

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE MAR 2003		2. REPORT TYPE		3. DATES COVERED 00-00-2003 to 00-00-2003	
4. TITLE AND SUBTITLE Dynamic Coverage via Multi-Robot Cooperation				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Southern California ,Robotic Embedded Systems Laboratory,Computer Science Department,Los Angeles,CA,90089				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES U.S. Government or Federal Rights License					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	unclassified	unclassified	Same as Report (SAR)	2	

DYNAMIC COVERAGE VIA MULTI-ROBOT COOPERATION

Maxim A. Batalin, Gaurav S. Sukhatme
Robotic Embedded Systems Laboratory,
Computer Science Department, USC, Los Angeles, CA
[maxim.gaurav@robotics.usc.edu]

The coverage problem in the context of multi-robot teams can be defined as the maximization of the total area covered by the sensors of all robots in the team. Some coverage algorithms cause a robot group to converge to a static configuration, such that every point under the robots' sensor shadow is covered at every instant of time. We term such a coverage task *static*, since as soon as the desired dispersion is achieved, the system is at equilibrium. For complete static coverage of an environment the robot team should have a certain critical number of robots (depending on environment size, complexity, and robot sensor ranges). Determining the critical number is difficult or impossible if the environment is unknown a priori.

Some applications of coverage (patrolling, for example) do not require every part of the environment to be covered at every instant in time. Imagine a task where a team of robots continually explores the environment but does not settle to a static configuration. This is an example of a *dynamic* coverage task. Note that the *static* coverage problem is a special case of the *dynamic* coverage problem.

There are many applications of autonomous coverage such as tracking unfriendly targets (e.g. military operations), demining or monitoring (e.g. security), and urban search and rescue (USAR) in the aftermath of a natural or man-made disaster (e.g. building rubble due to an earthquake or other causes).

In this paper we address the *dynamic* coverage problem, which requires all areas of free space in the environment to be covered by sensors with as high a frequency as possible, given a fixed number of robots. Our solution to the problem relies on the deployment of beacons (small stationary nodes with radios) into the environment as support infrastructure which the mobile robots use to solve the coverage problem. Robots explore the environment, and based on certain *local criteria*, drop a bea-

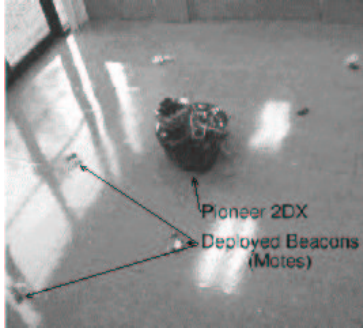


Figure 1. Screen shot of a preliminary experiment involving two platforms: Pioneer 2DX robot, the carrier and a mote, several of which are used as beacons.

con into the environment, from time to time. Each beacon is equipped with a small processor and a radio of limited range. The proposed algorithm is decentralized and performs the coverage task successfully using only local sensing and local interactions between the mobile robots and beacons. The mobile robots interact through the environment by deploying the beacons and changing their state when in the communication vicinity of beacons. The fundamental constraint that we impose on the solution is the lack of global information about the environment (neither a map nor access to global positioning information). We also do not require the robots to be localized. We measure coverage using a *frequency coverage metric* that measures frequency of every-point coverage over time.

We compared our algorithm to a (modified) version of a prior *static* approach. The prior approach, used as a baseline here, was based on robots dispersing themselves in the environment by locally repelling each other in order to 'fan out' and then applying local rules to maximize coverage (we call this the *Molecular* approach).

Simulations show that the *dynamic* algorithm outperforms the *Molecular* approach in cases where the number of robots in the team is less than the critical number. As the environment becomes saturated with mobile robots and the critical number is exceeded the performance of both algorithms, as expected, converges to the same value. In addition, the presented *dynamic* algorithm deploys a static network of nodes into the environment which has applications other than coverage. For example, a problem of recovery of a team of robots from the environment can be solved using the deployed static network of beacons for homing.

At the present time we are conducting real-world experiments to accomplish *dynamic* coverage of a planar bounded environment (Figure 1 shows screen shot of a preliminary experiment). In our experiments we use a team of Pioneer 2DX robots, equipped with 180° laser range finder, wireless communication, compass and a set of beacons. Beacons (motes) have onboard processor and a short range radio.