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Riverine Autonomy

Daniel J. Stilwell
Bradley Department of Electrical and Computer Engineering
Virginia Tech
340 Whittemore Hall
Blacksburg, VA 24061
Phone: (540) 231-3204 Fax: (540) 231-3362 Email: stilwell@vt.edu

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http://www.unmanned.vt.edu

LONG-TERM GOALS

The principal goal of this project is to develop the technology and algorithms that will enable an unmanned surface vehicle (USV) to operate fast and autonomously in unknown riverine environments, including tropical rivers. Robust autonomy requires that the USV senses the surface and subsurface environments, discriminates waterways that are navigable from those that are not, identifies stationary and moving obstacles, including other vessels, and then optimally plans and re-plans a route in real-time. Since speed is a vessel's principal defense, all of these tasks must be done as efficiently as possible to ensure successful operation at the greatest possible speed.

This project is tightly coordinated with collaborators at the Naval Postgraduate School (NPS) whose work is conducted under a related project.

OBJECTIVES

Specific objectives for VT and NPS during 2014 reported herein are

1. Development of a new SONAR mount design that can be adapted for a variety of vessels that possess a low gunnel.
2. Testing of the Helmsman Assist System and SONAR mount concepts on SOC-R.
3. Field trials of the fully integrated Sensing and Autonomy Package using the Virginia Tech USV in Clayor Lake and Peak Creek, near Dublin, Virginia.

APPROACH

We are developing technology and algorithm that enable a USV to autonomously travel over long distances in riverine environments. We are also developing the Helmsman Assist System as a first step toward integrating autonomy into riverine vessels. The Helmsman Assist System provides a display with real-time map and route guidance from the Sensing and Autonomy Package. It enables manned vessels to operate much faster than would otherwise be possible in all weather and in unfamiliar areas where unknown submerged hazards may exist. In November 2013, we exercised the Helmsman Assist System installed on the SOC-R. We sought feedback from NSWG4 operators on consequences of

proposed technical approaches (e.g., sonar capability) and on operational issues (e.g., location of display).

Experimentation has shown that the capabilities of currently available forward-looking sonar systems are only marginally acceptable for riverine subsurface sensing. However, new systems that are currently being developed may provide significantly better performance. Thus we seek a very general sonar mounting system that can accommodate both currently available and anticipated forward looking sonar systems.

For the Sensing and Autonomy Package, we seek to integrate all subsystems and behaviors and to demonstrate correct operation in the field. Although the operation of most subsystems and behaviors has been verified individually, we have not yet shown that they work correctly when integrated with all other subsystems and behaviors.

WORK COMPLETED

Helmsman Assist System

Experimental evaluation of the Helmsman Assist System occurred at Stennis Space Center, MS, 11-13 November 2014. Experiments were conducted collaboratively by personnel from the Naval Postgraduate School and from Virginia Tech.

The Helmsman Assist System consists of the sensing, mapping, and guidance subsystems of the Sensing and Autonomy Package. The real-time map created by the autonomy package along with guidance suggestions are shown on a display provided to an operator. The Helmsman Assist System enables the operator to visusalize the surface and subsurface environmet in all weater and at night.

The Helmsman Assist System was deployed on a SOC-R for engineering and user evaluation. A satellite compass, gimbaled laser line-scanner, attitude-heading-reference system, and a specialy packaged embedded computer were provided by Virginia Tech. A forward-looking sonar, user display and user-interface were provided by the Naval Postgraduate School. Virginia Tech also provided a mounting system for the forward-looking sonar. The line-scanner and satellite compass can be seen on the mast of SOC-R in Figure 1, and the sonar mount can be seen on the stern of SOC-R.

Feedback from operators was largely favorable. They felt that the subsurface mapping capability of the Helmsman Assist System is especially useful, but that guidance suggestions on the map are not useful. They also suggested that maps from the Helmsman Assist System could be integrated with their Falconview moving map display. They also provided specific guidance for the sonar mounting system.

Figure 1: Helmsman Assist System deployed on a SOC-R; (left) experimental sonar mount is visible at the stern; (right) gimbaled laser line-scanner and satellite compass are visible at the top of the mast.

Sonar Mount Design

The addition of a forward-looking sonar to the USV poses some interesting challenges from a mechanical design standpoint. Whereas the above-water sensors can simply be bolted in, the sonar system must be mounted in such a way that it does not limit the capability of the boat or its crew, it must withstand enormous forces that are generated by motion of the sonar and sonar mount in the water, and it must be protected from impacts. These requirements are used to assess potential mounting locations and mounting strategies.

The location of the sonar mount is of critical importance. This is because the mounting location has implications for sonar data quality, sensor longevity, extent of potentially large forces on the mounting structure, and the structural integrity of the boat. Two different mounting locations have been field-tested using the SOC-R as a test platform. The first location was at the side of SOC-R in FY2012. The second was the stern in FY2013. Photos of these two configurations are shown in Figure 2.

Figure 2: Sonar mounting locations on SOC-R that have been experimentally assessed; (left) side mount in FY2012; (right) stern mount in FY2013.

Each location has its own set of advantages and disadvantages. Mounting on the side of SOC-R is convenient in that it is relatively simple and strong, but it makes the boat wider, which is undesirable when the boat is operating is narrow areas. It also means that the sonar must be mounted at a depth that is greater than the boat's draft in order to ensure that the hull is not blocking part of the image. This means that in shallow water the first thing to impact the bottom will often be the sonar instead of the hull. Mounting behind the boat to the stern is convenient because it allows the mount to be positioned much closer to the water, reducing its size. However, it suffers from the same drawback as the side mount due to the necessity of positioning the sonar below the hull. In addition, field trials showed that sonar image quality was reduced, likely due to turbulent flow from the water jets and reflections from the hull.

These trials have led us to the conclusion that there are two viable options for mounting locations: at the bow or on the hull. Permanently mounting the sonar either in or on the hull is the most unobtrusive option. The sonar's effect on onboard operations would be minimized, it would require no assembly, and minimal maintenance. However, there are concerns about how hull vibration and near-hull turbulence would affect performance. There is also the issue of how to protect the sonar from impact damage. At a minimum, this would require structural modifications to the hull, which is a non-trivial endeavor. For this reason a hull-mounted imaging sonar would be prohibitively expensive as a modification to an existing vessel, but could be achieved if it were incorporated from the early stages of hull design.

This leaves mounting at the bow as the best option for an existing vessel. This location is advantageous because a sonar at the bow will be in front of the hull and propulsion system which should reduce their impact on image quality. Also, because the sonar has an unobstructed forward view at any depth, it can be positioned such that the hull will absorb most impacts instead of the sonar. That said, mounting at the bow is not without its drawbacks. For one, on most boats the bow is one of the taller parts of the vessel, so mounting here requires a larger structure. This translates to greater weight, expense, and a more difficult assembly. Despite these drawbacks, it is believed that mounting at the bow will mitigate many of the issues seen in earlier field trials. A rendering of the bow mount is shown in Figure 3.

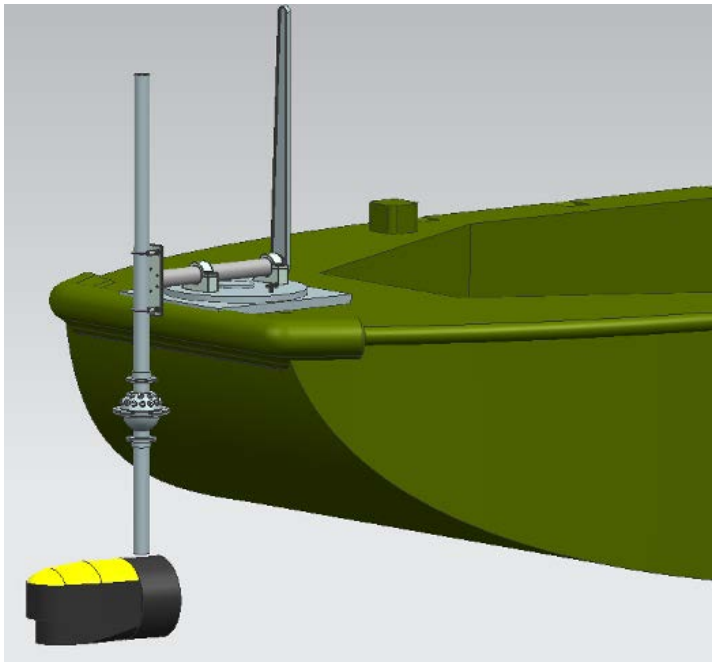

Figure 3: Rendering of SOC-R with bow mounted sonar

In addition to determining an ideal mounting location, there were also several flaws with the old mount design that needed to be addressed. The first was with the method of retracting the sonar. In previous versions of the sonar mount, this was accomplished with the use of a linear actuator. This was done so that retraction commands could be sent via software in anticipation of the need for greater levels of autonomy in future design iterations. However, if the actuator failed, retracting the sonar became very difficult. For this reason the new version of the mount is manually retractable only to reduce the number of failure points. If future versions require autonomous retraction, the mount can be retrofitted with an actuator with minimal difficulty.

The second design flaw was with a flange welded onto the end of a large tube. Field trials proved that the weld lacked the strength necessary to carry the loads being placed on it. This has been addressed with a redesign of the flange and the weld.

The third and arguably the most important design modification is to the breakaway device. Previous versions of the mount incorporated a shear pin that would break if the sonar struck an object or hit bottom. This was very effective at preventing damage to the sonar, but only for forward impacts, so if the operator needed to back up or turn around, the sonar was unprotected. To remedy this problem we need a breakaway device that could hold the sonar rigidly, but that would respond to impacts from any direction. The proposed solution to this problem is a ball and socket breakaway device, shown in Figure 4. The device has three components: a socket, a ball, and a retainer. The ball is six inches in diameter and fits into the socket. It is held in place with the retainer, which bolts to the socket. This device is designed to attach two sections of flanged structural tubing together. The tubes are held fixed relative to one another until a radial load applied to one of the tubes causes the breakaway device to release. The holding power of the breakaway device comes from 22 ball detents positioned around the socket, each capable of providing up to 50 lbs of holding power. This translates to a maximum breakaway torque of 2644 lb-in. Assuming a sonar depth of 2 ft, and making some assumptions about

the shape of the sonar (which has not yet been provided), this should allow the sonar to travel through the water at speeds of up to 8-9 kt before the breakaway releases.

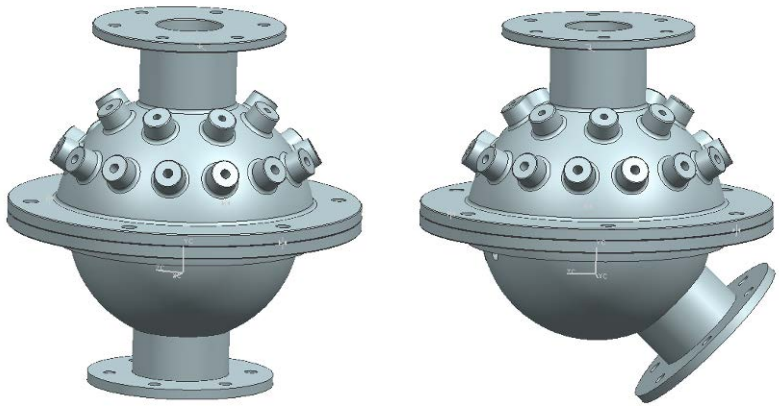

Figure 4: Ball and socket breakaway device in the locked and released positions

Field Trials of the Sensing and Autonomy Package

A series of field trials for the Sensing and Autonomy Package were conducted at Claytor Lake and Peak Creek, Virginia, during late fall 2013 and summer 2014 using the Virginia Tech USV. The overall goal of the field trials was to verify integration of a several autonomy subsystems that had previsouly been tested independently, but had not yet been tested together. The autonomy subsystems and capabilities that were integrated and tested include,

1. Controlled backward motion
2. Transition between backward and forward motion
3. New local trajectory generator that provides smooth (twice continuously differentiable) and dynamically feasible state and control reference trajectories for the autopilot.
4. New value function with which the system is able to choose trajectories that formally minimize the probability of mission failure. This approach is facilitated by using a map that represents the probability of mission failure per unit distance at each location. Probability of mission failure is due to the probability of hitting an object and also the background probability of equipment failure.

A example of a succesful field trial is shown in Figure 5. The USV initially starts too close to shore and discovers that it must move backward after which it moves forward. The arrows indicate the direction of the bow of the boat. This is an important behavior for operating in complex waterways where dead-ends are possible and occational backward motion is necessary.

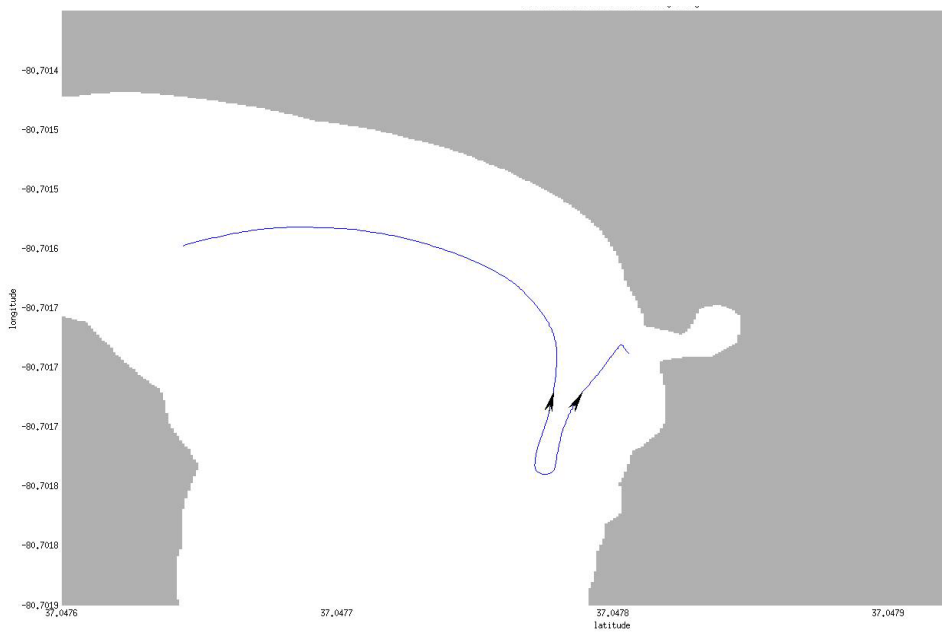

Figure 5: Trajectory of the USV during an experiment where it was started too close to shore and needed to move backward before moving forward. Arrows indicate the direction of the bow. The starting position is the right-most end-point.

RESULTS

The principal results of the research conducted during FY14 are

1. The design of a generalized sonar mounting system has been proposed. Detailed design is presently being finalized.
2. All autonony behaviors and subsystems of the Sensing and Autonomy Package have been integrated and tested using the Virginia Tech USV.

IMPACT/APPLICATIONS

The principal result of this project will be a set of algorithms and best-practice tools for robust autonomous surface vehicle operations in dynamic and partially mapped riverine systems.

RELATED PROJECTS

None