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Flocking Small Smart Machines: An Experiment in Cooperative, Multi-Machine Control

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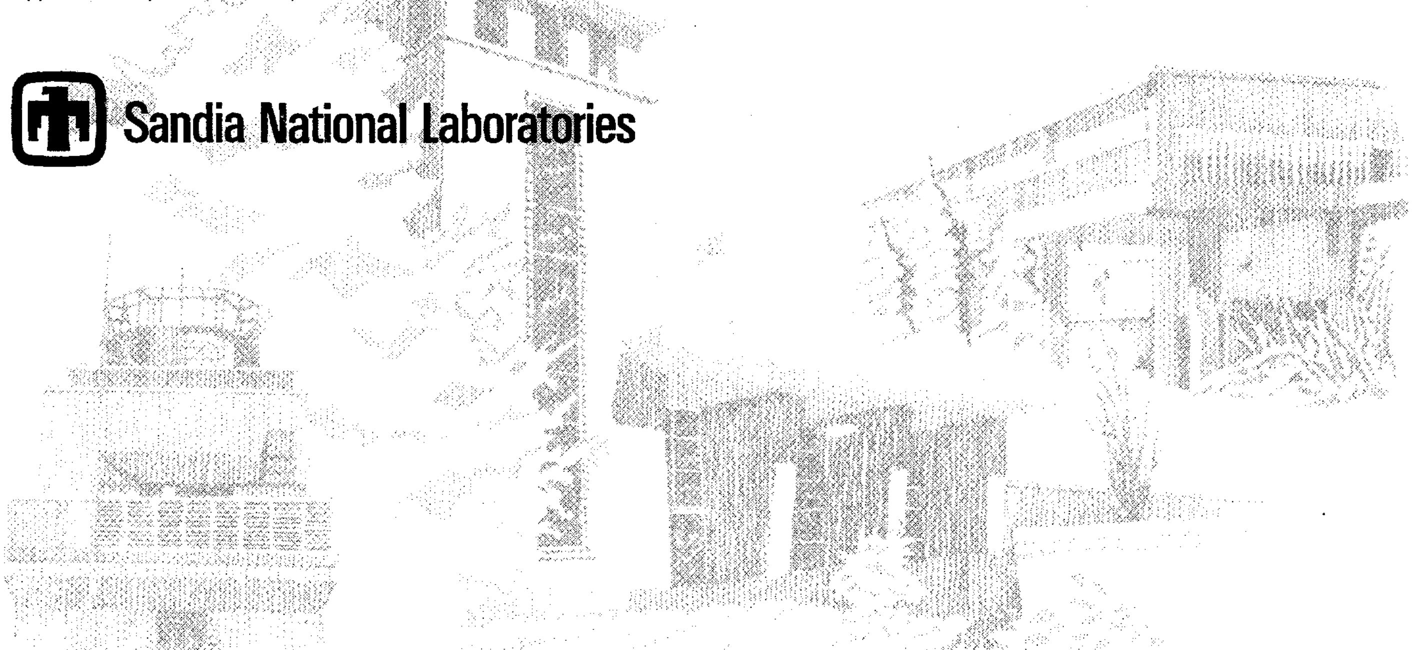

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Abstract

The intent and purpose of this work was to investigate and demonstrate cooperative behavior among a group of mobile robot machines. The specific goal of this work was to build a small swarm of identical machines and control them in such a way as to show a coordinated movement of the group in a 'flocking' manner, similar to that observed in nature. Control of the swarm's individual members and its overall configuration is available to the human user via a graphic man-machine interface running on a base station control computer. Any robot may be designated as the nominal 'leader' through the interface tool, which then may be commanded to proceed to a particular geographic destination. The remainder of the flock follows the leader by maintaining their relative positions 'in formation', as specified by the human controller through the interface. The formation's configuration can be altered manually through an interactive graphic-based tool. An alternative mode of control allows for teleoperation of one robot, with the flock following along as described above.

Introduction

This work is an initial step in the development and demonstration of swarms of mobile robotic vehicles, each of which cooperates and coordinates its activities with other members of the swarm to accomplish a specified goal. Although ultimately swarms will not require any centralized control or coordination, this work did make use of a centrally located computing node to provide a user interface to the swarm and to explicitly coordinate their movements. The goal of the work was to demonstrate an ability to interact with several mobile robotic vehicles by explicitly specifying the actions of a single vehicle's movements and having the remaining vehicles 'follow' or 'flock' along with the first vehicle according to a user-specified set of criteria or pattern. In short, we wish to specify a geometric formation for the swarm to assume relative to a designated leader vehicle, and then teleoperate or telemanage the movements of the leader vehicle explicitly and have the other vehicles maintain their formation as the group moves across terrain. Figure 1 shows three of the vehicles in a typical formation as they have just formed up and are beginning to move out.

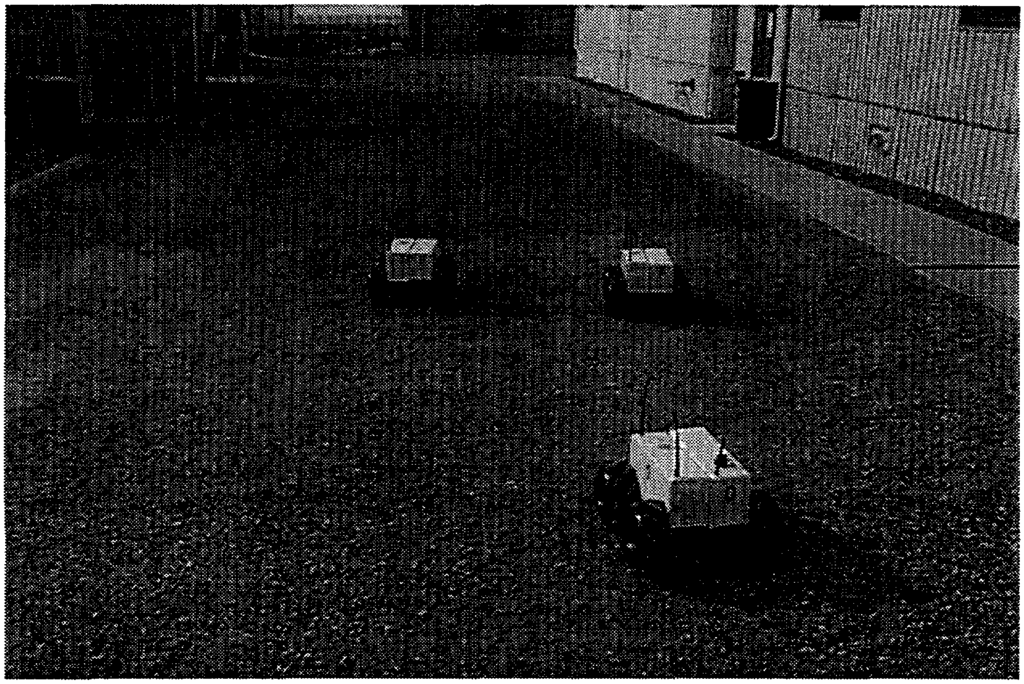

Figure 1. Swarm in a 'Wedge" Formation

Project Development Items

The project items developed include a MS-Windows NT based application for the base station laptop PC and a set of four mobile robotic vehicles with onboard sensing, communications, and control software.

The mobile platform design chosen for use as a testbed for this work was a scaled-down version of Sandia's Robotic All-Terrain Lunar Exploration Rover (RATLER). This was due primarily to the RATLER's excellent performance characteristics in moderate to rough terrain. The original RATLER was a 1-meter vehicle weighing 100 kg, whereas the SWARM-RATLERs used in this work are approximately 40 cm long and weigh 12 kg each. The vehicles were configured to allow integration of sensing and other payloads to be as flexible as possible, with plenty of unused payload space, power and signal path capacity. The platforms are built entirely of carbon-epoxy composite, with the wheels having a tread pattern molded/bonded to the outer surface in high durometer polyurethane. The onboard power system provides 24 V raw DC power from the battery system, and regulated power at 12V, 9V and 5V at 2A, 2A, and 3A respectively. Each of the SWARM-RATLER vehicles is fitted with a PC-104 based computing system utilizing an Intel 80486 cpu running at 66 MHz and 4 Mb RAM with onboard SVGA capability and 2 Type-III PCMCIA slots for mass data storage. Data acquisition channels provided include 16ea, 12 bit analog inputs, 16ea digital input/output (TTL level), 2ea 12 bit analog outputs (used for drive motor control), and 6ea RS232 serial ports, of which only about 20% has been used. Additional I/O channels can be added very easily. Control of the drive motors is accomplished through the analog output channels and a pair of integrated H-bridge servo drives (one for each side) running in torque control mode. The motors are conventional brushed DC gearhead units, one for each of the four wheels. Sensors onboard include pitch and roll for each chassis body, compass heading, raw 3-axis magnetometer flux, ambient temperature, and differentially corrected GPS-based latitude, longitude, and elevation.

The control station is a laptop PC running Windows NT and the application control interface software. The application control software provides a graphic user interface to the swarm of robots, allowing a swarm pattern to be arranged as a set of points (individual robots) with separation distances and orientations along a curve or line using the mouse. A menu-driven interface allows the user to select a particular robot to control, and also allows the user to choose either a teleoperation mode or an autonomous mode of operation for that robot. In teleoperation mode, a 'virtual joystick' is displayed in a window and is controlled using the mouse. Video from any of the vehicles' on-board cameras can be displayed in a window directly on the laptop. In autonomous mode, a geographical destination point is specified for the 'leader' as a goal to proceed towards. Either by driving the designated 'leader' robot or commanding it to proceed towards a specific location, that vehicle begins moving when directed by the user and the remainder of the swarm follows that vehicle's movements by maintaining the separation distance and orientation with respect to the leader as specified by the user. Each vehicle is modeled internally as a mass in a spring-mass system, where the 'springs' describe the 'interconnections' of the swarm's individual robots. Manipulating the parameters of the masses and springs allows the flocking behavior to be tuned and optimized for a particular vehicle/terrain combination.

Results

Field testing to date has shown the flocking activity to be working in smooth to moderate terrain. Several improvements to both the vehicle hardware and software are required to increase the system's performance, including both mechanical and software enhancements. The differentially corrected GPS works well but experiences data drop-outs that are as yet unexplained. Vehicle position-tracking performance can be improved considerably by tweaking the onboard control algorithms and through a slight modification in the servo-amplifier hardware configuration. Although we have not made formal measurements of position-seeking performance of the vehicles with regard to GPS, we have informally observed the vehicles to be maintaining their specified latitude/longitude goal positions to within approximately 1 to 2 meters of ground truth when operating with differentially corrected GPS data in real-time.

Summary

To date, the swarm consists of 4 identical robots, and they have been tested individually for functionality. Individual robots have been controlled in teleoperation and autonomous modes, and the flocking control algorithm has been tested in the field. The swarm is currently being doubled in size, with four new improved vehicles due to be on-line within the next few months. The control station code is being improved as well, incorporating improved algorithms for flocking and additional functionality for various field applications of this technique.

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