SEAFLOOR MAPPING AUV PROJECT

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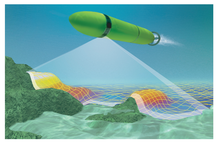
BACKGROUND

One of the fundamental efforts in oceanography is the use of sonar to map the morphology, character, and structure of the seafloor. MBARI scientists make extensive use of multibeam bathymetry and sidescan data for geological research, for ROV dive basemaps, and in support of other science and development projects. Almost all of our seafloor mapping data has been collected using hull-mounted multibeam sonars. Although much of this data is very high quality (e.g. the 1998 EM300 surveys), data from hull-mounted sonars lose lateral resolution in the deep ocean because of the large distance between the sonar and the seafloor. Many MBARI science goals, including Canyon Dynamics, require higher resolution seafloor bathymetry than conventional sonar platforms can deliver. In order to perform high resolution mapping in the deep ocean, we need an efficient platform or vehicle that can bring high-frequency sonars close to the seafloor.

The MBARI Seafloor Mapping Project's goal is to field current-generation mapping sonars from a Dorado Autonomous Underwater Vehicle (AUV) capable of operating to depths of 6000 m. This vehicle will be equipped with a 200 kHz multibeam sonar to provide high-resolution bathymetry, a dual-frequency 110/410 kHz sidescan sonar for high resolution backscatter imagery, and a 3-15 kHz CHIRP subbottom profiler for imaging sediment structure beneath the seafloor. The Seafloor Mapping project also encompasses the development of software and infrastructure to handle the data that will be produced by this system. This poster presents our progress towards field trials of our Mapping AUV late this year.



CHALLENGES

The deployment of mapping sonars on an AUV involves several significant challenges:

- Power Constraints: an AUV is power limited for both propulsion and sensors by the batteries it carries. Unmodified sonar and data logging electronics typically draw too much power to allow long missions.
- Size and Weight Constraints: Because of its 21" diameter, the Dorado AUV also imposes constraints on the shape and volume of the electronics packages, and the amount of buoyancy compensation required. Operational realities (the vehicle must be deployed and recovered at sea) dictate that any protuberances from the cylindrical Dorado vehicle will tend to be damaged. Consequently, another very desirable design feature for Dorado systems is to keep all sensor elements, including sonar arrays, conformal to the cylindrical AUV body.
- Navigation: Navigation is another difficult issue for surveys conducted on any submerged platform. Swath surveys with sub-meter lateral resolution require navigation with a similar precision, or else the resulting maps will show artifacts where bottom features mismatch on overlapping swaths.

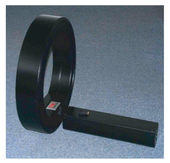
PROGRESS

This project is behind its original schedule primarily because of delays in the development and delivery of the most important sensor, the Reson 7100 multibeam sonar. We expect to take delivery of the Reson multibeam late this year, and to complete the assembly of the complete vehicle by the end of 2003.

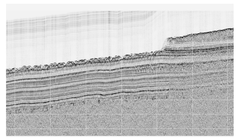
- The Concept Design Review for the Mapping AUV as a whole was held early this year. More recently, Preliminary Design Reviews (PDRs) have been held for the nose and midbody sections of the vehicle. The PDR for the tail section will be held shortly.
- The Kearfott SeaDeViL inertial navigation system has been acquired. This system has been field tested successfully using ROV Ventana.
- The Edgetech FS-AU sidescan and subbottom profiler sonar system has been acquired. These sonars have been tested in the lab and the test tank.
- The 6000 m rated titanium pressure housing for the mapping sonar electronics has been fabricated and pressure tested.
- The MBARI Dorado tailcone is in-house.
- The Benthos acoustic modems have been ordered and will arrive this summer.
- The Syntactic foam order is imminent; the flotation components will be delivered by the end of the summer.

Vehicle testing and debugging is planned for the first half of 2004. Deployment of the new AUV mapping capability for science projects will commence in the latter half of 2004.

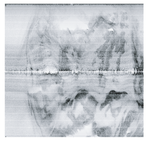
MAPPING SONARS



Reson 7100 multibeam sonar receive (ring) and transmit array. The receive array is designed to be conformal to the Dorado AUV skin. The receive array also encompasses the analog signal conditioning and A/D functions in pressure tolerant electronics.



Edgetech FS-AU subbottom profiler data sample (image from C&C Technologies)



Edgetech FS-AU sidescan data sample (image from C&C Technologies)

The sonar electronics pressure housing. This titanium housing is rated to 6000 m depth.

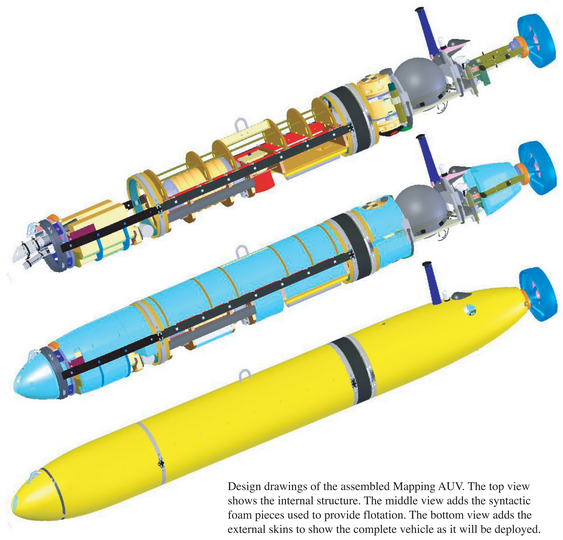
VEHICLE DESIGN

OVERVIEW

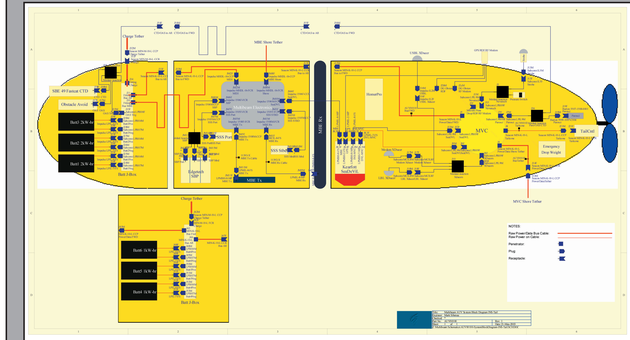
The Mapping AUV is being constructed with three sections. The nose section contains the rechargeable batteries and CTD sensors. The midbody includes the three mapping sonars (multibeam, sidescan, and subbottom profiler) and a data logging computer. The tail section includes the navigation system, the main vehicle computer, acoustic and RF communications, the propulsion system, and an emergency drop weight.

Among the highlights of the Mapping AUV system functional requirements and design decisions are:

- General
  - 21" diameter Dorado class AUV
  - Depth rated to 6000 m
  - Operable from the Zephyr and from blue water UNOLS vessels
- Instrumentation
  - Reson 7100 Multibeam Sonar
    200 kHz
    1 degree by 1 degree beams
    349 beams reported across a maximum 150 degree swath
    Swath width 5 times altitude at 200 m altitude
  - Edgetech FS-AU CHIRP Sidescan and Subbottom Profiler Sonar
    4 kHz – 16 kHz FM sweep Subbottom Profiler
    110 kHz low frequency sidescan
    410 kHz high frequency sidescan
  - Paroscientific UCB7000-I-005 Pressure sensor
    0.005% precision for vehicle depth
  - Sea-Bird SBE-49 FastCat CTD
  - Datasonics PSA-916D 225 kHz Sonar Altimeter
- Navigation
  - Kearfott SeaDeVil inertial navigation system
    Integrated with RDI 300 kHz DVL
    Integrated with GPS at surface
- Power
  - Bluefin "Smart" Lithium-Polymer rechargeable batteries
  - Initial configuration carries three 2 kWhr batteries
  - The 6 kWhr configuration should allow 12-14 hour missions.
- Propulsion
  - MBARI articulated tailcone (manufactured by Bluefin Robotics)
- Acoustic Communications
  - Benthos acoustic modems
  - 7-15 kHz omnidirectional transducers at surface and on vehicle
  - Integrated functions for long baseline navigation and acoustic abort
- Safety
  - Single vertical lift point
  - Front tow hook
  - Emergency drop weight with internal and remote acoustic trigger
  - Homerpro acoustic beacon, RDF, strobe light
  - RF modem for communications at surface



Design drawings of the assembled Mapping AUV. The top view shows the internal structure. The middle view adds the syntactic foam pieces used to provide flotation. The bottom view adds the external skins to show the complete vehicle as it will be deployed.



Mapping AUV Systems Block Diagram

NOSE SECTION

The Mapping AUV nose section is fashioned from a Gertler body of revolution to minimize drag. The forward component of the nose section is a removable nosecone containing sensors and the aft component is the battery section. Most of the interstitial spacing is filled with syntactic foam for flotation.

The nosecone houses two instruments, the Sea-Bird SBE-49 FastCat CTD, and the Datasonics PSA-916D Programmable Sonar Altimeter. The primary use of the CTD data on the Mapping AUV is for calculating the speed of sound in the water, a critical parameter for the multibeam sonar. The altimeter provides high-resolution altitude and ranging information used for vehicle control. The nosecone is removable without disassembly of other portions of the vehicle, allowing maintenance of the sensors.

The battery section contains three pressure compensated "Smart" 2kw-hr batteries manufactured by Bluefin Robotics; a pressure-compensated, oil-filled junction box, and an oil filled pressure compensator. The batteries provide power for the entire vehicle. Each battery is comprised of dual sections. The first section contains Lithium Polymer Cells and four Temperature sensors. These items are embedded in an epoxy matrix. The second section contains the battery controller. The controller is placed in a small oil-filled, pressure compensated cavity.

MIDBODY SECTION

The midbody section contains the mapping sonars and the data logging computer.

The Reson 7100 is a 200 kHz multibeam sonar that will provide high resolution, 1 degree by 1 degree bathymetry and backscatter imagery. The multibeam receive array is constructed as a 533 mm (21") diameter ring that is conformal to the AUV skin. The multibeam projector is 122 mm long, and is mounted inside the AUV skin along the bottom of the vehicle. Both transducer arrays are pressure rated to depths of 6000 m. A particularly important innovation for the Reson 7100 multibeam is the use of pressure compensated electronics for analog signal conditioning and the analog-to-digital (A/D) conversion. Conventional multibeams feed many analog channels through large cables to electronics that, in an AUV, must be contained in a pressure housing. Such large cables are difficult to accommodate in penetrations into a deep rated pressure housing. Since the Reson 7100 A/D conversion occurs outside the pressure housing, the many raw channels can be multiplexed and passed into the pressure housing through small penetrations.

The EdgeTech FS-AU is a dual frequency (110 kHz and 410 kHz) CHIRP sidescan sonar combined with a 4-16 kHz CHIRP subbottom profiler. The sidescans both use port and starboard transducer staves for both project and receive, and the subbottom profiler combines a downward focused projector with port and starboard receivers. All of these transducer arrays are mounted within the AUV skin.

The sonar electronics for both the Reson 7100 and the Edgetech FS-AU are contained in a 6000 m depth rated pressure housing constructed of titanium. Also packaged inside this pressure housing is a Reson 6046 data logging computer that will log the multibeam, sidescan, subbottom, navigation, and CTD data on dual 40 GB hard drives. The data records from the various sensors are logged asynchronously in a single stream.

TAIL SECTION

The Mapping AUV tail section includes the propulsion system, the main vehicle computer (MVC), the navigation system, the acoustic and RF communications systems, and an emergency drop weight system.

Propulsion is provided by the same MBARI articulated tailcone used in other MBARI Dorado AUVs.

The MVC is responsible for executing planned missions, communicating with all sensors, controlling the vehicle, and logging all of the sensor data (excepting sonar data from the mapping payload). The MVC is packaged within a Benthos glass sphere.

The primary vehicle navigation sensor is a Kearfott SeaDeViL intertial navigation system (INS) that integrates ring laser gyros, accelerometers, and a 300 kHz RDI Doppler Velocity Log (DVL). This INS is packaged in its own 6000 m rated pressure housing. Use of a high performance INS allows mapping AUV operations without having to deploy and recover acoustic transponder networks. The INS navigation is initialized at the surface using the vehicle's GPS receiver. During survey operations the DVL provides velocity relative to the bottom, stabilizing the inertial navigation.

The INS also provides highly accurate vehicle attitude data to the multibeam sonar. In order to generate bathymetry accurate to 0.5% of vehicle altitude, the vehicle roll must be known to 0.05 degrees. The midbody and tail designs incorporate brackets allowing the INS at the front of the tail section to be physically coupled to the multibeam's receive head (located at the aft of the midbody).

Acoustic communication between the AUV and the surface is accomplished using Benthos acoustic modems. This low rate communication is used to check system status, mapping data quality, and to modify mission parameters.

DATA PROCESSING

MB-SYSTEM

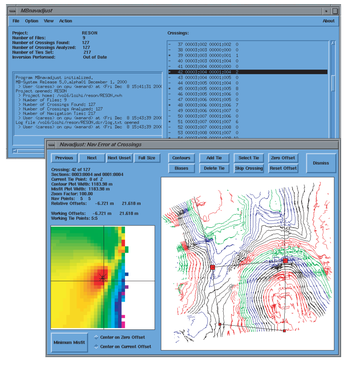
The multibeam and sidescan sonar data collected using the MBARI Mapping AUV will be processed using MB-System. MB-System is an open source software package for the processing and display of swath mapping sonar data that is widely used because it supports data from many different multibeam, interferometry, and sidescan sonars in many different data formats.. The development of this software is an NSF-supported collaboration between David Caress of MBARI and Dale Chayes of the Lamont-Doherty Earth Observatory. Individuals from more than 120 institutes and companies have downloaded updated source code distributions over the past year.

A NEW TOOL FOR PROCESSING MAPPING AUV NAVIGATION

One common problem for swath bathymetry surveys conducted using multibeam sonars on towed platforms, ROVs, submersibles, and AUVs is that navigational errors become large with respect to the lateral bathymetry resolution. The result is obvious artifacts in the bathymetric maps where bathymetry in overlapping swathes fails to match. Although the MBARI Mapping AUV will have a sophisticated DVL-aided INS navigation system, the result will be to minimize but not eliminate navigational artifacts. However, bathymetric features observed on multiple swathes can be used to measure the relative navigation error between the two swathes (e.g. move one swath until the features match). Given many crossing or overlapping points in a survey, it is possible to generate a complete navigation solution that is as accurate, in a relative sense, as the lateral bathymetric resolution. Thus, instead of poor navigation limiting the usefulness of swath bathymetry data, the availability of swath bathymetry presents an opportunity to solve for better navigation.

We have developed new navigation processing software for use with data from the MBARI Mapping AUV. This MB-System utility, called MBnavadjust, facilitates solving for navigation which matches crossing and overlapping bathymetric swathes. MBnavadjust:

- Automatically identifies places where bathymetry swaths overlap or cross.
- Displays the bathymetry of crossing/overlap points, allowing users to interactively determine the navigation offset required to match common features.
- Solves for an optimal navigation adjustment solution that fits the interactively determined crossing/overlap offsets while minimizing the first (speed) and second (acceleration) derivatives.
- Automatically applies the navigation adjustment solution to the relevant swath data files.



Screen dump of MBnavadjust showing interactive analysis of two overlapping swathes of Reson SeaBat 8101 bathymetry. The right map has 10 m contours. The left map shows misfit as a function of relative offset, with small misfits red. In this case, one swath must be moved 6.7 meters west and 21.6 meters north to make the bathymetry features match.

DATA PROCESSING EXAMPLE

The summit of Loihi Seamount was surveyed in 1997 using a towed Reson SeaBat 8101 multibeam sonar at altitudes of 100 to 150 m over the seafloor. This 240 kHz multibeam produces an 101 beam, 150 degree swath. This dataset provides a useful analog for the multibeam data we will collect with the MBARI Mapping AUV, though we expect our navigation and bathymetry data to be substantially better than in this example.

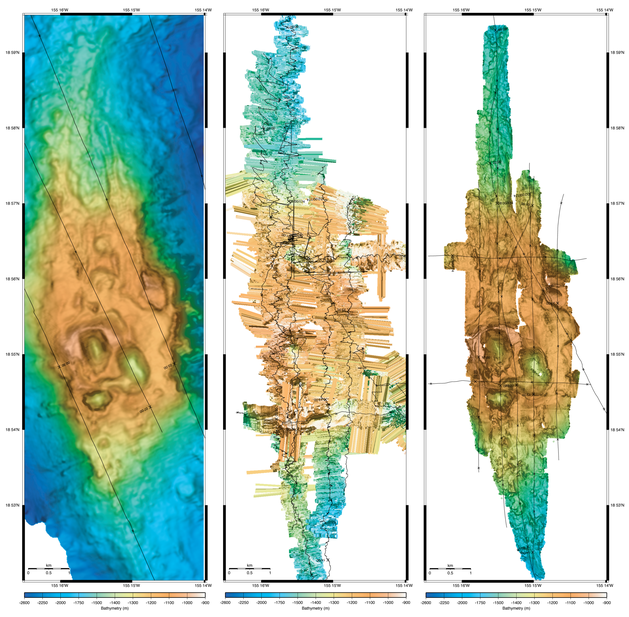
The left figure shows the summit of Loihi Seamount as surveyed for MBARI with a well-navigated, hull-mounted, 30 kHz Simrad EM300 multibeam sonar in 1998. The middle figure shows the Reson 8101 bathymetry swathes as collected. The raw multibeam bathymetry data exhibited a number of problems, including:

- The ultra-short baseline (USBL) towfish navigation was noisy and intermittent, with frequent jumps of several hundred meters
- The towfish depth (pressure) sensor data contains frequent spikes
- The multibeam bathymetry data contains considerable artifacts

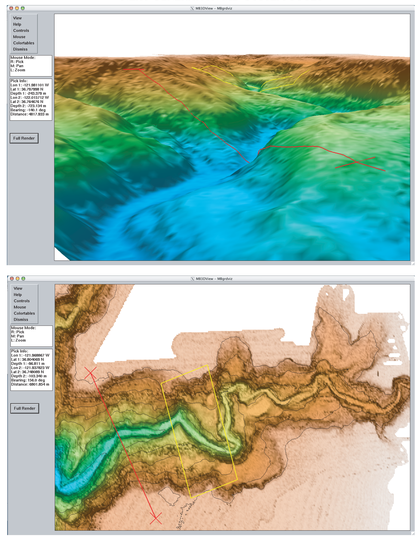
The Reson 8101 bathymetry data were processed using MB-System tools in the following sequence:

- MBnavedit was used to replace the original navigation with smooth, reasonable dead reckoning (DR) estimates. This step resulted in plausible navigation with large (> 1 km) position errors.
- MBnavedit was also used to flag and interpolate over spikes in the sonar depth data .
- The bathymetry was edited using MBedit.
- MBnavadjust was used to renavigate the edited Reson 8101 bathymetry relative to the EM300 bathymetry. This step produced navigation good enough that crossing and overlap points among the Reson 8101 swathes could be reliably found.
- MBnavadjust was again used to renavigate the Reson 8101 bathymetry, but this time using only crossing and overlap points among the 8101 swathes

The right figure shows the final processed Reson 8101 bathemetry survey. The resolution advantage of a high frequency multibeam operated near the seafloor over lower frequency, hull-mounted sonars is clear.



NEXT GENERATION MB-SYSTEM TOOLS



Over the past year, the MB-System team has focused primarily on developing the capability for managing large swath data archives. Our next focus will be on developing new tools for browsing surveys, editing swath bathymetry, and determining sonar bias settings that all include a 3D visualization based interface. The screen dumps above show a simple grid view program that utilizes a prototype 2D/3D visualization library. The next major MB-System release will include several new processing tools using this vizualization interface.