstacles

● Identify leader's subgroup called subleaders, and keep leader's communication lines with it open. This is a subset of members who can immediately take over the leadership in case the current leader crashes, or the current leader turns into a Byzantine-faulty agent, or the leader calls for a fresh election. Any member of the subset the subleaders can call for a fresh election if

they fail to detect the 'heart-beat' of the current leader within the timeout period $tout_{leader} = \gamma$. Here we assume that all channels connecting two agents (even though they are wireless) are FIFO,



and the agent clocks are synchronized within their maximum tolerable relative drift limit of the skew, δ.



3.4Agents hierarchy

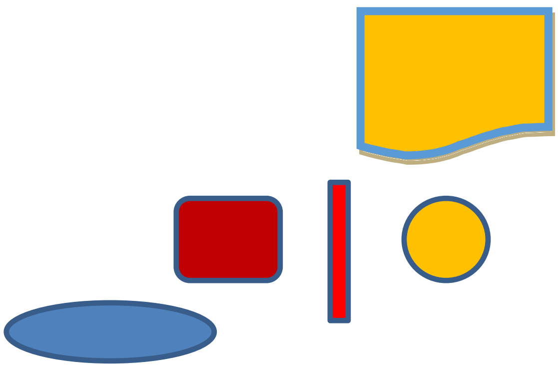
● A leader ideally, at all time, must decide if the group or swarm needs to be split into 2 or more swarms owing to some reason which makes the current swarm difficult to navigate. One reason could be lack of visibility, or difficult terrain which cannot accommodate a large swarm. This may be strategically desirable too; it may be less risky to attend to a mission with multiple subswarms (partition of original swarm into a subset of swarms, assigning a different mission m_k^λ to each subswarm μ^λ where

$\bigcup_\lambda \mu^\lambda = \mu$ **and** $\mu^\varsigma \bigcap_{\varsigma \neq \xi} \mu^\xi = 0$ **and** $\mu^\lambda \subseteq \mu$ **(Swarm-splits)**

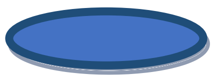
● Scheduling the next swarm-state change is a task left to the leader only. A swarm might change its current state via its sub leaders

$\mu_{current}{}^{state} \in \{fly, rest, \ldots\} \longrightarrow \mu_{next}{}^{state} \in \{fly, rest, \ldots\}$

to affect the current state of the entire swarm within a certain time-interval ΔT to accomplish its mission at a lower cost or risk. If this cannot be accomplished, the current leader might decide to split its swarm group into manageable fragments, and schedule each of them appropriately aligning its entire mission to abide by any hitherto unknown mission constraints. A typical management profile might appear as iginal Swarm



After Fragmentation
Changed schedule after fragmentation



First to fly-out with a different leader at time t_a

Next to fly-out with a different leader at time t_b

The third one to fly-out with the current leader at time t_c

3.5 Fragmentation in case of obstacles

IV. Conclusion

Initially I have started by analyzing Artificial Swarms and the set of rules considered while designing them and the task allocation in the homogeneous swarm system. Later I have extended it to Heterogeneous swarm systems. This paper presents a simple and efficient way to solve the task allocation problem and, more specifically, to decide how many robots are needed to execute a specific task. The algorithm allows both changing the robots assigned to a task as new objectives are found and interchanging robots between working groups. Thus, the specified algorithm have provided a faster and flexible way to regulate the optimal number of robots as a function of the kind of the task, the priority of the task and the available robots.

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