Real-World Testing of a Multi-Robot Team
(Extended Abstract)

Paul Scerri, Prasanna Velagapudi, Balajee Kannan, Abhinav Valada, Christopher Tomaszewski,
John Dolan, Adrian Scerri, Kumar Shaurya Shankar, Luis Bill and George Kantor
The Robotics Institute
Carnegie Mellon University
pscerri@cs.cmu.edu

Categories and Subject Descriptors

I.2.9 [**Artificial Intelligence**]: Robotics

General Terms

Experimentation

Keywords

Multi-robot systems, Autonomous surface vehicle, Human-robot/agent interaction, Flood disaster mitigation, Autonomous sampling

Introduction

Multi-robot systems (MRS) have received a great deal of attention recently due to their potential to address complex distributed tasks such as environmental monitoring, search and rescue, agriculture, and security[3, 4, 5, 1, 2]. One specific type of multi-robot system that has significant near term promise is fleets of autonomous watercraft for applications such as flood response, water monitoring and bathymetry. Small watercraft are an attractive option for real world multi-robot systems because some of the most critical robotic problems are minimized on water - movement is relatively simple and dangers are relatively low.

In this work, we have addressed many engineering issues behind developing teams of Cooperative Robotic Watercraft (CRW). Deploying fleets of boats at remote locations helped clarify assumptions, change priorities and expose new issues for the community as well as help close the gap between the identified challenges and real-world deployment of such systems.

The success of our approach has been validated through field trials, including a four-day test at an irrigation pond in Maryland, a six-week expedition to various locations in the Philippines, a two day trip to a highly polluted canal in New York and hundreds of boat hours around Pittsburgh.

Design

Hardware.

We chose an airboat design (Figure 1), where the propulsion provided by a fan placed above water, for our watercraft platform for two important reasons. First, keeping the propeller above water is advantageous where the water might be shallow, e.g., in flooded environments or in ecologically interesting areas like reefs or estuaries. Second, the above water fan can be simply encased in a wire mesh for safety, making the boats safe for autonomous operation even around curious children.

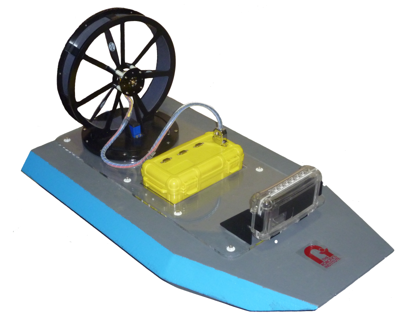

Figure 1: A complete airboat.

Figure 2 shows the basic components of the airboat. A boat is approximately 70cm long and weighs about 4.4kg without batteries. A NiMh battery that weighs 1.5kg allows the boat to drive continuously at approximately 10km/h for a period of two hours. The size and weight of the boat were chosen to suit urban flood conditions, where safety and maneuverability are key requirements.

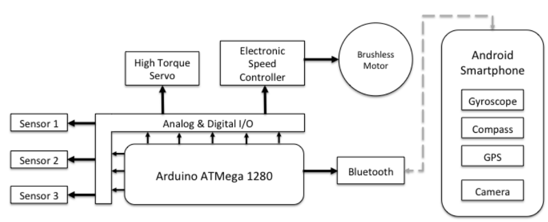

Figure 2: Hardware functional diagram.

Electronics.

Rather than individually assembling a computing platform, a core design decision was to use a commercial smartphone to provide the computing, camera and communications for the boat. It is impractical to put together a similarly powerful, robust and tightly packaged custom computing platform at anywhere near the cost of a smartphone. Moreover, using a smartphone gives us access to multiple modes of communication, since most phones have WiFi, 3G

Appears in: *Proceedings of the 11th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2012)*, Conitzer, Winikoff, Padgham, and van der Hoek (eds.), June, 4–8, 2012, Valencia, Spain.

and Bluetooth. We chose Android-based phones because of their relatively open and powerful development environment.

For communicating with sensors, motors and servos, we used an Arduino Mega, a relatively low-cost microcontroller board that provides a fast, flexible array of digital and analog I/O for controlling the fan shroud, gyros, and external sensor modules. The Arduino and smart phone communicate via Bluetooth, which works extremely well over the short distance between the phone and Arduino. The servo for actuating the fan, the fan itself and sensors are all connected directly to the Arduino which has a simple, high-level protocol to the phone.

External sensors are plugged directly into the Arduino, using either digital or analog channels, depending on the sensor. The entire electronics assembly is encased in two waterproof boxes.

Software.

The control software builds on the Robot Operating System (ROS), which provides a flexible *publish-subscribe* architecture with extensive built in debugging capabilities and a manageable development path. Layers of functionality separate general modules from application specific modules. An end user interface provides a single operator with an overview of the state of the boats and provides high and low level commands for interacting with them.

Field Trials

In September 2011, three undergraduate students took five boats to the Philippines. They were joined by observers from the University of the Philippines and from local aid organizations. Primary testing lasted for one week, after which two of the students returned home leaving one (non-CS) undergraduate student to continue testing. Testing was performed in several locations including Laguna de Bay, Taal volcano, a village during flooding in the aftermath of twin typhoons and a fish farm. A key aim was to have all five boats in the water at the same time, under the control of the same operator. This was achieved a number of times. In total there were more than 15 tests in seven different locations. The boats were predominantly used for water sampling, but were also briefly evaluated in the aftermath of a typhoon. The testing resulted in more than 100 boat hours in the water, tens of kilometers covered and hundreds of thousands of data points. While initial testing was slow, frustrating and involved a lot more time with the boats out of the water than in, by the end the process and boats were sufficiently usable and robust that one non-computer science undergraduate student and local Filipinos with no formal education were able to deploy and use the boats. In fact, one of the biggest surprises was the comfort of local Filipino people with the technology and the speed at which they were able to familiarize themselves with it. By far the biggest problem encountered was with wireless communication, with the real-world details of various wireless technologies, particularly 3G, causing difficulties.

Figure 3 shows the path taken by a boat at the fish farm, an interesting environment because of the complexity of the water and the need to keep the water healthy. Figure 4 shows a plot of the water temperature in the lake inside Taal volcano immediately before (left) and after (right) rain. This lake is important because a recent unexpected, rapid and significant rise in temperature caused $1.3M in losses to fish farming in the lake. The plot shows considerable variation in the temperature and significant differences due to the rain.

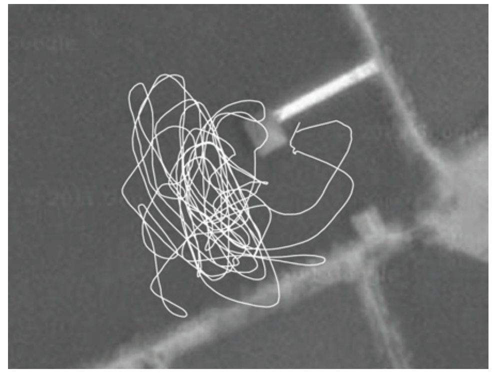

Figure 3: Airboat trajectory of a single airboat operating in a fish farming pong in Dagupan.

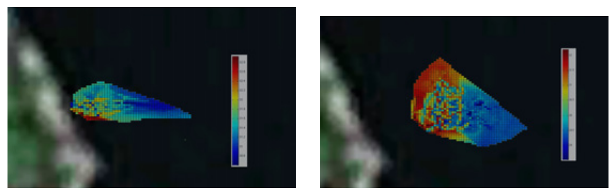

Figure 4: Plots of temperature in Taal Lake before (left) and after (right) a tropical rain storm.

Figure 5: Our six-week deployment in the Philippines demonstrated an ability to deploy five airboats simultaneously in remote locations with a control interface simple enough to be used by a child.

REFERENCES

[1] H. Endres, W. Feiten, and G. Lawitzky. Field test of a navigation system: Autonomous cleaning in supermarkets. In *ICRA*, 1998.

[2] S. Hayashi, K. Shigematsu, S. Yamamoto, K. Kobayashi, Y. Kohno, J. Kamata, and M. Kurita. Evaluation of a strawberry-harvesting robot in a field test. *Biosystems Engineering*, 105(2):160–171, 2010.

[3] K.H. Low, G. Podnar, S. Stancliff, J.M. Dolan, and A. Elfes. Robot boats as a mobile aquatic sensor network. In *Workshop on Sensor Networks for Earth and Space Science Applications at IPSN*, 2009.

[4] G.A. Oosthuizen, A. Al Shaalane, et al. Evaluation of existing robot technologies for deep level mining applications. In *ISEM 2011*, 2011.

[5] Charles L. Ortiz, Regis Vincent, and Benoit Morisset. Task inference and distributed task management in centibots robotic systems. In *AAMAS*, 2005.