Communication-Restricted Exploration for Small Teams

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Abstract

We propose a novel algorithm that allows a small team of robots to fully explore an unknown environment, even in the face of extreme communication restrictions. We verify, through proofs and experiments, that the algorithm will achieve full exploration.

Introduction

In a disaster scenario, a search and rescue team may be prevented from entering an area until it is deemed safe. This costs valuable time for finding and rescuing survivors, so sending in an advance team of robots to scout the environment and locate points of interest can save time by assisting the rescue team in planning their operation. For this approach to be effective, we must be able to guarantee that the robots completely explore the environment.

Multiple methods for a team of robots to explore an unknown environment have been proposed. Most coverage algorithms aim to achieve blanket coverage, but this can require a prohibitively large number of robots (more than 50). Dirafzoon et al. (2012) provide an overview of sensor network coverage algorithms, many of which rely on individual robots knowing the distance and bearing to other robots around them. For example, Kurazume and Hirose (2000) 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 the groups traded roles. This was effective, but the robots relied on sophisticated sensors to perform dead reckoning to determine the locations of the stationary robots. The focus in Ludwig and Gini's (2006) work is to use small, simple robots, which disperse into an unknown environment using only wireless signal intensity and proximity sensors to guide their movement. In our work, we have focused on performing sweep coverage, so that the algorithm can achieve full exploration regardless of team size. Our previous work shows that a small team of robots can completely explore an unknown environment while staying together in a group (Jensen and Gini 2013).

We now propose an algorithm that can guarantee full exploration of an unknown and dynamic environment. The environment itself may change due to additional walls collaps-

ing, and there may be mobile survivors within the environment. Our algorithm can handle both, with any size robot team, and under extreme communication restrictions. These restrictions were imposed because the environment might not be conducive to wi-fi or other radio communication. This would reduce the robots to using more basic means of communication, such as using colored LEDs or chemical signals (Mizuguchi and Sugawara 2006). These types of communication are much more limiting, since a color or chemical must represent the entire message.

Our primary contribution is the development of an algorithm that uses a small set of distinct messages but still achieves full exploration using a robot team that is too small to achieve blanket coverage of the environment.

Sweep Exploration Algorithms

To achieve full exploration of an unknown environment using a team of robots, we are using a distributed sweep coverage approach. This takes advantage of the robustness inherent in a multi-robot system. We assume that the robots can detect and avoid obstacles, communicate within a limited range, and have the means to carry and drop small beacons.

Similar to the previous algorithm in Jensen and Gini's (2013) work, the robots disperse into the environment using signal intensity to spread apart. When they need to move into an unexplored area beyond their communication range, they call for additional robots. When there are no free robots left, the robot nearest the entrance will drop a beacon to mark the path and proceed to the frontier. From there, this work diverges. We are focused on the number of distinct messages required to complete full exploration and have reduced it to the following seven messages.

Explorer: Explores frontier or follows call or failure paths.

Sentry: Stays in place to mark location.

Branch: Marks an intersection with open paths.

Repel: Marks explored areas to prevent repeated coverage.

Call Path: Marks path to frontier.

Retract Path: Marks return path for retraction.

Failure Path: Marks path to location of failed robot.

An important feature of our algorithm is that the robots use communication not only as a means to send messages,
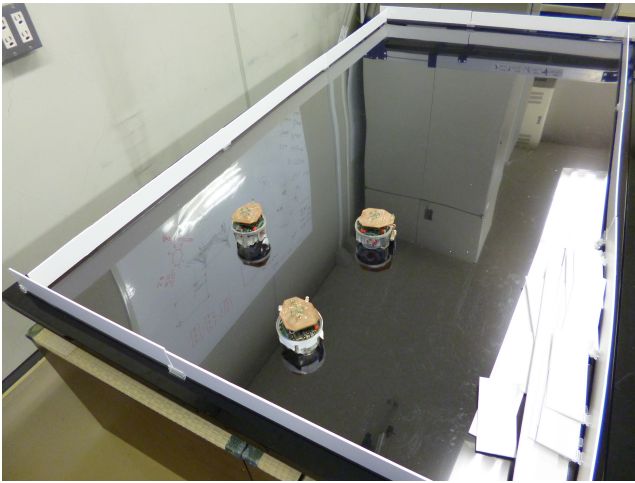
Figure 1: Experimental setup of three robots on the screen with an open environment with only exterior walls.

Figure 2: Different stages in the exploration of a corridor. Robots are identified by R#, beacons by B#, and each message by its initials.

but also as a means to direct their movements. This helps to ensure that the robots stay within range of each other, so that the group stays together to complete the exploration. In addition the algorithm is not dependent on any specific communication method to function, making it versatile and usable on multiple types of robots in many different environments.

Experimental Setup

Our experiments were conducted using modified e-puck robots on a LED flat screen TV laid flat (shown in Figure 1), with a camera above to track the robots' locations. Because we were using an LED screen, we had only three distinct colors we could use to simulate the chemical signals. However, the screen also gave us a benefit, in that we could overlap different colors, and the robots would still detect the individual colors, not the combination. We added IR sensors with color filters for the robots to detect the signals displayed below them on the screen, and IR LEDs on top of the robots for tracking their locations.

With only three colors to work with, we also had to use sequences of colors to communicate the messages. In Figure 2 we show how three robots explored a simple corridor. The figure uses five colors because sequences cannot easily be shown in a still image, and, similarly, we do not show every change of state. In the left column of the example we show the initial dispersion of the three robots. Robot R1 set up as a sentry and immediately called for another robot to continue the exploration, which R2 did. When R2 requested another robot, R3 moved past both R1 and R2, which switched back to sentries after being passed. When R3 calls, the message passes through R2, and it is R1 that responds because there are no more free robots, and beacon B1 is left as a sentry at the entrance. At the top of the right column, R1 detects it is in a dead-end, and signals a retraction. It drops B2 to repel further exploration, and then returns to the entrance along the retract path and leaves the corridor entirely. Each robot follows this pattern until all have exited, leaving behind only
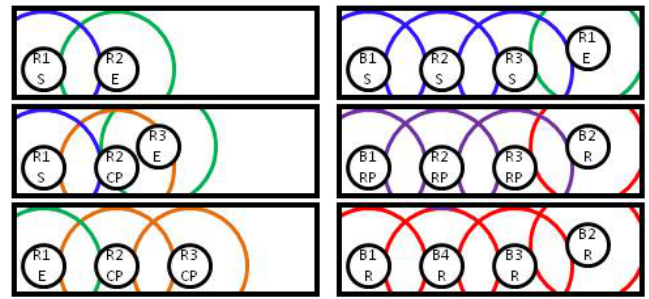
the four repel beacons. In a more complex environment, with larger open areas and multiple rooms, the robots drop more beacons to mark paths and explored areas.

Conclusions and Future Work

Our main contribution is a distributed algorithm for robot team exploration of unknown environments with extremely limited communication. Our algorithm uses the communication signal intensity to help guide the exploration, and we show that this method is viable with multiple types of communication, including highly restricted forms, such as chemical signals. In the supplementary materials we provide proofs that guarantee full coverage and that the seven messages detailed above are the minimum required.

As future work, we plan to incorporate a means of communicating directly with humans in real-time during the exploration to help a mobile survivor find a safe path to an exit or to allow the rescuers to request additional information about a specific location. We also plan to include human input during the exploration to test the algorithm under several levels of autonomy.

References

A. Dirafzoon, S. Emrani, S. M. Amin Salehizadeh, and M. B. Menhaj. Coverage control in unknown environments using neural networks. *Artificial Intelligence Review*, pages 237–255, 2012.

E. A. Jensen and M. Gini. Rolling dispersion for robot teams. In *Proc. Int'l Joint Conf. on Artificial Intelligence*, pages 2473–2479, 2013.

R. Kurazume and S. Hirose. An experimental study of a cooperative positioning system. *Autonomous Robots*, pages 43–52, 2000.

L. Ludwig and M. Gini. Robotic swarm dispersion using wireless intensity signals. In *Distributed Autonomous Robotic Systems 7*, pages 135–144, 2006.

T. Mizuguchi and K. Sugawara. Proportion regulation in task allocation systems. *IEICE Trans. Fundamentals*, E89-A(10):2745–2751, 2006.