Multi-robot Automated Search for Non-Adversarial Moving Evaders in an Unknown Environment

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Abstract

In this paper, the problem of searching for moving evaders in unknown environment using group of mobile robots is investigated. The aim is to find the moving evaders as fast as possible. Three different search techniques are proposed and evaluated through extensive experimentation. In the first two techniques, robots do not cooperate or coordinate their actions. Alternatively, they implement simple movement strategies to locate the evaders. On the contrary, in the third technique, robots employ explicit coordination among each other and they implement a relatively complex algorithm based on *voronio graph* to find the evaders. In the later technique, each robot needs to be equipped with communication and localization capabilities. The results showed that graph-based technique led to shortest search time. However, it also showed that a reasonable performance is possible with cheap robots implementing simple and non-coordination techniques.
Keywords: Search, Multi-Robot, Voronio Graph, Moving Target, Coordination.

1. Introduction

The problem of searching for a moving evader is relevant to many real-world scenarios [1]. In search and rescue scenario, it is often necessary to search environments for survivors or first responders, some of whom may be moving and not stationary. In some military applications, human often need to locate friendly or hostile evaders in theaters of battle or peace keeping situations [2]. Military and first response teams need to find lost humans or survivors in disaster scenarios. In [3], Kumar et al proposed a technique to find a lost first responder in an indoor environment where a moving first responder is lost during disaster response, and a team of robots must locate the first responder. In such applications, it is important to capture the evader quickly, for example, to increase chances of survival. A similar scenario arises when a group of ground vehicles try to locate an evader on a road network while an air vehicle provides surveillance [1].

There are two general approaches for searching for targets in a given area based on the coordination among robots. In the first approach, the robots (robots) are completely coordinated through different strategies. These strategies employ strict rules to govern the behavior of the individual robots. The second approach employs randomized and uncoordinated strategies; these strategies minimize explicit control of the robot's actions and instead behave in a directed random fashion. Generally, the first approach tends to accomplish their goals quicker than randomized approach. However, the randomized approach is simpler and easier to design and more immune for failure of one or more of its agents.

In this paper, it is assumed that evaders are *non-adversarial* and move randomly in the environment. Such an assumption is consistent with the task of locating a moving survivor in a disaster scenario. The proposed search techniques presented in this paper can be easily applied to a stationary "evader". In this paper, we developed three different search techniques for multiple robots pursuing a non-adversarial mobile evader. The proposed techniques are designed to minimize the time of capture the evaders. Our techniques are relevant in complex environments where the guaranteed capture of an evader would be impossible.

2. Related Work

Pursuit-evasion problem was heavily researched in the fields of robotics and computer science. Cheng summarized the previous work in pursuit evasion [2, 4]. This survey includes some recent and old developments in the field. In [5], Parsons investigated the pursuit-evasion problem in graphs where he considered the graph to be a system of tunnels in which an evader was hiding, and *search number* of a graph was defined as the minimum number of guards necessary to catch an adversarial evader with arbitrary speed. Parsons technique was extended by Adler et al. to randomized environments by examining the hunter and rabbit problem [6], where the *escape length* of a strategy was defined as the worst case expected number of rounds for the hunter to catch the rabbit.

Guibas et al. [7] improved the classical pursuit-evasion techniques to guarantee capture in polyg onal environments. They proposed an algorithm to divide polygonal environments into conservative visibility regions and then information space approach is employed to develop complete algorithms that guarantee capture in a searchable graph. Gerkey et al [8] applied same ideas to robots with limited sensing.

Searching or unknown environment is related to the art gallery problem, where the problem is to find the positions for static robots to fully detect an unknown area [9]. For example Isler *et al.* [10] triangulated the search space, abstracted it into a graph and also suggested using stationary robots to reduce more complex environments to simple polygons. In [11], Ferris et al. suggest using Gaussian Processes to estimate the position of a moving evader that propagates wireless signal strength. They depend on the strength and the direction of the wireless signal to estimate position with the aid of particle filter.

The main idea in this paper is based on voronio graph employed in some important previous research woks [12-15]. With the aid of Voronio graph, robots model the environment and at the same time they search the environment for the evaders. With this proposed search technique, robots try to cover the whole environment quickly. As evaders are not stationary, searching the whole environment does not guarantee finding the evaders. In such a case, the search is restarted again based on voronio graph.

The main difference between the work presented in this paper and our previous work in [16] is that in this paper we propose search techniques to locate moving evaders while the work in [16] deals with stationary evaders. Moreover, the work in this paper employs completely different search techniques from the one presented in [16].

3. Search Techniques

In this paper we propose three search techniques. The first technique is called non-coordinated random search, in this technique each robot moves randomly and after each step they check if a evader is within its sensor range, if so this evader is considered as a captured evader. The second technique is called non-coordinated reactive search, in this technique each robot moves forward until it hits a wall, if so it rotates by a random angle and then it moves forward again and so on. Clearly, the above mentioned two search techniques do not require any coordination or communication amongst robots. More importantly, robots are not required to localize themselves during the navigation. These search techniques can be easily implemented by very simple robots.
The third technique is called graph-based search in which the robots build a voronio graph based on the environment map, and they use this graph to control the search task. To find Voronoi Graph G(m) = (V,E) of the current map m, we need to find the set Op(m) which contains for each point p in the free-space C of the map the set of closest obstacle points. The Voronoi Graph then is given by the set of points in Op(m) for which there are at least two obstacle points with an equal minimal distance:

$$v = \{p \in C \| O_p(m) | \geq 2\}$$

$$E = \{(p,q) | p,q \in V \text{ p adjacent q in m}\}$$

For each pair of nodes an edge is added if their corresponding points in m are adjacent. The Voronoi Graph can be generated from occupancy grid maps as given in [17, 18]. In particular, this can be done by applying the Euclidean distance transformation [19] to a grid-based map. More information about navigation according to voroino graph is available in [20].
Each robot scans the environment by its sensors and the collected scanning data is used to build a map. Also the collected data are sent to other robots. When a robot receives a data from a colleague, it includes this data in its map and this map is used to build a voronio graph [17-18]. The robots follow the graph during the search task, as a result, the whole environment is covered. If the whole environment is covered and still there are un-captured evaders, the search is restarted again and the whole environment is covered again. This procedure is repeated until all of the evaders are captured.
To implement the graph-based search technique, robots must be equipped with robust search algorithm with a rigid localization strategy. Moreover, each robot needs to be equipped with communication capabilities. Such capabilities results in considerable increase in the cost.

4. Results

The three above mentioned search techniques are tested with the indoor environment shown below. The experimentation started with one robot and one evader. The evader is placed at the center of the environment and it moves randomly. The robot is placed at the lower left corner of the environment. The time the robot requires to capture the evader is recorded. Same experiment is repeated 20 times and the average and the standard deviation are recoded. Then same proceed is repeated with two, three, four, five and six robots. The results of these experiments are shown in Figure 2.

Then we switch to two evaders and the same set of experiments is repeated with one, two, three, four, five and six robots. The results of these experiments are shown in Figure 3. Similarly, Figure 4 and 5 shows the results for searching for four and eight evaders respectively.

The results show that the random non-coordinated search leads to a considerably long search time compared with the other two techniques. While the reactive non-coordinated search results in much better performance. Such results are expected to appear as robots tend to cover the search area quickly. None the less, the graph-based search has consumed the shortest search time as compared to the other techniques.

5. Conclusions

In this paper, three different search techniques is developed and tested. In the first, robots moves randomly until they find the evaders. In the second, each robot moves forward in straight line until it is obstructed by an object or a wall. When a robot is obstructed, it rotates randomly and so on until all of the evaders are captured. After each movement step, each robot checks if any evader is within its sensor range. If so, this evader is considered as a captured evader. The results show that the second technique, where the robots have better and more flexible mobility, is much more efficient than the first one.

In the third technique, robots build voronio graph and they follow the graph to cover the environment quickly. Quick cover of the environment helps reduce the search time. This third technique outperformed the other two and achieved shortest search time. However, robots with advanced communication and localization capabilities are required.

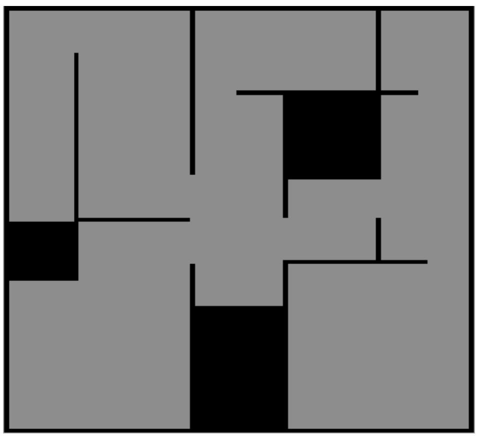

Figure 1: Indoor home environment used for testing the search algorithms

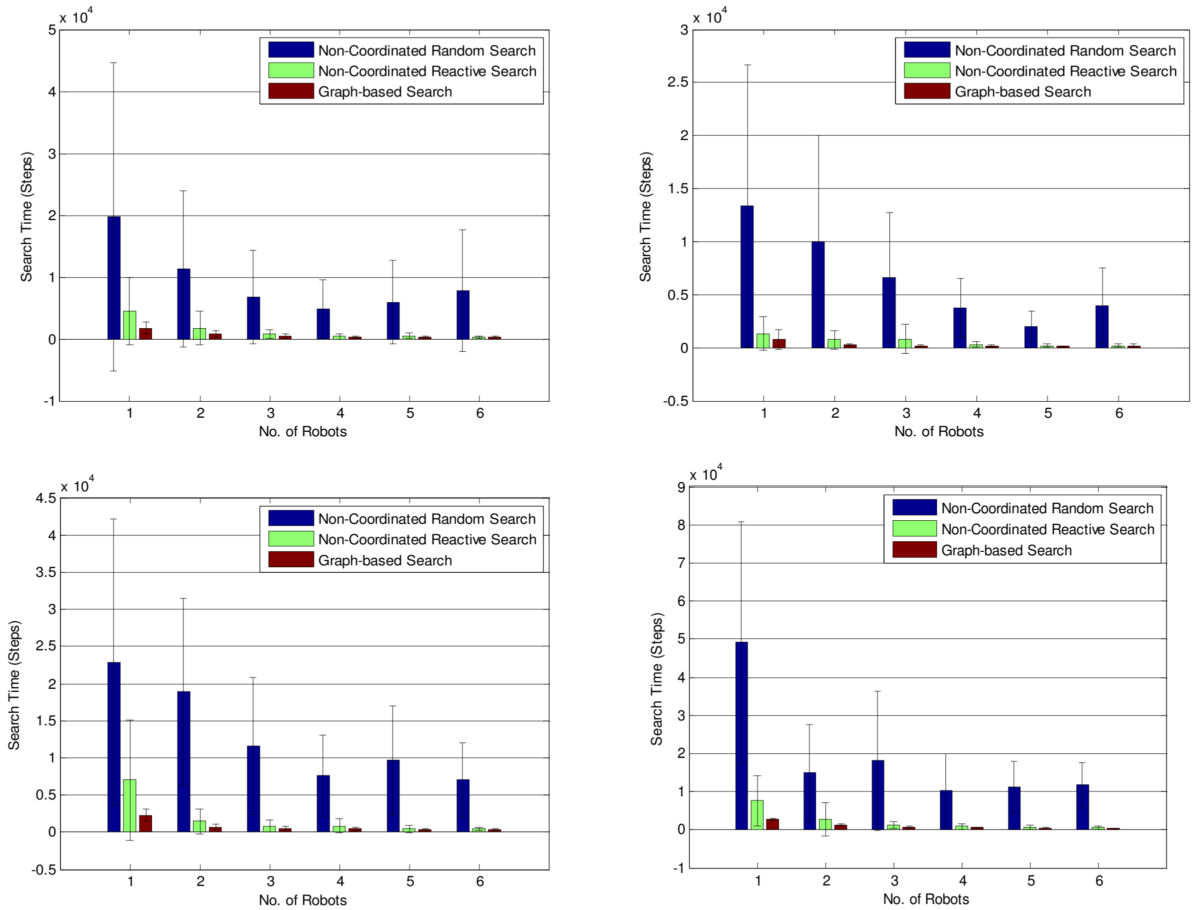

Figure2: Search time vs number of robots; (a): Searching for one evader, (b): Searching for two evaders, (c): Searching for four evaders, (d): Searching for eight evaders

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Bibliography

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