Mola Mola, NIUST's Low-Altitude Photo and Multibeam AUV

M. Woolsey and A.-R. Diercks

National Institute for Undersea Science and Technology
Undersea Vehicle Technology Center
UM Field Station
15 CR 2078, Abbeville, MS 38601 USA

V. L. Asper

National Institute for Undersea Science and Technology
Undersea Vehicle Technology Center
University of Southern Mississippi
1020 Balch Blvd, Stennis Space Center, MS 39529 USA

***Abstract*–Mola Mola is a seafloor mapping AUV owned and operated by the National Institute for Undersea Science and Technology (NIUST). Its primary sensor is a downward-facing camera producing color-corrected seafloor imagery which, with proper navigation and post processing, can be converted to a photo mosaic. It also uses a multibeam sonar to gather bathymetry encompassing the photo coverage. Since its delivery in May of 2009 Mola Mola has been modified in the areas of its imaging and navigation systems as well as several mechanical systems.**

I. SeaBED Class AUV Mola Mola

The Mola Mola AUV (Fig. 1) was acquired by the National Institute for Undersea Science and Technology (NIUST) in May of 2009. Since then, it has performed transects over coral, and a shipwreck survey. It has worked independently and in tandem with NIUST's other AUV, the Eagle Ray. This larger and faster vehicle can complete a broad survey, which may be followed by a more focused Mola Mola survey after identifying points of interest. This two-phase survey approach was successfully carried out during a shipwreck study [1].

Figure 1. Mola Mola AUV during operations on October 15, 2009

Mola Mola is named for the Ocean Sunfish, with which it has a common form factor. It is a SeaBED class AUV designed and built by Dr. Hanumant Singh and his team at WHOI [2]. It has an upper and lower torpedo shaped pod separated by two vertical struts. This multihull configuration further contributes to its double name. The upper pod is buoyant and the lower pod provides ballast from the Li-ion batteries and sensors. This generates a passive stability with regard to pitch and roll. The SeaBED vehicles can operate safely at low speed near the bottom with maneuverability provided by two main thrusters, port and starboard, and a vertical thruster. Typical survey parameters for the Mola Mola are 3 m altitude and 0.15-0.25 m/s, with a maximum depth capability of 2000 m.

The Mola Mola was ordered essentially as a "base model" SeaBED. Its suite of navigation sensors included an RDI doppler velocity log (DVL), Paroscientific depth sensor, and LBL capability provided by a WHOI Micromodem. Attitude and heading were measured using the tilt sensors and magnetic compass internal to the DVL. An IXSEA Phins configured as a gyrocompass was added at WHOI after the first cruise to improve attitude and heading quality. The vehicle was equipped with a down-facing camera in the forward end of the lower pod and flash unit in the rear of the pod. Software for adding an Imagenex multibeam sonar was provided.

II. Science Payload

The Mola Mola imaging system has been modified from its original design in an effort to create a more useful data product with even and consistent lighting. During a research cruise described in [1], images were acquired over a shipwreck. The footprint of each image at 3 m altitude is roughly 2.6 m along-track and 3.2 m across track with approximately 775 pixels per meter. Although the high-resolution imagery, such as that of Fig. 2, met the goals of the mission, changes would be needed to generate a smoothly lit georeferenced photomosaic of the site.

Faults present in the survey included uneven lighting and dropped frames, which placed gaps in the lines of images. The mosaic was initially generated using a graphical technique, which would stretch and deform each subsequent image to fit onto the previously placed images. The distortion prevented the output from being georeferenced with adequate quality, and since the technique required image overlap, multiple geographically independent mosaics resulted from the gaps in the survey.

To produce a mosaic with this data, images were aligned by hand to create a transect over the shipwreck. Due to inconsistent lighting, the image boundaries formed a rough transition between brightness and shadow.

To produce a mosaic better suited to the research goals of the Mola Mola, a geographic technique was developed. A post processing step extracts vehicle log data for each image recorded. Vehicle altitude, attitude, heading, and position are used to derive coefficients for an affine transform that properly stretches, rotates, and translates the image in a Cartesian coordinate system. The images are then tiled using GIS software.

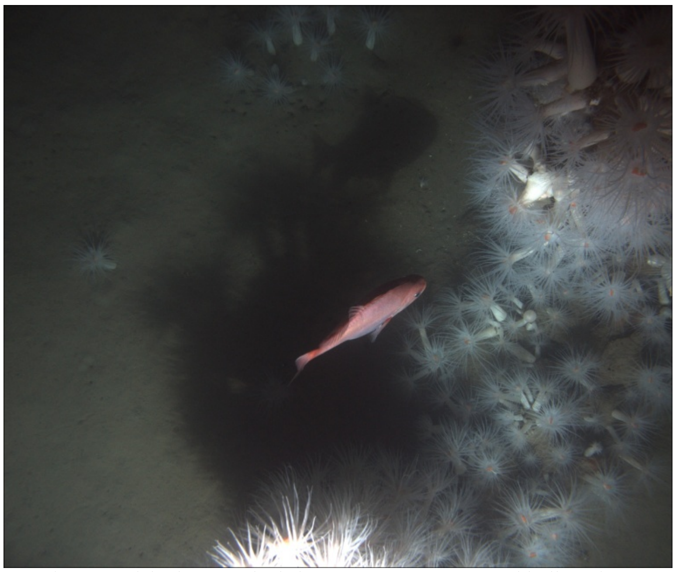

Figure 2. Fish photographed above an anemone-covered hull section.

Positive aspects of this solution include minimal distortion to the images and the ability to handle gaps in the survey. The main negative attribute of the technique is that the resulting mosaic has rough boundaries due to navigation errors. An improved approach may be to perform a graphical smoothing of the images after they are tiled geographically.

The original lighting solution produced dramatic single images, but the bright spot and shadows diminished the quality of mosaics as shown in Fig. 3. The Australian Center for Field Robotics at the University of Sydney operates a SeaBED class vehicle, Sirius [3]. This vehicle is modified to use strobes mounted in the fore and aft ends of the lower sensor pod while mounting a stereo pair of cameras near the center.

To incorporate this solution, the camera and capacitive strobe were removed, and DeepSea Power and Light LED arrays were mounted at either end of the sensor pod. These lights can be pulsed like a strobe or used as constant sources for video work. The camera was moved to the unused space starboard of the vertical thruster, and the port side is reserved for a second camera, currently on order. The two cameras and lights will allow a variety of imaging configurations. Both cameras may be used to acquire stereo imagery, or one may take still photographs while another records lower resolution video. Additionally, the cameras may be faced in different directions with lighting adjusted accordingly.

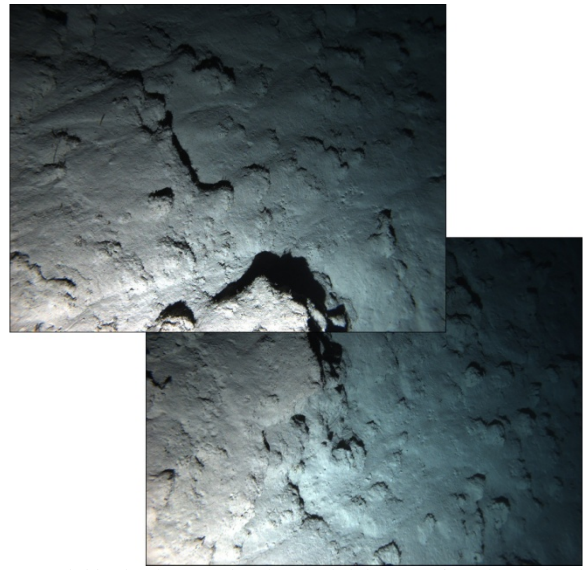

Figure 3. Neighboring images showing the bright spot of one image bordering shadows of the other.

Development of the multibeam system has been avoided since the photomosaic capability required expansion. Since the multibeam system does not receive any vehicle navigation information, positions must be added in post processing. The software to perform this navigation and multibeam data merge has not been developed, so in-house processing of existing multibeam records is not possible. After thoroughly testing the newly overhauled navigation system, development will begin on properly storing navigation information alongside the multibeam data as it is collected, allowing subsequent multibeam records to be processed using standard software suites.

III. Navigation

The majority of engineering time was spent enhancing the navigation system of the Mola Mola. The original system used dead reckoning from the DVL and gyrocompass inputs. The navigation routine integrated horizontal velocities to obtain position, which requires that the vehicle is in bottom lock mode (within ~30 m of the seafloor).

Relative to an origin, the vehicle would keep up with its offset in meters north and east. When LBL navigation is used, the origin is computed relative to the surveyed beacons before launching the vehicle. If LBL is not used, the origin is an arbitrary point defined by resetting the vehicle position upon reaching bottom lock. The downfall of operating in LBL mode is that whenever a new LBL solution is obtained, it replaces the previous position. This introduces a jitter in the navigation that is large compared to the scale of the data products.

In order to set up the Mola Mola for spatially-critical multibeam and photo surveys requiring smooth navigation, the Phins was reconfigured to serve as the position source for the vehicle rather than just a gyrocompass. The Phins is a complete inertial navigation system which consists of an inertial measurement unit (IMU) and a signal processor. The IMU itself contains gyros and accelerometers for all three axes. The heart of the signal processor is an extended Kalman filter which merges data from the IMU and external aiding sensors, while considering their respective error models. Fig. 4 summarizes the current configuration of the navigation system.

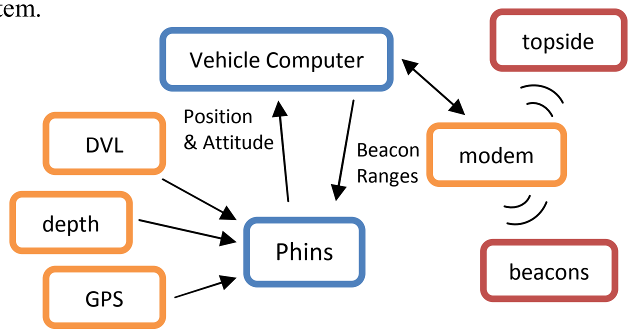

Figure 4. Block diagram of data flow within the navigation system.

A GPS was added to the vehicle to provide initial alignment of the Phins at startup and position aiding while on the surface before and after a mission. The DVL was configured to provide its output directly to the Phins, as it is the most important aiding sensor during a mission. The vehicle software was further modified so that ranges to LBL beacons also serve as aiding to the Phins.

The Phins was originally located in the upper pod, aft of the electronics housing. It was relocated to the lower pod after some structural changes so that it could be solidly mounted to the DVL and also be positioned near the vehicle's yaw axis.

The above modifications have been evaluated during engineering trials; however, the water was cloudy in the test area during these deployments. Unfortunately, the seafloor could not be seen through the mud in the resulting photomosaics to confirm navigational accuracy.

After an unpleasant encounter with a large boulder during acceptance trials, the Mola Mola has shown its need for an obstacle avoidance system. A Tritech altimeter has been added as a forward-looking sonar with a 20° beam. This has not yet been integrated into the control system of the AUV, but it will be able to log ranges during subsequent collision should one occur.

IV. Miscellaneous Systems

The vehicle sends its position as reported by the navigation system in an acoustic data packet. As a second opinion a LinkQuest ultra-short baseline (USBL) transponder was added. This system is self-powered and also serves as a backup position source if the vehicle electronics fail. The transponder is interrogated by a ship-mounted transducer, and it responds with a signal that is received by a ship-mounted hydrophone array. Before the navigation system overhaul, the transponder was located within the sensor pod, but it has since been displaced to the exterior, where it is strapped to brackets on the forward strut.

The vehicle was delivered with a Novatech strobe which works extremely well for locating it during night operations. While surfaced during the day, Mola Mola is very low profile, with only a few inches above the waterline. This makes the vehicle difficult to spot despite its bright yellow coloring. An RF beacon was added as a recovery aid if the vehicle surfaces outside of visual range. A temporary mast has been assembled to elevate the GPS antenna and recovery strobe. This will be replaced by a foil-shaped fiberglass mast aft of the lift point that will serve to elevate and protect the antennas and beacons used by the vehicle.

The thruster system has required some field repair during cruises. One of the original ball bearings used between the propeller shaft and thruster housing failed during a cruise. The ceramic bearing race fractured, either due to sediment contamination of the exposed bearing or by axial force caused by a loosening shaft screw. The fix was to replace the bearing with a PVC bushing that was machined from a boat hook shaft. This bushing is actually still in use, and works well enough that spares have been made in case other ceramic bearings fail.

The propellers had been locked to the round shaft with pins that fit into groves milled in the propeller hubs. These pins eventually cut into the composite hubs, and in one extreme case, the propeller could spin on the shaft with little resistance. To prevent this from happening again, the shafts were grooved and fitted with a protruding key. A square bushing was machined to accept the key and then fitted into each propeller hub, as pictured in Fig. 5.

Figure 5. Redesigned propeller hub and keyed shaft.

The last addition to the vehicle is a small sensor module designed to monitor temperature, pressure, and the presence of seawater within the electronics housing. This sensor, which has been built but not yet integrated, will be used to prevent overheating while running the vehicle on deck, to monitor vacuum when closing the housing, and to abort missions if anomalies are detected.

V. SUMMARY

Starting with a WHOI SeaBED class AUV, modifications were implemented to enhance vehicle safety and capability as well as to improve the quality of its navigation and scientific data. While the Mola Mola has already been used to gather geological, biological, and archaeological data, the first science missions in its new configuration have been scheduled for the summer of 2010. Engineering trials have been conducted successfully in the lab and at sea, off the Mississippi Gulf Coast, but the definitive measure of the vehicle's performance will be the quality of its scientific data products.

ACKNOWLEDGMENTS

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