Online Multi-Robot Coverage: Algorithm Comparisons

Extended Abstract

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ABSTRACT

We consider the common assumptions made when multi-robot systems are used for exploration and coverage and the metrics used to compare performance. We then take three algorithms – the Rolling Dispersion Algorithm (RDA), the Multi-Robot Depth-First-Search (MR-DFS) algorithm, and the BoB algorithm – chosen for their different strengths and assumptions, and compare, using a set of common metrics, their performance in different simulation environments. We present two simple extensions to RDA – RDA-MS (multi-start) and RDA-EC (extended communication), which preserve RDA's original assumptions, but are able to perform as well as the algorithms that make more demanding assumptions.

KEYWORDS

multi-robot systems; distributed systems; online coverage

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1 INTRODUCTION

Investigating an environment in the aftermath of a natural disaster, such as an earthquake or tsunami, comes with many risks to the human search and rescue team, but timing is also critical. Using a robot can provide early information about points of interest and share that information with the human rescuers [16]. However, the very nature of disaster situations leads to two difficult problems: the number of robots needed and how to control and coordinate those robots. Normal means of communication are often overloaded or completely down in the aftermath of a disaster [3]. Both of these real world problems are often ignored when multi-robot exploration and coverage algorithms are designed.

We have taken our multi-robot exploration algorithm, the Rolling Dispersion Algorithm (RDA), [14] which was developed with disaster search and rescue in mind, and compare it with two other online coverage algorithms which do not consider the communication aspect of real world scenarios. We then developed two modifications to RDA to incorporate important facets of the comparison algorithms, while maintaining the communication restrictions that make it more widely applicable. We show in simulation that the RDA modifications can perform at the same level as the comparison algorithms in terms of time to coverage and distance covered.

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2 RELATED WORK

Multi-robot systems have become popular due to reduced cost and advantages over a single robot in terms of efficiency and robustness [10]. Robustness is especially important for search and rescue.

The most common assumption, that there are enough robots for blanket coverage of the environment [2], is not viable in a real world scenario, and maximizing coverage [15] is insufficient for search and rescue. In sweep coverage, the robots move progressively through the environment and ensure every point has been seen by at least one robot [1]. While sweep coverage requires only a single pass, it is also used for a patrol or repeated coverage [9]. This type of coverage keeps the team small, hence easier to deploy, but still provides complete coverage [14], as required for search and rescue.

Another common assumption is that robots have a map to direct their movement [5, 17]. Some previous work assumes that the robots can create maps and merge them when they regroup [12, 20], but this is actually difficult to achieve in practice [6].

The last common assumption is that communication is unlimited in range and bandwidth. Nearly all centralized systems assume that the individual robots can communicate directly with the central controller [18], and algorithms that create maps assume global communication [20]. Since communication systems are often down in the aftermath of a disaster [10, 16], we must focus instead on achieving coverage with limited communication [8]. Most robots can provide some local communication means themselves, such as wi-fi [15, 19] or line-of-sight methods [13], which can then be used to direct the exploration of the team.

Comparing algorithms with vastly different assumptions and requirements can be challenging [21]. In a search and rescue situation, there are two key metrics: guaranteeing full coverage, and the time to complete coverage. An additional metric that is important in real world scenarios is distance traveled, because power consumption has a significant impact on completion [7]. We also consider return time, because the robots may have additional information then, and so that we can reuse the robots.

3 ALGORITHMS

In reviewing coverage and exploration algorithms, we decided to compare RDA with algorithms not designed with disaster scenario limitations in mind. We chose to limit the scope of comparison to distributed online coverage algorithms for indoor environments, meaning that the environments are bounded and highly structured. All the three chosen algorithms guarantee complete coverage, which is critical in search and rescue. The algorithms differ in their communication requirements and movement patterns.

RDA [14] operates by using the communication signal intensity to keep the robots together during the exploration. It initially disperses the robots as far apart as possible, and then explores individual paths to completion, as in Depth-First-Search (DFS). The robots carry and deposit beacons in the environment to create paths to the entrance and remaining frontiers, and to block off explored areas and loops to prevent repeated exploration. We have previously shown that the algorithm guarantees full coverage and all functional robots returned to the entrance.

MR-DFS [4] implements DFS for teams of robots on undirected graphs, which are then re-arranged as trees. At any vertex, the robots divide evenly among the edges. The robots leave markers at each vertex to inform subsequent robots which direction the earlier robots have gone. MR-DFS allows the robots to split up and completely lose contact with one another, which results in parts of the environment being explored multiple times, or robots traveling down a path where help might be needed, only to arrive after all the remaining unexplored paths have been fully explored. In contrast, RDA is slower to reach full coverage, because the robots must stay in communication with each other, but covers less overall distance. With RDA-EC (extended communication), we can approach the same coverage time as MR-DFS, while traveling significantly less.

BoB [20] uses a combination of the boustrophedon motion, in which the robots move along straight paths and then double back beside the original path, and backtracking using Greedy A*. The boustrophedon motion ensures that the robots cover everything in their area, and the backtracking allows them to quickly move to an open frontier when they reach an end point in their area. It does rely on the robots being able to globally communicate their paths and maps of their areas as they explore, but the map is not needed in advance, making it a good comparison alongside RDA and MR-DFS. RDA-MS (multi-start), reduces the interference at the start of the exploration, due to multiple starting locations and results in faster initial rates of coverage. Teams executing RDA-MS with no knowledge of each other are able to still interact such that the robots will not enter an area that another team has already entered. RDA-MS can match BoB in coverage time, though it lags a bit in distance traveled.

4 SIMULATION EXPERIMENTS

We performed comparison simulations in the Hospital Section (see Figure 1) with 1, 4, and 8 robots. We used ROS/Stage [11] and the Pioneer robot model equipped with a laser range-finder.Results are presented in Table 1 and Figure 2.

In the Hospital Section environment, though BoB performs best with 4 robots, RDA-MS has very similar distance traveled and return

Figure 1: Hospital Section environment used in simulations.

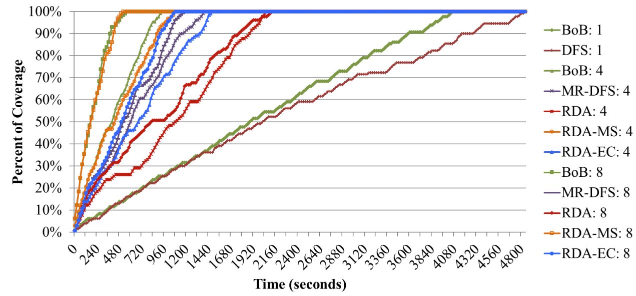

Figure 2: Rate of coverage for the Hospital Section for each algorithm using 1, 4, and 8 robots.

Table 1: Travel distance in number of edges traversed and time to coverage and return in seconds. Values in bold denote best for that metric in that section.

# of Robots	Metric \ Alg.	Travel Distance (meters)	Time to Coverage (seconds)	Time to Return (seconds)
4	BoB	**238**	**960**	**1260**
	MR-DFS	396	1420	2080
	RDA	381	2100	2660
	RDA-MS	254	1100	1340
	RDA-EC	324	1500	2020
8	BoB	**225**	580	**640**
	MR-DFS	685	1200	1800
	RDA	486	2160	2580
	RDA-MS	240	**540**	760
	RDA-EC	528	1100	1620

time, because the BoB robots will travel towards a frontier until they know there isn't actually more to explore in that area. RDA-MS, on the other hand, does not allow the robots to enter an area previously covered by another robot, making the overall distance and return time closer to that of BoB. With 8 robots in the Hospital section, we see that RDA-MS still has a longer total distance traveled and return time, but averages a faster time to complete coverage. The fact that RDA-MS is able to match and in some areas outperform the BoB algorithm, which requires global communication and perfect mapping/localization, makes RDA-MS more robust and appealing for use in a disaster scenario, in which communication is often limited in both range and availability.

5 CONCLUSIONS AND FUTURE WORK

We have discussed how the number of available robots and level of communication impact the viability of coverage algorithms for use in disaster situations. We have compared our RDA algorithm and two minor modifications, with two algorithms that have very different communication requirements. The simulations showed that the modifications perform on par with the comparison algorithms, making them not only feasible, but also effective for real world applications. Future work includes comparisons in less structured environments, and using more robots.

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