

# The Cornerstone AUV Navigator

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## LONG-TERM GOALS

Bluefin's business focus is the design and manufacture of autonomous underwater vehicles for use in military, scientific, and commercial applications. For many AUV missions, accurate navigation that does not depend on acoustic beacons in the operating region is one of the primary remaining technical hurdles. This effort will address this need through the creation of the Cornerstone AUV Navigator, an extensible, flexible, low-cost AUV navigator that will solve the navigation needs of a variety of AUVs.

## OBJECTIVES

The objective of the Cornerstone AUV Navigator (CAN) effort is to create a high-accuracy navigation solution tailored for use on AUVs (i.e., low power consumption, small size, low cost) using a "system of systems" approach. The CAN will be extensible to new techniques as they become available, flexible to adding new sensors, and adaptable to lower-accuracy, lower-cost applications. The fruits of this effort will be made available to other ONR-funded AUV programs.

Our technical objectives are to enable AUV missions with: Navigation accuracy of 0.1 % of distance traveled without DGPS and/or acoustic aiding,

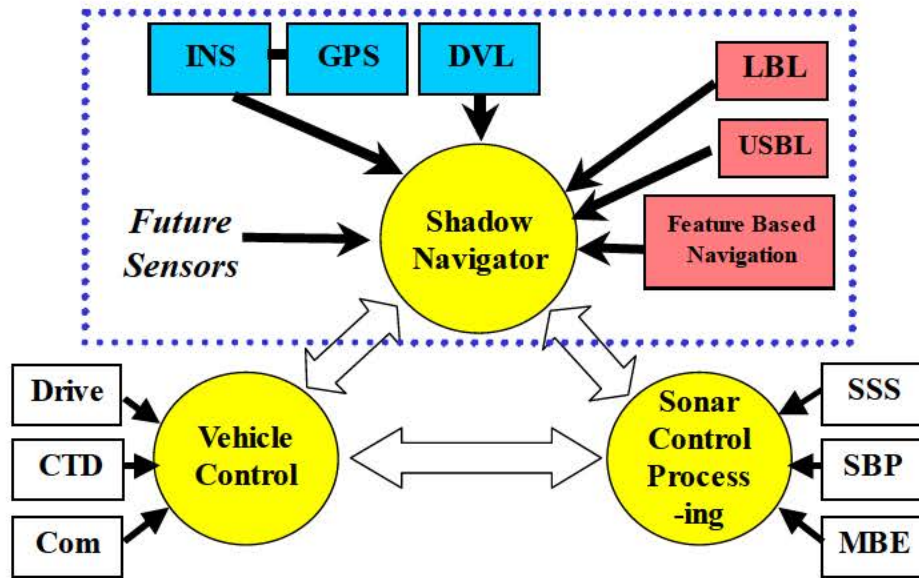
- Over-the-horizon (> 20 nmi) ingress/egress to the OpArea,
- Extended periods of fully submerged operation without DGPS or acoustic aiding,
- Survey tracklines to within  $\pm 20$  m absolute (infrequent DGPS fixes).

# Report Documentation Page

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*Figure 1: The Cornerstone AUV Navigator concept consists of a system of systems (blue-dotted box) coordinated by the “shadow” navigator code running on a dedicated navigation engine. The shadow navigator communicates with vehicle control and payload control nodes on-board the AUV.*

## APPROACH

In a traditional INS/DVL integration, incorporating additional navigation information to improve the fix has been difficult, if not impossible, because the navigation code was inaccessible inside the INS. The CAN takes a different approach. Mechanized by an extended Kalman filter running on a dedicated, external navigation computer, the “Shadow” navigation code allows the CAN system to be readily extensible. Software hooks will facilitate adding external navigation information from sources such as DGPS, acoustic systems such as LBL or USBL, and external position updates communicated via an acoustic modem. In addition, new feature-based navigation algorithms can be adapted for later incorporation into the extensible AUV navigator. Feature-based navigation methods offer the potential of achieving bounded errors for long-duration missions, offering a method to avoid the need for acoustic beacons or surfacing for GPS resets. Furthermore, the modular framework developed in the CAN project facilitates the addition of new navigation sensors to the CAN system. This allows the navigation accuracy of the CAN to be tailored to the requirements of a particular mission or AUV.

The initial implementation of the Cornerstone AUV Navigator, Figure 1, will exploit recent technical advances to create a high-performance navigator tailored for operation on an AUV. The CAN will use state-of-the-art sensors including a Litton LN-250 INS and a 300 kHz Doppler Velocity Log (DVL) from RD Instruments. The Litton LN-250’s low power consumption, small size, and navigation-grade INS performance make it ideally suited for use on an AUV. The 300 kHz Doppler Velocity Log from RD Instruments has been employed on several Bluefin AUVs and provides an important external measurement of AUV velocity to null out INS drift errors. After this project is completed, the CAN will be made available as a community resource to other government-funded AUVs.

We have assembled a “team of experts” drawn from the leading players in each component technology area. The prime contractor, Bluefin Robotics, has extensive experience in the design and manufacture of AUVs. The Charles Stark Draper Laboratory has conducted research programs in the navigation of undersea vehicles, both manned and unmanned, for over 30 years. The Litton LN-250 INS and the RDI 300 kHz DVL are high-performance instruments that are designed for high-volume, low-cost, sales. Litton and RDI are both widely recognized as leaders in their respective areas of expertise.

## **WORK COMPLETED**

The Cornerstone AUV Navigator (CAN) project is an on-going effort to produce a state-of-the-art navigation system for AUVs based on a flexible, modular architecture. The CAN work is split between several organizations: Bluefin is conducting the system architecture design, system electrical integration, integration into the AUV, and overall project management; Litton Guidance and Control Systems is providing the LN250 INS system along with modifications to the LN250 hardware and software to support the CAN program; RD Instruments is developing a DVL error model for incorporation into the navigation filter; and the C.S. Draper Laboratory is supplying the navigation filtering code. C. S. Draper Laboratory has experienced several technical difficulties with the VxWorks operating system on the embedded PC/104 hardware. To mitigate these problems, Bluefin has agreed with Draper to play a larger role in the CAN software development software development effort, including software framework implementation, navigation sensor implementation, and re-writing the navigation filter to tailor its use to autonomous underwater vehicles. The work completed by all participants is summarized below:

*Bluefin:* Bluefin has completed the design of the CAN system architecture. Bluefin has designed the CAN architecture to ensure that the system can be extended to accept inputs from long-baseline (LBL) and ultra-short baseline (USBL) acoustic navigation systems, as well as methods under development such as external position updates via acoustic modem and feature-relative navigation algorithms. Bluefin has completed the design of the rigid mechanical mounting between the INS, DVL, and deep- and shallow-water versions of the main electronics housing. A few tasks remain to complete the electrical integration of the CAN system into the BPAUV. These tasks will be addressed during the installation process.

Bluefin has begun to port the navigation filtering code to the QNX real-time operating system to solve the problems that Draper ran into using VxWorks. This will have the immediate effect of allowing the CAN code to boot out of either DiskOnChip or from the hard-drive and will also allow us to log all sensor and filter data to the hard-drive using Bluefin’s existing modular AUV software framework. Bluefin has also taken on the responsibility for interfacing all navigation sensors with the navigation computer, including data logging and time synchronization. Bluefin has completed the LN-250, DVL, GPS (both PLGR and Ashtech), and PDS interface code, including bench testing of the individual drivers. The precision timing hardware interface is still pending. Bluefin has completed the interface specification for the data output sockets that publishes data from the navigation computer. The interface specification for controlling the navigation system from the main vehicle computer is underway.

Bluefin has completed the initial bench tests with the LN-250 INS and is making preparations to conduct in-motion (“van”) testing at the beginning of October. These tests will verify the operation of

the new moving-base alignment software inside the CAN. Following these tests, the CAN system will be integrated into the BPAUV for sea trials and additional testing.

*Draper:* The C. S. Draper Laboratory is concentrating on finishing the “beta” version of the navigation filtering code. They have completed the modifications of the legacy Shadow Navigator code to include external position updates. Draper has implemented and is testing a range-dependent error model to incorporate DVL measurements into the navigation system. This is a simplified DVL error model and Bluefin will replace it with RDI’s sophisticated DVL error model after initial at-sea testing of the CAN system is complete. Draper has implemented and is in the process of testing the algorithm for incorporating external position fixes into the navigation filter. Draper is also supporting Bluefin’s port of navigation code to the embedded operating system and the AUV software framework. Draper has completed implementation of a 6-DOF SIU trajectory generator as well as an “on-board” test program that uses the SIU trajectory generator. Draper has also completed the DVL, GPS, and PDS simulation software for the SIU. Draper is also conducting “pre-hand-off” testing of the their legacy Shadow Navigator code base. Draper has nearly completed the performance tests of the Shadow Navigator code using simulated sensor inputs. This testing will ensure proper functioning and completeness of the paired down navigation algorithm before transitioning the code to Bluefin. Bluefin has taken on the responsibility of porting the algorithms to a suitable software architecture and RTOS. Draper has also participated in the design and review of the CAN bench, van, and sea trials test plans. During the sea trials, Draper will participate in the sea trials data analysis and will aid Bluefin in the navigation filter tuning process to ensure optimal navigation performance. Finally, Draper will deliver documentation for the beta-version of the Shadow Navigator filtering code as well as documentation of the as-implemented filtering algorithms.

*Litton:* During FY01 Litton completed the bulk of their contributions to the CAN system. This included implementation of the moving-base alignment mode on the LN-250 using external (D)GPS position and velocity information. Litton also added external GPS specific interface messages to their interface and created a 1 pulse-per-second discrete logic interface. Bluefin will continue to rely on Litton for technical support as Bluefin integrates the navigation system into a vehicle. In June 2001, Litton delivered the first fully functional LN-250 to Bluefin. Using the SIU, Draper conducted performance tests on the first unit. Draper concluded that the device was not functioning properly and was returned to Litton for analysis and repair. Litton concluded that the problem was related to the LN250 internal software and the necessary software modifications are currently underway. During the summer of 2001, Litton delivered the second LN-250 to Bluefin. This device was also handed off to Draper for performance testing. Draper was able to demonstrate an In-Motion alignment with this unit using a simulated GPS unit providing the reference input. The unit was return to Bluefin in August and Bluefin is currently verifying the Draper results using Bluefin’s QNX-based software driver.

*RD Instruments:* RDI has supported Draper’s effort to include a DVL error model in the Shadow Navigator code. RDI is also developing a more sophisticated DVL error model that Bluefin will integrate into the CAN system after the initial sea trials. RDI has also provided input into the sea trials test plans.

## RESULTS

The Cornerstone AUV Navigator program is nearing completion. Bench testing of the CAN system with the LN250 is currently underway and favorable progress is being made. Field-testing of the complete CAN system will start as soon as the system has been installed into the BPAUV.

## IMPACT/APPLICATIONS

The Cornerstone AUV Navigator represents a major technological leap forward in AUV navigation. It will be the first low-power, low-cost, high-accuracy INS/DVL-based navigation solution suitable for operation on the new generation of small AUVs that have arisen in the last decade. The Cornerstone AUV Navigator is an enabling technology for a variety of potential missions to be conducted by these AUVs. Several ONR-funded vehicle programs could benefit from the efforts of this program.

## TRANSITIONS

Bluefin estimates that the commercial AUV market will grow to around one hundred units per year. The market will be split between inspection and mapping AUVs, both requiring INS/DVL navigation. Additional sales can be expected from non-AUV platform such as ROVs and towed systems. Bluefin intends to make the CAN available as a COTS product both directly and through distributors.

## RELATED PROJECTS

The *Battlespace Preparation AUV (BPAUV)*, shown in Figure 2, is an ONR-funded program to produce a modular AUV for autonomous bottom mapping and classification. The high-resolution, multi-beam Klein 5000 side-scan sonar carried by the BPAUV allows the vehicle to be used to locate mine targets. Due to its modular section design, the BPAUV is capable of carrying different or additional sensors and payloads.



***Figure 2: The Battlespace Preparation AUV (BPAUV) provides autonomous bottom mapping/classification and target localization capabilities for MCM missions.***

The Bluefin team recently successfully demonstrated the BPAUV in March, 2001, over the mine-fields installed for Kernel Blitz '01. The BPAUV executed 135 hours of bottom mapping, change detection, and mine-hunting missions during the course of the exercise. Numerous mine targets were detected and classified. Once completed, the Cornerstone AUV Navigator will be installed and demonstrated on-board the BPAUV. A second program, the *US/UK Collaboration on UUVs for MCM Applications*, for which Bluefin will build two BPAUV-style vehicles, will also use the Cornerstone AUV Navigator to provide precise navigation and attitude information to the high-resolution Synthetic Aperture Sonar (SAS) payloads carried by these vehicles.