Miniature mobile robots for plume tracking and source localization research

RAYMOND H. BYRNE *, DOUGLAS R. ADKINS, STEVEN E. ESKRIDGE, JOHN J. HARRINGTON, EDWIN J. HELLER and JOHNNY E. HURTADO
Sandia National Laboratories, MS 1003, PO Box 5800, Albuquerque, NM 87185-1003, USA †

Abstract—Cooperating robots have the potential to achieve tasks more quickly and with a higher probability of success than a single robot acting alone. This paper describes a system of miniature mobile robots and the algorithms used to demonstrate cooperative plume tracking and source localization. The robots share sensor information, but individually decide a course of action based on their estimate of the plume field. This algorithm was implemented on a group of miniature mobile robots capable of measuring temperature plumes. Experimental results are presented for a representative test run. We also describe a ‘next-generation’ miniature mobile robot under development that occupies only 0.25 cubic inches in volume.

Keywords: Miniature robots; source localization.

1. INTRODUCTION

There is currently considerable interest in expanding the role of robotic vehicles in surveillance and inspection; searching, following and tagging; and locating and identifying targets. In particular, researchers are beginning to focus on using small autonomous robotic vehicles for these tasks. This focus has been brought about largely because of the many recent advances in microelectronics and sensors, which include small, low power, CCD cameras; small microprocessors with expanded capabilities; and autonomous navigation systems using GPS. It seems likely that these technological advances will lead to inexpensive, easy to fabricate, autonomous vehicles outfitted with an array of sensors. This, in turn, will allow researchers to

*e-mail: rhbyrne@sandia.gov
†Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL8500.
consider teams, or even swarms, of these robots to perform a particular task. It is natural then to wonder how one might effectively control a team of robotic vehicles. In this paper, we discuss an approach to effectively control a team of autonomous robotic vehicles as they perform a search and tag operation. In particular, the robots are to find a single source. The robots work together by sampling and sharing information with others.

As part of this research, we also developed a system of miniature robotic vehicles to evaluate theoretical algorithms in hardware. These robots, which measure \(1.6 \times 0.75 \times 0.71\) in\(^3\), employ a temperature sensor to seek out thermal sources in a room. Because of their small size, a relatively large number of robots may be used for experiments. We have built 36 miniature robots, and typically use 20 in experiments. Studies have also been conducted to evaluate the relationship between the number of robotic vehicles and the time required to find the source. Previous related work on miniature robotic vehicles is described in Refs [1–6].

There was considerable research done during the late 1960’s and early 1970’s in the area of multilevel optimization. In multilevel optimization, units (i.e. subsystems or robots) in a process are uncoupled and optimized individually, while subject to equality constraints that require a match of certain conditions between the units. This is an attractive approach; however, Avery and Foss [7] showed that this approach is not applicable to certain systems. Our approach is contrary to the multilevel optimization approach in that while the robots are uncoupled and optimize individually, they utilize each other’s information for their update strategies.

There are many definitions of cooperation. While other researchers [8] have investigated cooperative behaviors for teams of robotic vehicles, the definition is usually taken to mean ‘help manipulate’. In our work, cooperate is taken to mean ‘share information so that better decisions can be made’.

The next section describes our algorithm for distributed cooperative control. A description of the miniature robotic vehicles appears in Section 3. Section 4 contains experimental results for a test conducted with our miniature robotic vehicles.

2. ALGORITHM FOR DISTRIBUTED COOPERATIVE CONTROL

Our algorithm assumes that the robots have relative position and sensor information. Furthermore, the robots have onboard processing capability and are able to communicate with one another. Each robot is then able to communicate and share information with all others, or with only a subset depending upon whether the communications mode is set to ‘global’ or ‘local’. These communications modes have advantages over one another. After a robot samples its environment, it broadcasts its information to the others. Each robot assembles the information that it receives and determines a projected target of where it believes the source is located. The position update for each robot is then based upon its current position and the position of the projected target. We have performed many simulations and hardware tests to