# Dispersion and Exploration for Robot Teams (Doctoral Consortium)

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## ABSTRACT

Dispersing a team of robots into an unknown and dangerous environment, such as a collapsed building, can provide information about structural damage and locations of survivors to help rescuers plan their actions. We have developed a rolling dispersion algorithm, which makes use of a small number of robots and achieves full exploration. The robots disperse as much as possible while maintaining communication, and then advance as a group, leaving behind beacons to mark explored areas and provide a path back to the entrance. The novelty of this algorithm comes from the manner in which the robots continue their exploration as a group after reaching the maximum dispersion possible while staying in contact with each other. We use simulation to show that the algorithm works in multiple environments and for varying numbers of robots.

## Categories and Subject Descriptors

I.2.9 [**Artificial Intelligence**]: Robotics

## Keywords

Multi-Robot Systems; Robot Teams; Search and Rescue

## 1. INTRODUCTION

In the event of a fire or earthquake, it is not always possible for a rescue team to enter a building immediately, due to safety concerns for the human rescuers. However, a team of small robots could be deployed to explore the building, locate survivors, and mark pathways to the exits. This information can then be relayed back to the human search and rescue team, who can use it to prioritize tasks.

There are multiple methods for robots to explore an unknown environment. Gage [2] proposed three categories of coverage–blanket, barrier and sweep coverage. Most coverage algorithms are focused on surveillance and usually entail creating a sensor network to provide either blanket or barrier coverage. Dirafzoon et al. [1] provide an overview of many sensor network coverage algorithms. Many of these rely on individual robots knowing the distance and bearing to other robots around them. For example, Kurazume and Hirose [4] developed an algorithm in which the team of robots was split into two groups, one of which remained stationary while the other moved, and then they traded roles. This made for effective movement through an unknown environment, but the robots relied on sophisticated sensors to perform dead reckoning to determine the locations of the stationary robots. There is also research that has shown that a team of robots can disperse into an unknown environment using only wireless signal intensity to guide the dispersion [5]. This method allows the use of small, simple robots, which can be less expensive, making it possible to assemble a larger team. However, attempting to provide blanket coverage can require a prohibitively large number of robots and some algorithms still don't achieve full coverage.

Our main contribution is a novel distributed algorithm, which guarantees that the entire environment is seen, that the robots maintain communication, and that they return to the entry point upon completion of the task. The key feature of the algorithm is that the robots advance as a group as they explore the environment, leaving behind beacons to mark both explored areas and the path to the exit. The robots use wireless signal intensity to ensure that they stay in communication with at least one other robot at all times, so no robot gets lost or is left behind. The algorithm is fully distributed, and each robot makes its own decisions on which behavior to execute depending on the situation and the robot's current role, yet the robots operate as a team.

## 2. ROLLING DISPERSION ALGORITHM

In our algorithm, we wish to achieve full coverage–every point in the environment has been viewed by a robot at least once, so that nothing is overlooked–but we wish to do it with a small team of basic robots. This rules out blanket coverage, due to team size, and dead reckoning methods, due to limited sensor and computational capability. We have also chosen a distributed method so that we can take advantage of the redundancy and robust nature of a team of robots.

Keeping the above items in mind in designing the rolling dispersion algorithm, we established one major constraint on the scenario–that there are not enough robots to provide blanket coverage of the environment. We assume that the robots have proximity sensor(s) for collision avoidance, a wireless card for communication, and a means for carrying and dropping beacons. We also assume a disaster scenario, so the specifics of the current environment are unknown, even if information for the pre-disaster environment (such as a map) is available.

During the exploration of the environment, each robot

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will execute the algorithm and make decisions as an individual, but it will have input from nearby beacons and robots. Beacons are used to mark explored areas, the unexplored frontier, and the path to the entrance.

The robots use the wireless signal not only for communication, but also to direct their movement, both in dispersing to explore a larger area and to return to the entrance. Wireless signal intensity can fluctuate due to obstacles between robots, and may not be the same at every point a set distance from the origin, but this is not critical to the operation of our algorithm. The goal is to maintain communication, so the robots only need to know if the signal intensity is increasing or decreasing to inform their decision on which direction to move. This may not lead to the maximal dispersion, but suboptimal dispersion is acceptable since our main priority is to achieve full coverage without loss of communication.

While our algorithm uses wireless signal intensity to disperse the robots, and beacons to mark locations, the innovation in our approach lies in the manner in which the robots continue the exploration past the bounds of their initial dispersion. The robots are not allowed to move in isolation, but must always stay within communication range of the team. When there is an area to be explored that is beyond the reach of the robots nearby, then the entire team of robots will move towards the unexplored area. This approach has two main benefits. First, it means that the robots are less likely to get lost, since they will have a wireless signal to follow to get back to the entrance. Second, the robots will clear each room and corridor in a methodical manner, similar to the pattern used in law enforcement, thus reducing the likelihood of missing an area.

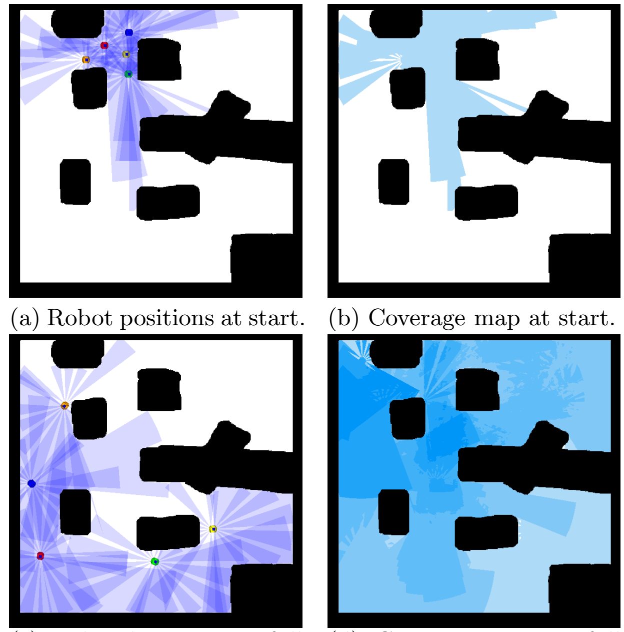
## 3. EXPERIMENTAL RESULTS

We ran our experiments in the Player/Stage [3] simulation environment. In one set of experiments, we used a cave-like environment, which requires ten robots for blanket coverage. We ran these experiments with five and eight robots. Figure 1 shows the simulation view and coverage map for the start and end of a simulation run with five robots. In the simulation view, one can see the five robots as well as their sensors' field of view. The coverage maps show the area that was viewed by the robots' sensors, with locations that were viewed multiple times shaded darker than locations that were viewed only once. On average, it took 170 seconds for five robots to complete the exploration, and 161 seconds with eight robots. The robots turn a random amount when they encounter obstacles, making each run slightly different.

## 4. CONCLUSIONS AND FUTURE WORK

We have developed an algorithm to disperse a small team of robots into an unknown environment to completely explore the space while staying connected at all times during the exploration. The algorithm requires fewer robots than would be needed for blanket coverage, but still provides the necessary information about the environment. Our algorithm also ensures that the robots maintain communication, and are able to exit the environment upon task completion. We have shown in simulation that the algorithm can provide complete coverage of an unknown environment.

In future work, we will test the algorithm in larger and more complex environments in simulation. In particular, we are looking at the hospital section environment that is



(a) Robot positions at start. (b) Coverage map at start.

(c) Robot locations at full coverage. (d) Coverage map at full coverage.

**Figure 1: Five robots in the cave environment.**

provided with Player/Stage, as it has been used in previous exploration and dispersion research, and has proven difficult to fully cover (requiring more than 100 robots for blanket coverage), so we feel it makes a good candidate to show the effectiveness of our algorithm, as well as provide a direct comparison to previous work. We will also be running experiments with physical robots. This is critical to show that the wireless signal intensity can be used to disperse the robots and maintain communication without interfering with the end goal of fully covering an environment. Additional extensions to the algorithm include using the beacons to guide mobile survivors to the exit, and developing the interface and protocols for working with human search and rescue members in performing the exploration. Formal proofs of algorithm correctness have also been left to future work.

## 5. REFERENCES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