HIGH FIDELITY HYDROGRAPHIC SURVEYS USING AN AUTONOMOUS SURFACE CRAFT

Justin E. Manley, Thomas W. Vaneck

Massachusetts Institute of Technology
Sea Grant College Program
Cambridge, MA 02142

Abstract - At the MIT Sea Grant College Program, Autonomous Surface Craft (ASCs) have been under development since 1993. An ASC is a small vessel outfitted with navigation and control systems that permit it to carry out functions autonomously. The first ASC developed was the ASC ARTEMIS, which was used to study command and control architectures, navigation systems, and basic data collection techniques. This vehicle successfully demonstrated the ability to operate autonomously and collect hydrographic data.

ARTEMIS served well as a test platform, but its small size made it unsuitable for coastal surveys. A second generation ASC, ACES (Autonomous Coastal Exploration System), was designed and built to demonstrate the potential to perform high fidelity hydrographic surveys using an ASC.

ACES is comprised of a small catamaran hull equipped with a gasoline engine and sophisticated electronics for navigation and bathymetry. Since it is small, light, and easy to control ACES is simple to deploy and operate in the field. In its basic configuration, ACES permits two individuals with a portable computer to survey small coastal areas to approximately US Army Corps of Engineers Class 1 standards.

This paper describes initial tests of ACES as a hydrographic survey tool. Some background on the development of hydrographic survey ASCs is presented. Early surveys performed in Boston Harbor are described and the results are discussed. The limitations of the basic configuration are identified and the steps taken to improve the ASC are described.

I. Introduction and Background

In an effort to reduce the costs of hydrographic surveying, while increasing the amount of information available, many new technologies have evolved. In recent years, the development of multibeam mapping sonars and airborne bathymetry technologies has provided alternatives to traditional survey vessels. To eliminate one of the primary costs of surveying it is necessary to reduce crew requirements. Autonomous Underwater Vehicles (AUVs) have been developed for this purpose. Recent tests have demonstrated the feasibility of using AUVs for hydrographic surveys. [1] To further reduce the costs of surveying, and enhance the utility of autonomous survey systems, the MIT Sea Grant College program has pioneered the development of free roaming robotic surface vessels to perform hydrographic surveys.

Autonomous Surface Craft (ASCs) present several advantages over AUVs. The Global Positioning System (GPS) has provided a high performance navigation aid, and commercially available satellite communication receivers allow for nearly instantaneous communication over much of the globe. This powerful navigation and communications capability is an advantage available to surface craft. Operating on the surface also makes tracking and control much simpler. Using these advantages, MIT Sea Grant has developed a new survey tool.

A. The ASC ARTEMIS

The first ASC produced at MIT Sea Grant was named ARTEMIS. This vessel is a 1/17 scale replica of a fishing trawler, which was originally used for model basin testing. Installation of an electric motor and a servo actuated rudder made the basic model into a platform capable of testing the navigation and control systems required by an ASC.

Initial work focused on the development of control systems for the ASC. Follow on work added a Differential GPS (DGPS) receiver to enhance the navigation system of ARTEMIS. To investigate the use of ASCs in data collection, a depth sounder was added and ARTEMIS executed waypoint-defined surveys to generate bathymetric maps of the Charles River in Cambridge, MA. The addition of a radio modem allowed these bathymetric maps to be generated in real time and provided human supervisory control of the ASC. [2] Fig. 1 is a picture of ARTEMIS in “automated bathymetry” configuration.

ARTEMIS provided a useful proof-of-concept and facilitated the development of useful electronic systems but did not provide the appropriate platform for a hydrographic survey ASC.
B. The ASC ACES

At the conclusion of the automated bathymetry experiments with ARTEMIS, development of a new ASC was begun. The specifications of the next ASC were based on a desire to create a system as versatile and useful as a small manned vessel while maintaining a small size to allow for easy deployment and survey operations. As ARTEMIS was slow, unstable, had poor endurance and a small payload the next ASC represented a significant improvement in platform capabilities.

To provide enhanced roll stability and greater payload, a catamaran was selected as the best hullform for the new ASC. The wide beam and large waterplane area of catamarans reduces rolling motions and increases displacement without the significant drag penalty a similarly sized monohull would experience. This design also had the virtue of providing redundancy in the hull flotation. The failure of one hull would not result in a complete loss of buoyancy. The remaining hull could keep the ASC afloat long enough to be rescued.

A custom structure was created to join two commercially available rotationally molded polyethylene hulls. This structure allowed for flexible mounting of instruments and equipment. Some of the loading bays are designated for propulsion, steering, and vehicle control systems but the others can be configured to carry instruments or sensors a particular mission requires. Another feature designed into the structure was a quick release mechanism. This allows the hulls to be removed from the structure so that the entire ASC can be broken down into small pieces for transport to an operation site.

A 3.3 horsepower gasoline engine was selected for installation on ACES. The engine weighs 33 pounds and its fuel consumption rate requires approximately 50 pounds of fuel to operate for 12 hours. For initial testing, electrical power for the computers, navigation, and control systems was provided entirely by batteries. A generator will be installed on the engine to recharge these batteries and make the fuel capacity of ACES the limiting factor on endurance. Limiting the total weight of the power and propulsion system to under a third of the total ASC weight is the primary advantage of using a gasoline engine.

The final ACES platform fulfills the requirements identified for the successor to ARTEMIS. Table 1 presents the characteristics of ACES.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>75 inches</td>
</tr>
<tr>
<td>Beam</td>
<td>51 inches</td>
</tr>
<tr>
<td>Draft</td>
<td>18 inches</td>
</tr>
<tr>
<td>Maximum Displacement</td>
<td>350 pounds</td>
</tr>
<tr>
<td>Endurance</td>
<td>12-18 hours</td>
</tr>
<tr>
<td>Speed - Cruise/Maximum</td>
<td>5 / 10 knots</td>
</tr>
</tbody>
</table>

In terms of cost, ACES is also competitive with small manned vessels. By using off-the-shelf systems and simple construction techniques the cost of the basic ACES platform was kept low. Prototype costs for the platform were approximately $7500. This includes several systems, used in initial tests, which would not be needed on a production vehicle. The cost to manufacture a production ACES platform is estimated at $4500. The addition of a control, navigation and sensor suite, like that used on ARTEMIS, increases the cost to around $20,000. When compared to the costs of purchasing and operating conventional survey launches, ACES is a competitive alternative.

II. Survey Trials

A. Preliminary Survey Demonstrations

During the summer of 1997 ACES demonstrated its ability to collect hydrographic data off the coast of Gloucester, MA. Although the value of motion sensors in hydrographic surveying was identified, they were not installed on ACES at this time. This yielded a simpler prototype, which could be easily deployed and used to collect basic depth and position information. Using a simple microprocessor, a DGPS receiver, a digital compass, and a basic recreational depth sounder ACES performed many test missions. Fig. 2 shows ACES underway in Gloucester Harbor.

These missions validated the basic systems and the control software. Static position recording on shore indicated
that the DGPS system provided position accuracy to 2 to 3 meters. Tank tests of the depth sounder indicated that the unit could achieve accuracy within ±0.5 feet. These experiments indicated that the sensors on ACES could provide hydrographic data that would meet the Class 1 standards of the U.S. Army Corps of Engineers (USACE). Class 1 data requires position accuracy to ± 6 meters and depth accuracy to ± 0.5 feet. It was decided that field surveys should be performed to determine if ACES could provide such data in actual survey conditions.

B. Survey of Conley Marine Terminal

To provide a useful analysis of the accuracy of ACES as a survey tool, a region that had been previously surveyed to USACE Class 1 standards was selected. During the summer of 1997 the USACE surveyed the Port of Boston Conley Marine Terminal after it had been dredged. The data from these surveys was obtained from the USACE and ACES was used to perform a survey in the same region. Since the USACE data represented a post-dredge survey, it was expected that the bottom topography would be relatively stable. Conley Marine Terminal is in Boston Harbor near Logan Airport.

On December 18, 1997, ACES performed three surveys to cover an area approximately 1500 by 400 feet. Two surveys were run perpendicular to the pier and one was run parallel to it. These surveys yielded a total 23 tracklines and took approximately 45 minutes of total run time. The entire survey process took just under 2 hours on site. After each survey was run, the data was moved from RAM to the hard drive, which required an amount of time equal to the length of the survey. This process could be streamlined to permit continuous streaming of data to the hard disk. For the initial surveys it was decided to ensure the retrieval of at least some data, so the runs were broken up and downloaded individually.

ACES collected over 3000 depth and position measurements in the survey area. The USACE survey, which covered over twice as much area, collected only 1288 points. The specific region surveyed was selected because it covered part of the recently dredged area and part of the bottom that had not been dredged and was therefore shallower. It was expected that these two distinct depth regions would help provide a better comparison between the USACE and the ACES data. Fig. 3 shows ACES surveying off Conley terminal.

Fig. 3: ACES Surveying at Conley
regions (using delauney triangularization) defined by the ACES data points. The nearest USACE point found within each triangle was then identified as the geographic coordinate of interest. This coordinate was assigned a depth value computed from the three vertices (ACES data points) which defined the triangular region it occupied. This yielded two sets of 300 data points with the same geographic coordinates. One set was assigned the USACE recorded depth and the other was assigned a numerical interpolation based on the three ACES depths nearest to it. The difference in these depth measurements was then calculated. These results are presented in Fig. 5, below.

Fig. 5 is a graphical presentation of the depth differences between the two data sets. The chart represents the USACE depth minus the ACES depth for each of the 300 geographically matched points. All depths within ±0.5 feet, and therefore within Class 1 standards, were assigned one color (green). Points with positive differences indicate that the ACES depths were too shallow, and therefore more conservative than the USACE data. These were assigned another color (blue). Negative depth differences indicate that the ACES data showed deeper water than the USACE data. These dangerous errors were assigned a third color (red). Fig. 5 reveals that there were no errors greater than ±2 feet. There may have been larger errors in the blank areas but, as described above, these areas were rejected before the comparison was made. Statistically, the results showed that 72% of the ACES data met Class 1 standards, 13% revealed conservative, and therefore “safe,” errors outside Class 1 standards, and 15% of the points were dangerous errors not meeting Class 1 requirements.

IV. Further Development

In an effort to improve the accuracy of hydrographic data collected by ACES, several additional sensors were installed. A GPS based attitude sensing unit has been installed to account for pitch and roll. This system provides angular measurements within 0.2 degrees. A real time kinematic (RTK) GPS system has been added to provide better navigation and to provide vertical position (heave) measurements. Since these measurements are referenced to a fixed shore station this system also serves to account for tidal changes. To provide better depth measurements a high quality depth sounder was purchased. As an alternative to this system an acoustic doppler current profiler (ADCP) with a bottom lock mode has been installed to provide both accurate depth data and dead reckoning navigation support to the GPS systems in shallower waters (30 meter depth limit). While these systems have not yet been tested in field surveys, it is expected that they will eliminate the types of errors present in the initial results presented above.

V. Conclusion

The MIT Sea Grant College Program has developed two small, easily deployed ASCs for use in hydrographic surveying. Early efforts with ARTEMIS demonstrated the potential for such systems. The ASC ACES is a more capable system that can provide hydrographic surveys in near coastal waters.

ACES was used to survey Conley Marine Terminal in the Port of Boston. These results were compared to those of a USACE Class 1 survey of the site. It was found that the ACES data met Class 1 standards 72% of the time. Given that this survey was performed without the benefit of motion sensors and with a recreational depth sounder, these results are encouraging.

It is expected that installation of more sophisticated instruments will allow ACES to provide hydrographic data which fully satisfies Class 1 standards. Once this capability is demonstrated, the ease of deployment and low cost of ASCs will provide a new resource to the hydrographic survey community. This technology, together with conventional manned vessels, and airborne survey assets, will help provide more hydrographic data essential to the production of accurate charts.

VI. Acknowledgments

The authors would like to acknowledge the support of their colleagues at the MIT Sea Grant College Program. Several undergraduate students, including Mads Schmidt, Taryn Westberg, and Amanda Underwood, participated in the ASC research at MIT Sea Grant and their contributions are gratefully acknowledged. The MIT Sea Grant College Program and the Department of Ocean Engineering supported the work described here.

VII. References


USACE Survey of Conley Terminal

ACES Survey of Conley Terminal (12/18/97)

Fig. 4: Conley Marine Terminal Survey Results

Fig. 5: Depth Differences (USACE-ACES), Feet