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A Multi-vehicle Testbed for Multi-modal, Decentralized Sensing of the Environment

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I. INTRODUCTION

To facilitate the development of novel cooperative control algorithms specifically for environmental sensing, monitoring, and mapping, we extend our current multi-vehicle testbed to enable a quick turnaround from simulations of the control algorithms to actual hardware implementation. The addition to our multi-vehicle testbed consists of four Pioneer P3-AT mobile robots each equipped with an environmental sensor suite. The multi-vehicle testbed was designed to accommodate various types of sensors as well as various numbers of vehicles and types. Sensors and robots can be added and removed on the fly to accommodate user needs. Also, the multi-vehicle testbed is able to carry out indoor as well as outdoor experiments.

We expand on our original testbed [1] COMET, to include mechanisms that allow for environmental sensing which enable validation and verification of cooperative control algorithms that depend on measurements of the sensed environment. The original COMET testbed consisted of ten all-terrain vehicles which are based on the Tamiya TXT-1 monster truck chasis. The COMET testbed is used for validation of cooperative control algorithms, however in its first generation lacked environmental sensing capabilities.

II. HARDWARE DESCRIPTION

A. Vehicle Description

The Pioneer P3-AT carries up to 252 Wh of hot-swappable batteries. The P3-AT can reach speeds of 0.8 m/s and carry a payload of up to 30 kg as well as climb a steep 45% gradient. Also, laser-based navigation options, integrated inertial correction to compensate for slippage, GPS, bumpers, gripper, vision, stereo rangefinders, and compass options are available commercially for the P3-AT [2].

Our current testbed can accommodate laser-based navigation, GPS navigation, as well as gripper/manipulator tasks. Although this paper concentrates on experiments conducted with the Pioneer P3-AT robots, our testbed also contains ten all-terrain vehicles as well as a Drangonflyer X-Pro quadrotor and two AscTec Hummingbird Quadrotors.

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B. Environmental Sensor Suite

The environmental sensor suite consists of a Phidgets 8/8/8 USB interface I/O board capable of measuring eight digital and eight analog inputs and driving eight digital outputs. The Phidgets I/O board can interface pressure, temperature, humidity, light intensity, and magnetic field sensors as well as many others.

A special aluminium plate and mounting system was created to accommodate the environmental sensor suite. The plate and mounting system allows for multiple sensor configurations as well as the ability to mount multiple accessories on each robotic platform.

The experimental testbed has its own dedicated IEEE 802.11 WLAN, which provides a low-latency communication network. The network is used for inter-robot communication as well as for Player server/client communications [3].

III. CONTROL ALGORITHMS

A. Prioritized Multi-Sensing Behavior

In [4], we proposed a decentralized coordination algorithm that allows a team of sensor-enabled robots to navigate a region containing non-convex obstacles and to take measurements within the region that contain the highest probability of having "good" information first. This approach is motivated by scenarios where prior knowledge of the search space is known or when time constraints are present that limit the amount of area that can be searched by a robot team. Our cooperative control algorithm combines Voronoi partitioning, a global optimization technique, and a modified navigation function to prioritize sensor detection.

As an extension to [4], we herein introduce the idea of a multi-sensing framework, where robotic platforms are equipped with more than one sensing modality [5]. To address prioritizing searching/sensing with multiple sensing capabilities we introduce the idea of logistic regression to express the contributions of each sensing modality and its factor on the combined or overall probability of detection (POD) map. This approach allows an operator to weigh a particular sensing behavior over another depending on need or usefulness of the sensing data. This becomes very practical in such applications as search and rescue or hazardous contaminations where more than one factor may play a role in decision making.

B. Adaptive Decentralized Nonholonomic Sensor Network

A group of nonholonomic sensors distributed in an unknown area should position themselves optimally over the

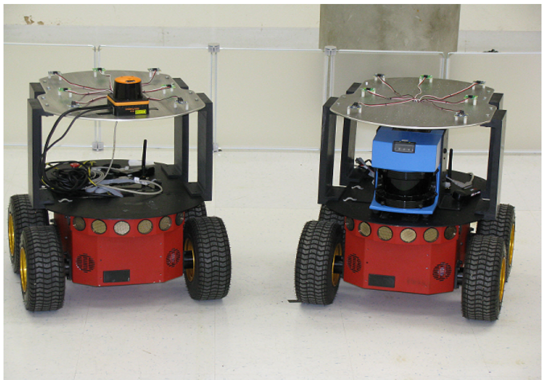

Fig. 1. Two Pioneer P3-AT robots equipped with custom made aluminum mounting system and environmental sensor suite.

sampling space to measure the available sensory information which is considered to be dynamic. Possible suitable applications are an oil spill [6] or a forest fire [7] where the sensory information is changing depending on currents or wind conditions respectively.

Our implementation is motivated by the previous work described in [8] where the authors implemented a stable and decentralized coverage control law. Their distributed controller considers the case of holonomic vehicles. We propose a nonlinear polar controller to drive a team of nonholonomic vehicles equipped with sensors to optimally configure with respect to the sensed information.

IV. VIDEO SUMMARY

This video presents experiments conducted on our multi-vehicle environmental testbed. The first experiment is the prioritized multi-sensing behavior, which uses a magnetic and light source for the robots to take sensor measurements. During the experiment robots create a Voronoi partitioning based on their current positions, then optimize the probability of detection map (POD) to determine a point in their own Voronoi partition that has the highest probability of obtaining good sensor readings from a magnetic or light source. When a point by each robot is identified, the robots navigate to that goal point while avoiding collisions with obstacles in the environment as well as with other robots. As the robots navigate to the goal point sensor measurements are taken. When each robot has reached its destination, sensor measurement information as well as position information is exchanged. This is then repeated for 30 iterations and the resulting magnetic and light intensity maps are shown.

The second experiment conducted is the adaptive decentralized nonholonomic sensor network algorithm. Initially the robot at the right corner is exposed to the greatest concentration of light. Light measurements are taken using four precision light sensors mounted on the aluminum plate. Every robot is moving to their estimated center of mass of its respective Voronoi cell. As they are using a difference equation approximation of the adaptive law we notice back and forth motion. This is due to the centers of mass variation at every calculation time. In another top view, we see the actual distribution of the robots and their Voronoi partitions related to the light concentration. This is approximately a centroidal Voronoi tesselation based on the estimate distribution function which is illustrated as well. The light distribution is changed by switching the light source concentration. At this point the robots change their estimate parameter vectors in order to excite the adaptation law by increasing the difference between what they are measuring and what they are estimating. The robots then start moving towards the new light concentration. Finally, a top view of the robots with respect to the light distribution and the estimated density function are shown. This experiment verifies the behavior of the adaptive decentralized nonholonomic sensor network controller.

V. CONCLUSIONS

This video shows the capability of our environmental testbed to validate novel cooperative control algorithms that rely on measurements from the environment. Through the design of our mounting plates, the testbed can accommodate multiple environmental sensors as well as different configurations of robot accessories. Also, our environmental sensor suite provides the ability to integrate a variety of sensors that provide measurements of physical quantities to address many different types of cooperative control algorithms.

VI. ACKNOWLEDGMENTS

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