Centibots: Very Large Scale Distributed Robotic Teams

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1 100 Robots

We describe the development of Centibots, a framework for very large teams of robots that are able to perceive, explore, plan and collaborate in unknown environments. The Centibots team currently consist of approximately 100 robots (Figure 1). The Centibots team can be deployed in unexplored areas, and can efficiently distribute tasks among themselves; the system also makes use of a mixed initiative mode of interaction in which a user can influence missions as necessary. In contrast to simulation-based systems which abstract away aspects of the environment for the purposes of exploring component technologies, the Centibots design reflects an integrated end-to-end system.

As part of DARPA's Software for Distributed Robotics (SDR) project, the Centibots were tested on a mapping and search mission in a new, unknown environment. This experiment involved deployment of Centibots in three successive stages: (1) a mapping stage for the coordinated exploration of the environment while simultaneously constructing a very high accuracy occupancy map using a laser range finder; (2) a search stage in which the environment is exhaustively searched for a predefined object of interest (OOI), chosen so that it could be easily distinguished within the environment by its shape and its color; and (3) an intruder detection stage in which robots are distributed throughout the environment to "guard" the OOI by continuously searching the environment for human intruders. This stage included recharging a portion of the robots to prove the system could continue indefinitely.

Previous work has largely focused on isolated aspects of our system, including multi-robot exploration [1], architecture [3], task allocation [12], coordination [9],

Fig. 1. 100 robots. Four of the robots are Pioneer IIs with SICK laser range-finders. The rest are Amigobots with sonars, a camera and a small PC on top. The OOI is in the hand of one of the authors.
and human interaction [11]. Here we describe the integration of various technologies to achieve an operational robot team, which was tested under rigorous conditions by SDR’s outside evaluation team during a final demonstration. The main criteria of the evaluation focussed on the effectiveness of the robot team in performing the mapping and surveillance task (Sections 2.2 and 3.3).1

Our approach to multirobot coordination is significantly different between the mapping phase and the subsequent search and surveillance. Mapping is performed with a small number (1-5) of robots working completely autonomously, often out of contact with the base station. Their interactions are tightly focussed on solving a single task, exhaustively mapping an area in the shortest time. We developed specialized algorithms based on utility theory to coordinate the mapping robots, under the condition of an unknown environment, intermittent communication and no centralized planner. In search and surveillance, a much larger number of robots (≈100) must be coordinated, and the tasking is more flexible, e.g., robots can be commanded to watch over a given area. Here, issues of spatial reasoning, task distribution, resource allocation, and user interaction become much more important.

In the following sections, we describe the coordination strategy for mapping and exploration, and give the results of the evaluation for this phase. We then give an account of search and surveillance, along with their results.

2 Distributed Mapping and Exploration

In the mapping phase, multiple robots explore the environment in order to build a map that can be used in the subsequent search and surveillance phases. We developed a decentralized system that goes beyond the state of the art in multi-robot mapping in that it does not depend on reliable communication between robots and makes no assumptions about the robots’ relative start locations.

2.1 Overview of Exploration System

Multi-robot Mapping Our technique for multi-robot mapping is based on a representation of local probabilistic constraints among robot poses. These constraints arise from robot motion (odometry) and matching laser range-finder scans. Figure 2 shows a laser map along with the trajectory of a robot (gray) and the constraint links (black). The trajectory also represents robot motion links. The optimal position of the poses is the one that maximizes the posterior probability of all the constraints. Although the constraints are nonlinear, there are efficient approximations that work well in practice [4, 7, 8]. Note the fine detail of the laser scan map resulting from this optimization, showing even the thickness of the walls.

1 Two other teams, one led by SAIC and one by MIT, also underwent the same evaluation process, but as of this writing we do not have access to their results for comparison.