Swarm Based Coverage Using Multiple Informed Leaders

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Abstract:

Robotic exploration typically involves navigation through unknown terrains. In this paper, collaborative strategy for coverage is presented, in which the concept of informed agents as a leader in a swarm has been introduced for autonomous coverage. The small population of robots in large swarm act as informed leaders and help others to accomplish their tasks related to the exploration. These informed leaders receive information about the environment from external sources (e.g. humans, media etc.), and influence uninformed robots using their swarm behaviors. Multiple Swarm behaviors have been designed for swarm navigation, and dynamic selection of the informed leaders. This approach has been tested in simulation of homogeneous swarm, with and without informed leaders. The number of informed agents needed to guide the swarm effectively has been investigated as well. Experimental results showed that the introduction of informed agents improves the coverage task.

Keywords: *Swarm Intelligence; Swarm robotics; Multi robotic exploration; leader selection.*

1. Introduction

Autonomous robotic exploration and coverage has been a hot research topic in which a robot visits the environment, build the map, and localize itself within the map simultaneously. If an environment is dangerous, remote, or expensive for human access, a mobile robot may help to build a map of its surroundings and navigate based on the map [1]. Furthermore, robots are resource-constrained specially in multi-robotic environments (where robots collectively perform a task) in which coverage is one of the key issues to be addressed effectively. Coverage problem has applications in exploration, navigation, search and rescue operations, particularly at city scale. In a multi-robotic environment, coverage becomes an issue due to limited capabilities of the robots, in terms of memory and computation. Either this can be achieved in a completely distributed fashion, where robots can only sense each other and do not communicate [2] or it can be achieved where robots can sense as well as communicate with each other. The behavior based coverage and exploration using multi-robots presented in [2] has been extended for the swarm. We have focused on leader based swarm coverage. Dynamic Leader selection is one of the challenges that have been addressed in this research. In this regard, social science based leader selection mechanisms have been considered as a starting point [3]-[4]. We have refined the model presented in [4], so that it works for large scale coverage. In addition to mobility issues, such as target selection, obstacle and collision avoidance, and density-based speed, we have also focused on natural group-based mobility paradigm; the swarm robotics [5]. The informed leaders are guiding other robots in the swarm to maximize the coverage rate. We have examined the usability of swarm base mobility as compared to the individual decision making using GIS map based simulations.

2. Related Work

Rekleitis et.al [18] proposed an exploration algorithm, in which one robot explores environment, while two stationary robots observe it, making a triangle shaped group [6].

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The main disadvantage of this techniques is a centralized control. In a later work, the same authors presented a technique in which couple of robots track the environment to search each other, for better mutual localization [7]. Arkin et.al suggested a behavior based exploration [8], where the "wander" behavior acts as communication actor, and "informed exploration" behavior helps to use map to explore the given arena. Powers et. al used "motor-schemas" [9] to preserve line-of-sight communication among members of a team [10]. This technique focuses on value based approach, in which all robots agree on a direction, then they move toward that direction, they make decisions in a distributed way, but stay connected every-time. Nguyen et al. [11] developed an actual real-world system using leader-follower approach. A similar leader-follow model has been designed by Howard and his team members [12] in which eighty robots were used to explore the building, and transmit all the acquired information to the remote operator. Yamauchi presented a revolutionary work in 1998 in which new exploration strategy using the concept of the "frontiers" [13] was introduced. In this technique, frontiers are the borders between visited area and un-visited area. In addition of Yamauchi's frontier-based exploration, Simmons et.al proposed a technique in which robots used 'bids' based on estimates of the travelling cost to major locations, and information gain [14]. These bids were submitted to chief agent, which assesses and allocates tasks based on maximum utilization. Stachniss et al. used place labels to define structures of the environment that can be used instead of frontiers based approach [15]. Wurm et.al's [16] work classifies unvisited area into segments, which are computed by Voronoi graph. Koenig et.al studied ant patterns and developed ant-like robot to explore [17]. Our approach is also inspired from nature and is using behavior-based approach. The swarm is steered toward the unexplored parts of the environment using multiple leaders.

3. Behavoir Based Swarm Design

3.1. Envirnoment

To simulate this problem, a portion of Vienna city map is used, which contains parks, roads, streets, narrow streets. The shape files of this GIS maps are imported into NetLogo, and this map is segmented into the small grids called cells. Furthermore, walkable, and non-walk-able cells were defined. Fig. 1 shows the screenshot of the whole environment.

For ease and visibility, walkable portion is shown in yellow, buildings in brown and robots in red color. In this environment, obstacles can be placed at any part of the map beside predefined buildings and other obstacles.

3.2. Behaviors

In this approach, it is assumed that robots have limited processing and memory. Therefore, behavioral based architecture is used for collective mobility and control of the swarm. Many behaviors have been designed including obstacle avoidance, avoid visiting past locations, Locating open area, leader selection, etc.

Fig. 1. GIS based environment for Robotics Coverage Simulation.

3.2.1. Obstacle Avoidance

It is the basic behavior in which robot detects the obstacle using local sensing capabilities and avoids these obstacles. This behavior is fused with other behaviors and it

avoids obstacles in such a manner that it could get largest free space to navigate.

3.2.2. Avoid Visited Locations

This behavior helps robots to navigate toward the newest locations. For this behavior, relatively long-range sensors are used as compared to the obstacle avoidance behavior. It keeps the track of previously visited locations. We have used efficient data structure to store and retrieve the information about the visited locations. Whenever robot coordinates are changed, it checks if cells ahead is already visited. If any of the cell up to predefined length is already visited, then it will rotate 45 degrees and check again for the patches ahead. It keeps on doing the same for all 8 possible angles until it returns to the same position. If all are visited, it moves to the patch ahead.

3.2.3. Locate Open Space

This behavior locates a wide area in which robot can search for targets, this may be an open room or hall. In our case, we have used this to locate open streets, roads, and open grounds like parks. It is a very useful behavior since it saves time going to closed type rooms and round shaped areas. In multi-robotic autonomous exploration, usually robots stuck in the corners and wasting time over there. This behavior also addresses this issue by gathering information of the largest fee space around the robot's current location. Whenever this behavior is triggered then robots stops its movement and starts searching open space around itself.

3.2.4. Leader Selection

This is most important behavior regarding our contribution in this work. We have tested many leader selection algorithms to find which best fits in our case for search and rescue of large open space area. We studied motion and movement of ants and birds and their swarm principles then we suggested our strategy which is more near to the nature. Moreover, our strategy for leader selection

(informed agent) is dynamic i.e. leader changes with the passage of time based on the shape of swarm. As the direction of swarm changes then leader is changed if it is necessary. Leader selection algorithm runs after every 30 ticks and elects for new leader if necessary. When leaders receive goals then they start moving toward their goal. Other agents observe the leader nearby them which helps swarm to move toward the goal. The algorithm of the leader selection is shown in Algorithm 1.

3.3. Inter-Agents Communication

In our approach, robots communicate the speed, previously visited locations, and other information with agents in their neighborhood. In this implementation, we are using Stigmergy, which is indirect communication mechanism. This technique is inspired from ant communication. Though in future, direct and explicit communication techniques can be used once this algorithm is extended to the real robots.

Algorithm 1. Leader Selection.

Procedure SETUP
  if *ticks > maximumTicks* **then**
    set percent = 10;
    set ticks = 0;
    set isLeader = false;
    set neighbor_agents = φ;
    broadcast message "*No leader*";
    SELECTLEADER(percent);
  end if
end procedure

Procedure SELECTLEADER (int PERCENT)
set neighbor_agents = ask all agents to broadcast their IDs, and no of other agents in radius of their vision;
sort neighbor_agents;
max_leaders = (total_agents * percent)/100;
ask neighbor_agents[max_leaders] top entries to set isLeader = true;
ask leaders to **broadcast** message "*I am leader*";
broadcast message "*Follow new leaders*";
set ticks=ticks + 1;
end procedure

3.4. Informed Agent and Swarm Control

Informed agents receive information about the unexplored region which is considered as goal. All the leaders receive the goal information simultaneously, so that swarm could be steered toward the goal. In real world situation, the goal information about unexplored and important regions can be received from other sources, e.g. human operator, media, other robots like aerial robots. Beside the goal information, global heading and speed is computed for leaders. Other robots move based on the local control laws of the swarm. These local control laws include align, attract, and repel. These control laws are fused with other behaviors described earlier including obstacle avoidance, avoid visited locations etc. Alignment and speed of the normal robots (robots other than leader) is the average of the other robots in the neighborhood, but if there is leader in the neighborhood, the heading and speed of the leader is given higher weightage, which helps the robot to be aligned with leader. This is how leaders influence the alignment and speed of the swarm. Robots avoid collisions and cohesion in swarm using repulsion and attraction behaviors. Attraction, repulsion, and alignment are fused with other behaviors, and normalized to compute the motion of the swarm. Leader in the swarm is selected dynamical based on leader selection algorithm.

3.5. Coverage Calculation

In this work our focus is to explore the whole area, we have used the formula derived for coverage as described by Schwager et.al. [19]. The coverage is the percentage of area explored by all the robots in a swarm. In our case, total walkable patches are counted, and the total patches visited by the swarm. So, we can easily estimate coverage in percentage using the equation defined below.

$$Coverage = \frac{AreaCovered}{TotalTargetArea}$$

4. Experiments, Results and Discussion

To validate our strategy using informed leaders, dynamic selection of leader, goal generation, and its effects on the coverage, series of different experiments were conducted. Each experiment was conducted 3 times to get most optimal reading. To simulate our proposed strategy, we used NetLogo simulator. Moreover, all simulations were carried out on computer having following specification.

- Intel Core i3, 3rd Generation Processors.
- Intel 4000 HD Graphics card.
- 8 GB of RAM.
- Linux Mint operating System.

We have compared proposed technique with the swarm navigates in the environment using random walk. Secondly, we have evaluated the effect of number of the informed leaders. These leaders receive the clues about major goals in the environment. We used 10% and 20% leaders of the entire population [19]. When they all move toward their goal, it creates a force toward some major points of environment, which is easily observed by the other agents, the mechanism is explained in the previous section. As goal information is communicated to the swarm, it drives the swarm toward the unexplored regions. Therefore, full coverage of the environment is possible. The stopping criteria for the experiment is full coverage of the environment for both with and without informed leaders' cases.

4.1. Agents Placment Technique

We have tested two types of agent placement strategies, "Randomly Distributed" and other one is "Group distributed".

In randomly distributed, we distrusted all the population over the whole area randomly, while in group distributed strategy we make one or two groups of all the available population. Size of group is entirely random.

Experiments are characterized according to these placement strategies. Total 7 different experiments were conducted. In experiment 1-

3 Randomly distrusted strategy were used, while in experiment 4-7 group distributed strategy is used. Detailed information about these experiments can be seen in table 1. Each experiment is conducted 3 times.

TABLE 1. Experiments details.

Strategy	Experiment	Agents	Leader %
Randomly Distributed	1	100	0
	2	100	10
	3	100	10
Group Distributed	4	100	0
	5	100	10
	6	100	10
	7	100	20

4.2. Experiment 1

First experiment was conducted with total of 100 agents which were randomly distributed over the whole environment. Agents can re-visit the visited places. Table 2 shows average and Standard deviation of three combined runs. Figure 2 shows exploration graph w.r.t time (in minutes).

TABLE 2. Average and SD for Experiment 1.

Run	Average	Standard Deviation
3	565 min	47.08 mins
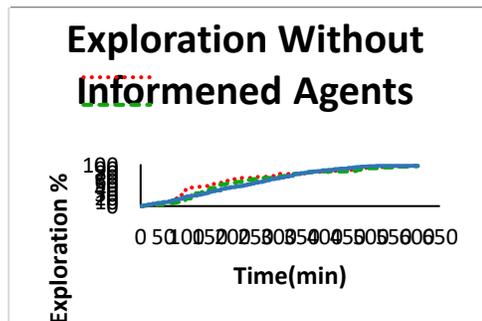
Fig. 2. Three Combined runs of Experiment 1.

Almost all the runs took around 10hours. We can see a lot of flat zones (in Figure. 2), because the exploration was conducted without any informed agents and also by avoid visited location behavior. This let the agents to visit the already visited locations. We simply call this a redundancy.

4.3. Experiment 2

Experiment 2 was conducted with the same configuration as for the previous experiment except now we have 10% informed agents. Average and Standard deviation of combined three runs can be seen in table 3. Figure 3 shows graph of three runs w.r.t time(in minutes).

TABLE 2. Average and SD for Experiment 2.

Run	Average	Standard Deviation
3	205.3 min	25.23 min
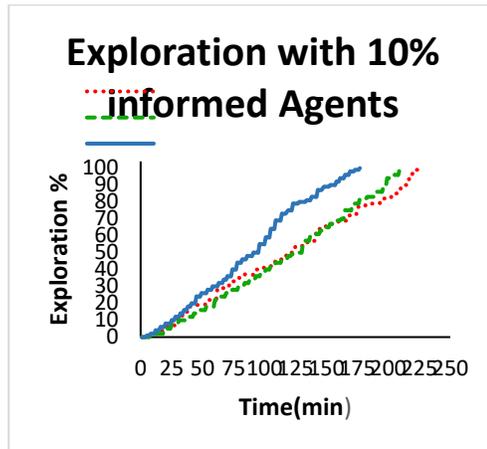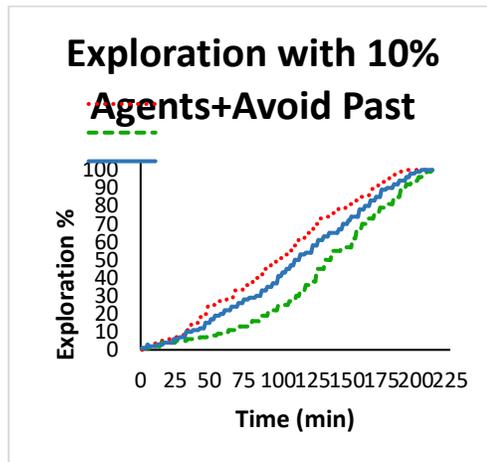
In figure 3 we can see that our flat zones were reduced. This is because we used 10% of informed agents but still we are lacking avoid visited location behavior that still costs us redundancy. Informed agents know some places of the environment that are still un-visited so they take the group to that places which leads us a quality exploration in corresponding against previous experiment. It is clear that by introducing informed agents total time taken to explore the whole environment drops to almost a half.

4.4. Experiment 3

Third experiment was conducted with 10% informed agents and with avoid visited locations behavior. Average and Standard deviation is listed under table 4. Figure 4 shows graph of exploration w.r.t time.

4.6. Experiment 5

Experiment 5 was the same as the experiment 4 but this time we used 10% leaders (informed agents) over the entire population. Average time and Standard deviation of combined three experiments can be seen in table 6. Figure 6 shows graph for all three runs of exploration v/s time.

TABLE 6. Average and SD for Experiment 5.

Run	Average	Standard Deviation
3	132.3 min	12.5 min
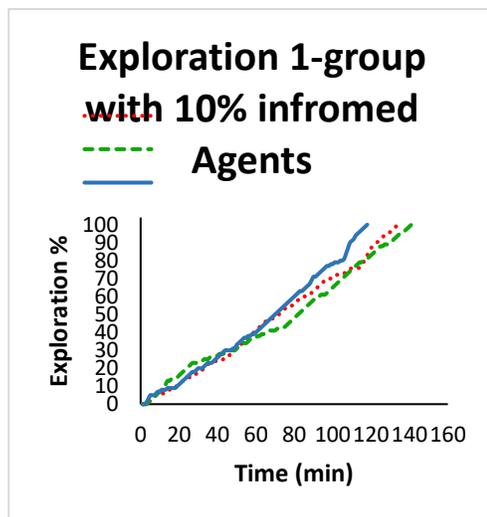
Fig. 6. Three Combined runs of Experiment 5.

It is clear to see in Table 6 that total average falls up to 50% if we compare it with experiment 4. By enabling informed agent behavior, the single group broke into several small groups. Informed agents took all the agents in their swarm to major location which led to a decent exploration.

4.7. Experiment 6

The only Change made in current experiment was to enable avoid visited location behavior. Figure 7 shows graph of whole three exploration v/s time, and Table 7 shows average and Standard deviation of all three combined runs performed for this experiment.

TABLE 7. Average and SD for experiment 6.

Run	Average	Standard Deviation
3	81.6 min	2.0 min

It is very clear to see that in Table 7 by using 2-group strategy with avoid visited locations and informed agent behavior our average is improved. Total time taken to cover the full environment fall up to around 1.5hours. The exploration was very smooth and informed agents led the groups to unvisited locations.

4.8. Experiment 7

In this last experiment, we used 20% informed agent rather than 10%, in-order to see whether increasing informed agents will effect the overall performance or not. Rest of the configuration was the same as in the experiment 6. Table 8 shows average and standard deviation of all the three runs which were performed for above mentioned experiments.
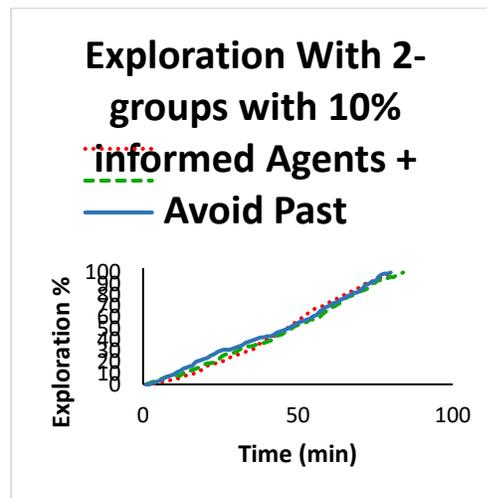
Fig. 7. Three Combined runs of Experiment 6.

TABLE 5. Average and SD for Experiment 7.

Run	Average	Standard Deviation
3	100.6 min	5.05 min
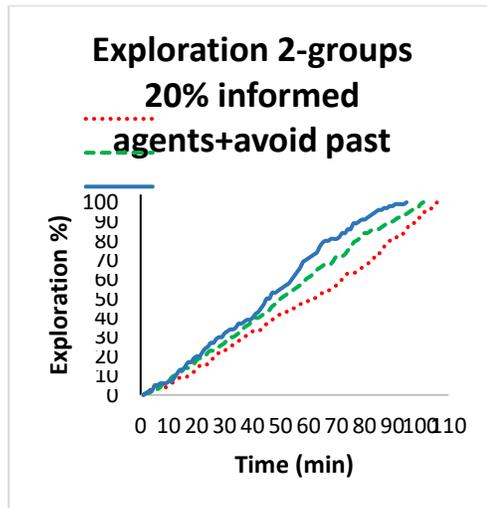
Fig. 8. Three Combined runs of Experiment 7.

In this last experiment, we used the same configuration as in the experiment 6. The only change was in the percentage of informed agents. In order to see influence of informed agent we used 20% instead of 10%. As discussed earlier, informed agent does not get whole map of the environment. They just got clues about major goals. As major goals are limited and not all informed agents got unique goals, a single goal was shared between more than one informed agent which led multiple groups(swarms) to a single location. Hence overall exploration effected.

5. Conclusion

In this paper, we have suggested a coverage technique for large scale environment. The basic implementation of this type is system is feasible in a disaster or search and rescue operation. As our results show that in large scale environment informed agents played key role in exploration of an unknown area. Also,

it was a behavior based technique so agents decide which behavior to call in which type of situation.

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