Project Number: 901012

Project Start: Jan. 1, **2010** **Project Duration (in years):** **2**

Please indicate what type of project is being proposed (mark only only one).

[ ]	[x]	[ ]	[ ]	[ ]
Feasibility/Scoping [Less than 100 days effort]	**Development**[1]	**Research**	**Infrastructure**[1]	**Education**
	[ ] **Time Series**	[ ] **Institute Initiative**		

Project Manager[2]: Brett Hobson

Principal Investigator: Brett Hobson

Lead Scientist: Jim Barry and Ken Smith

Lead Engineer:

Project Title: Imaging AUV

[1] Development and infrastructure projects must complete the risk matrix (see item #5 at the end of the proposal form).
[2] Not all projects will require all four titles to be filled in. Please indicate individuals only for those titles that are appropriate for your project.

1) ABSTRACT (new projects only)

The Benthic Imaging AUV (BIAUV) project will finish up at the end of 2009 and the platform will be operated by DMO for science missions in 2010. The project met all of its goals and early feedback on the quality of the images has been very positive. However, there is room for improvement so we are proposing follow-on work as outlined below.

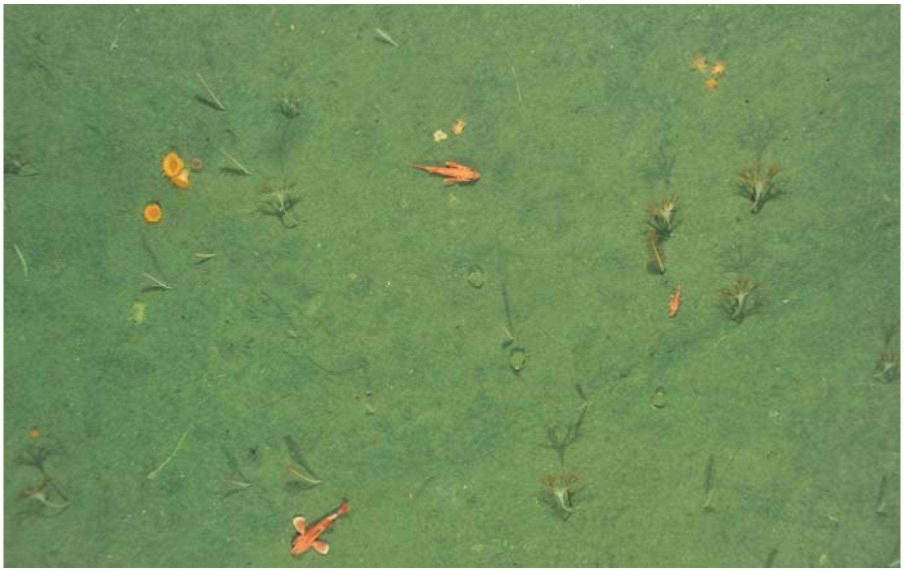

Figure 1: Sample BIAUV image from near the MARS observatory

The BIAUV has already collected several thousand images from a single cruise and this large dataset has exposed some shortcoming in the institute's infrastructure for dealing with still images. MBARI doesn't have a VARS-like database for the still images now being collected by this project, the Coolpix cameras on the ROVs, Smith's benthic tripod and Rover, or the new still camera being proposed for MOOS. Because this AUV will probably be collecting the most images, we propose to address this shortcoming under this effort. In addition to a still image annotation database, the overall work flow from raw images to counts of individual animals needs to be addressed by incorporating AVED processing, contextual metadata encoding and a Google Earth portal to view the images by not only our science partners, but the general public as well.

Currently, the BIAUV safely takes beautiful images of a flat seafloor. We know many of our science users will be interested in taking images in more complex terrain so we expect there to be conflict between those desires and the AUV supervisor's need to ensure safe AUV operations. Dave Caress is planning to develop a BIAUV mission planning tool for MB Systems that lays the proposed tracks directly over the high resolution bathymetry. This tool will tell us if we can safely fly the missions proposed, but we are also anxious to begin using Steve Rock's group's Terrain Relative Navigation (TRN) system to ensure the AUV is actually flying where we

told it to fly. We also feel we need to begin using a multibeam forward looking sonar and predictive terrain following algorithms to move beyond the existing Obstacle Avoidance system (OAS) that shuts off the thruster anytime a rise in the bottom is detected in front of the vehicle. The bottom following performance of the AUV (vertical turning radius) should also be improved to follow more challenging terrain. For extreme terrain, the ROV or a hovering AUV will be needed, but we propose to significantly increase the places the BIAUV can be safely deployed by improving the navigation, tuning the control and augmenting the turning radius by adding a simple bow thruster.

During 2010 we would also like to increase the breadth of operations the BIAUV can do. The first is to begin performing the MPA box mosaics that are currently done with the ROV. As some of these time-series mosaics are done in flat terrain, the only work needed on the BIAUV is to improve the parallel trackline following performance. A more ambitious effort is to begin using the BIAUV in the midwater to support the Biodiversity Initiative. A set of basic environmental sensors has been requested for the AUV to help answer questions about animal distributions. We feel this increase in the scope of tasks the AUV is doing warrants changing the name from Benthic Imaging AUV to the more generic Imaging AUV (IAUV).

2) PROPOSAL

a) New Projects

We are proposing to work on three main tasks in 2010.

Task 1 is to refine operations of the existing system
The first subtask (**Task 1.1**) is to develop a module within MB System to plan IAUV missions. Dave Caress is planning to do this task within his normal MB System project. Dave will modify the existing mission planner for the Mapping AUV to allow camera control and IAUV specific data to be planned. In addition, Dave will work with Rob McEwen to develop a tool to predict the vertical trackline following performance of the AUV to be sure the AUV can maneuver well enough not to crash into the seafloor. This work is related to the improved terrain following work presented later.

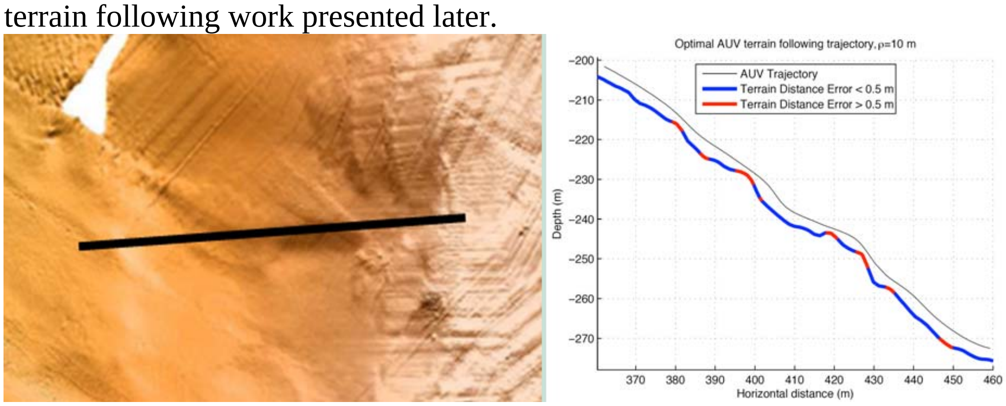

Figure 2 BIAUV Mission Planning Tool Concept

We'd like Brian Schlining to help with the image data flow for this project. Brian will start with **Task 1.2** that will build a utility to automatically annotate each image with relevant AUV and contextual information. For example, the width and height of the seafloor within the image can be extracted from the altitude of the AUV and camera field of view calibration information. Depth, vehicle pitch/roll and even temperature and dissolved oxygen are all important metadata that Brian will embed within the image EXIF database. John Graybeal was originally tasked with this work in 2009, but his departure required us to carry this over to 2010. Brian will also take on **Task 1.3,** which is focused on developing a VARS-like annotation database for still images. Brian will work with the video lab and will probably implement a variation of VARS for the still images. Google Earth (GE) has proved to be a very powerfully portal to view still images within the context of the geography as well as the rest of MBARI's ROV and AUV data. Mike McCann will work to **Task 1.4** to get the GE to recognize the AUV mission tracklines and images.

Danelle Cline with help with **Task 1.5**, that looks at the overall data flow from raw image to the final counts of animals many of our science partners need and how AVED can automate that process. Figure 3 below shows how AVED shall be used as an annotation assistant to automate the search for and automatically classify events in the AUV images.

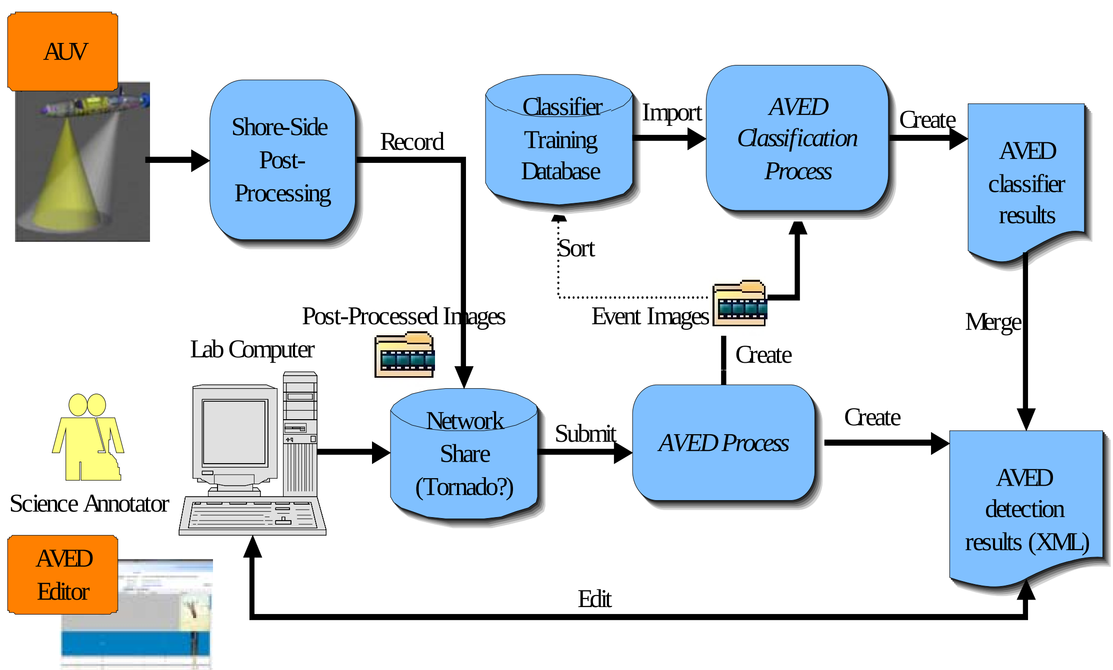

Figure 3: Still Image annotation data flow with AVED

After AUV image sequences in digital format are uploaded and post-processed on shore they are then ready to be sent to the *AVED Process* where events of interest are detected and tracked. Following AVED processing, event images (cropped images of events) are then sent to the *AVED Classification Process* to be classified into the lowest possible taxonomic category. Classifier results are then merged with the AVED detection results. The final AVED detection results are then sent back to the Science Annotator in its raw XML format to preview and edit the results. If integration with an existing data management system were desired, the data management system would ingest the AVED XML data.

Four sub-tasks needed for this data flow are:

Subtask 1.5.1: Create a training database
In order to classify images into the lowest possible taxonomic category, first a training database is needed. This training database consists of images that represent the classes desired (e.g. Three steps are needed to create a image training database for the IAUV

1) Identify the best images to generate the representative training database from. This can be a random sampling of images, but these are typically the images highly populated with representative animals of interest.

2) Process these images through *AVED Process* with the option to generate a cropped, event-centered image of all detections.

3) Sort these event-centered images using the AVED sorting graphical interface.

Most of these steps are automated and reuse the existing AVED software, except step 3 that requires an expert science user to verify the images are in fact representative of the target category. We know from previous classifier work that creating a training library requires many days of effort; therefore, a fair amount of time should be devoted to this task to create the training library. This task will be performed by the video lab, and time for this work is budgeted under Robison's proposal.

Subtask 1.5.2: Tune AVED algorithm for benthic and midwater imagery
There are many tunable parameters in AVED to improve the detection results. Danelle will create processing options optimized for each image type (e.g. benthic versus midwater). Preliminary work started on this task in 2009 on the IAUV benthic images; the work in 2010 will be to further optimize benthic as well as add midwater. Because the AVED software has existing optimized processing parameters for both midwater and benthic images from the Tiburon and Ventana ROV's, we expect this work to be similar to these parameters and straightforward.

Subtask 1.5.3: Work with integrate metadata
The AVED software will need to be modified to properly parse the contextual metadata that Brian will be embedding in every AUV image.

Task 1.6: We have demonstrated three modes of navigation for the IAUV: (1) normal DVL-aided dead reckoning, (2) Surface aided USBL tracking relay, and

(3) acoustic navigation relative to a single seafloor beacon. More work is needed to refine the ability of the IAUV to take strips of overlapping images along closely spaced parallel tracklines. This is needed before we can assembly box mosaics like those created by Ventana for Steve Rock's MPA project. We attempted to do this in '09 but "anomalies" arose during field testing that did not show up in simulation. We're requesting two days of testing near Soquel Canyon that will include more box mosaic work.

Task 1.7 is to add some basic sensors to the IAUV. When patchiness is observed in the distribution of benthic animal communities, it is probably a function of the seafloor, but we need to be sure it isn't due to variations in the overlying water mass, e.g. dissolved oxygen. Scientists involved in the Biodiversity Initiative who want to use this platform have asked us to equip the vehicle with a CTD, DO, Chlorophyll and optical backscatter sensors. We have selected an integrated suite of sensors from Seabird that are very high quality and the single combined data stream will be fairly easy to integrate. Design time is needed for Jon Erickson to mount the sensors and design the floatation needed to offset their in-water weight. The existing sensor software drivers will need to be modified for the SBE19, which is used on the ROVs, but has not been integrated on an AUV yet.

Task 2: Improve the terrain following performance of the BIAUV.
With the mission planning tool described above, the AUV shouldn' t crash into anything; if, it is flying where it should be. However, normal geo-referencing errors during map making typically introduce seafloor feature shifts of 10s of meters compared perfect geodetic navigation. Add normal navigation errors of at least 10 meters to this for the IAUV and you begin to hesitate before programming the AUV to fly over something like the Ruby whale fall. Ruby is on the flat seafloor in the axis of Soquel canyon, though within 30m of a steep outcropping. Fortunately, it looks like Steve Rock's group will be able to add a fourth navigation technique for the IAUV: Terrain Relative Navigation (TRN), which is described in Rock's Precision Control Proposal. TRN can use the data from the existing DVL and a stored map of the terrain to figure out almost exactly where the vehicle is within that map. Rob McEwen is working with Rock on this so we're asking for a little more time for Rob under **TASK 2.1** to help get TRN running on the IAUV as soon as possible.

Task 2.2 is to maximize the terrain following performance of the existing BIAUV. Rob will work to carefully tune the altitude controllers and increase the deflection angle of the tailcone to decrease the turning radius. We can then test the vehicle against progressively more challenging terrain in Rob's vehicle simulator. If we want to decrease the turning radius even more, extra actuation forces will be required. Nose mounted control surfaces, or dive planes and a good choice for this, but they'd get hung up in LARS straps on the Zephyr. At the relatively low speeds we fly during imaging runs (1 m/s), a through-body tunnel thruster can be very effective. **Task 2.3** is to build a short (~8"), removable hull module that contains a bow-thruster. This module will only be carried when the terrain requires it.

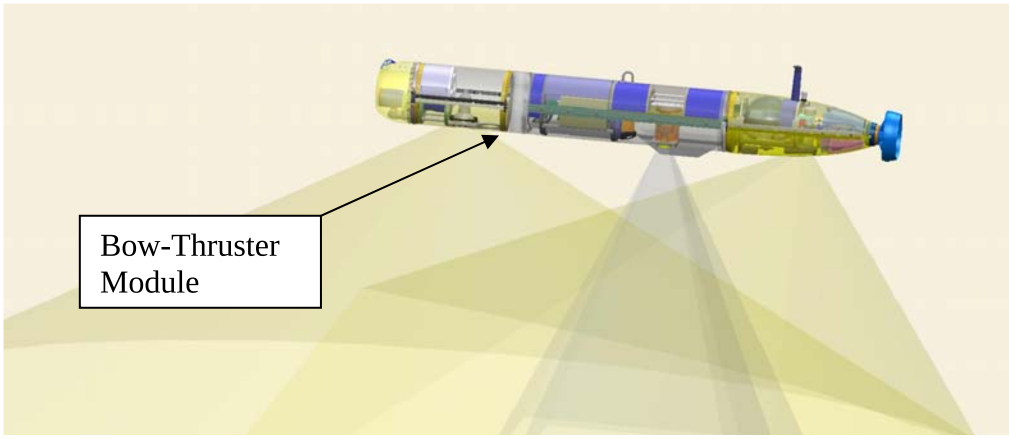

Figure 4: IAUV in Benthic Mode with bow-thruster module

In addition to sharpening the navigation and augmenting the turning performance of the AUV we want to add an organic capability to the AUV to allow it to precisely look ahead, asses the slope of the terrain and anticipate maneuvers to help in accurate altitude control. We've added **task 2.4** to work with Doug Horner at NPS to adapt their proven terrain following sensor and control algorithms to Dorado. Brett has collaborated with Dr. Horner before and is confident this would be a positive relationship. Doug has been working on the problem of terrain following for five years and the forward looking sonar and on-board algorithms he uses on his REMUS are fairly mature. Rob will be working with Doug's publications and actual control algorithms to jump start a predictive terrain following system on Dorado. The Obstacle Avoidance system (OAS) we run on the IAUV now is effective in detecting and avoiding obstacles in the path of the vehicle. The AUV stops it's propeller and drifts up for a preset time, then attempts to fly towards the waypoint again while checking for sonar targets in its path. As we start to follow undulating terrain the current OAS will constantly detect obstacles and instead of trying to smoothly fly over them, it will keep shutting down the thruster, which will cause gaps, or holidays, in the image record. The Blueview blazed array sonar that Doug uses "paints" the profile of the seafloor 50m in front of the vehicle. The onboard controllers then plan a path for the AUV to follow above that profile, long before the downward looking DVL detects any change in the angle of the seafloor. Doug has agreed to loan us one of his sonars for our initial testing and evaluation. A 4km depth rated version of the 450 kHz Blueview sonar is available to buy in 2011 for $42k if this system proves useful.

Task 3 is to develop a Midwater Mode for the IAUV to support the Biodiversity Initiative. The Midwater group at MBARI has been very successful identifying animals with a forward looking high definition camera and several kW of light. While the AUV can be configured to image in a forward-looking mode, the geometry of the camera and lights are sub-optimal and will cause strong backscatter unless something like range gating is used. Our approach is to use the AUV's length to our advantage by placing the strobes in the nose to illuminate a ~ 2m cube, then tilt the existing downward-looking high resolution still camera slightly forward. The still

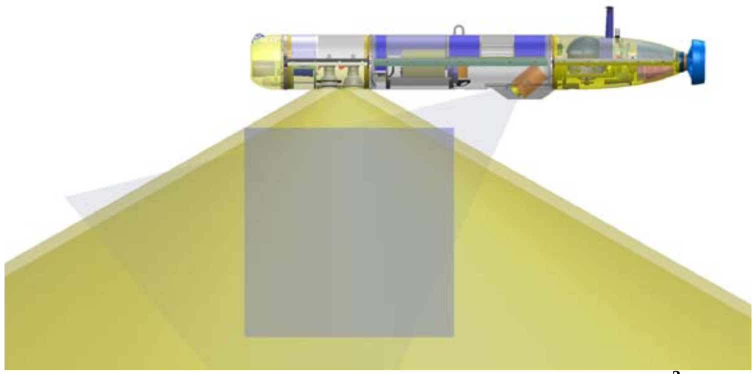

Figure 5: IAUV configured for Midwater Mode, showing the 2m^3 sample box

camera captures images at twice the resolution of the HD video, though at only 1 frame every 1.5 seconds. We can temporarily move the tail strobe up to the nose and either fire both strobes together for more light, or alternate firing to increase the lighting duty cycle. More light is needed for midwater imaging for two reasons: First, the animals are small and many are translucent so very little light is reflected back to the camera, and also, we need a much greater depth of field in the midwater to ensure animals close and in the background are all in focus, which requires a small lens aperture, which limits light reaching the imaging chip.

The current benthic camera system didn't need remote focusing or zoom. We will have to change the camera focus point when we switch between Benthic and Midwater modes and it may also be useful to change the angular field of view as well. We'd prefer not to open up the camera housing to make these changes so **task 3.2** is to add an internal focus and zoom motor assembly. We may have resources to do this work in '09, but as it is needed for the Midwater upgrade, a description of the work is included here. To test and tune the Midwater mode we will operate the AUV under **Task 3.3** within the view of John Horn's EK-60 installed on MARS. While operations all the way out at MARS reduce our in-water time, the EK-60 may be a valuable tool for the Biodiversity Initiative and we can use our test time to ground-truth the acoustic data.

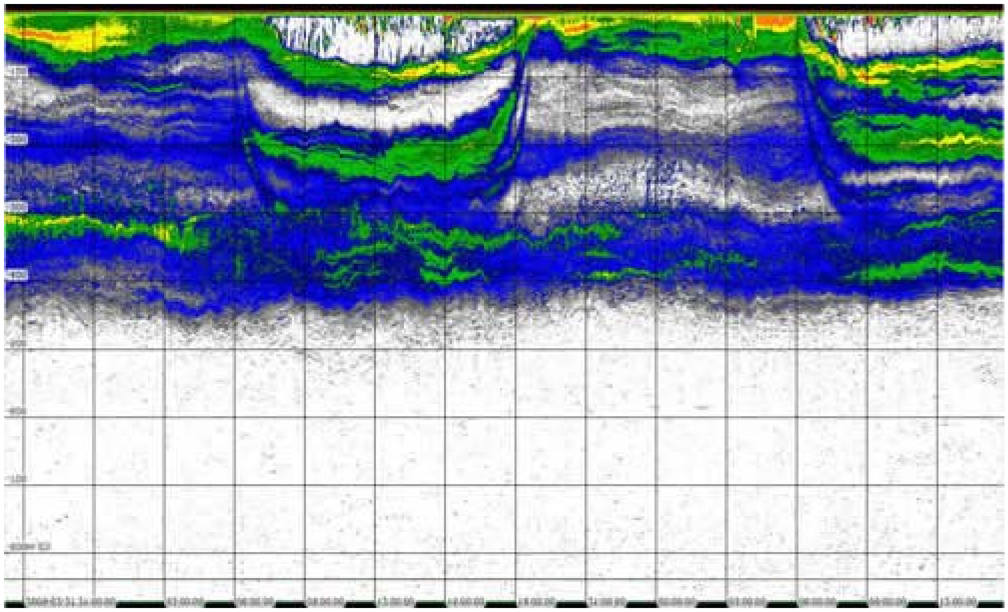

Figure 6: EK-60 view of the water colume above MARS over 42 hours. The diernal vertical migration is clearly visable, as well as horizontal bands of reflective biomass

Publications (from other projects over the last 5 years)

McEwen, R. S., Hobson, B. W., and Bellingham, J. G., "Docking Control System for a 54-cm-Diameter (21-in) AUV," IEEE J. Ocean. Eng, 33(4) 550-562, 2008.

Hobson, B. W., McEwen, R. S., Erickson, J., Hoover, T., McBride, L., Shane, F., and Bellingham, J. G., "The Development and Ocean Testing of an AUV Docking Station for a 21" AUV," Oceans, Vancouver, B.C., October 2007.

Bellingham, J. G., McEwen, R. S., and Hobson, B. W., "The Development of a Docking Station for a Regional Cabled Observatory," Proceedings of Scientific Submarine Cable 2006, Dublin Ireland, Feb 8-10, 2006.

Bellingham, J. G., and Hobson, B. W., "Future Developments and Applications of Marine Robotics," Proceedings of the 7th IFAC Conference on Manoeuvring and Control of a Marine Craft, Lisbon, Portugal 2006.

Robert S. McEwen, Brett W. Hobson, and James G. Bellingham, "Docking Control for a 21" Diameter AUV", Unmanned Untethered Systems Technology, New Hampshire, 2007. [AUGMENTED VERSION PUBLISHED IN IEEE JOE IN 2008, SEE ABOVE]

b) <u>Continuing Projects</u>

If the proposed project includes multiple individual projects, please list each of these projects as a subheading in the proposal. For each subheading, please address the following:

Current status of project and results to date

The BIAUV is operational and we've run one mission near of Jim Barry's 2.3km long 200m benthic transect.

c) New and Continuing Projects: Plans for 2010

Research Activities

We will be operating the IAUV for scientists involved with the Biodiversity Initiative to collect quantitative data on biodiversity.

Field programs (detail ship requirements/deployments)

Four days at MARS aboard the Zephyr are requested as well as two days near Soquel Canyon of engineering tests.

Budget justification

Task	Description	Cost
1.1, 1.5	Mac Laptop, 8 GB RAM, Running MB Systems, Matlab	$3753
1.5	Seabird 19Plus V2 CTD	$11,700
1.5	Seabird 43 DO	$4,900
1.5	Wetlabs FLNTUD Chlorophyll and backscatter	$4,800
2.3	Bow Thruster Module	$11,400
1.5, 3.1	Machined syntactic foam – Ideal Instruments	$5,700
1.5, 3.1	Wet cabling and connectors	$4,300
3.2	Camera lens upgrade	$2,950
	MARS port fees for the EK-60	$12,000
Total		**$61,503**

Project team

Brett Hobson, PM, 59 days total: (1D) Task 1.1, (2D) Task 1.2, (2D) Task 1.3, (1D) Task 1.4, (1D) Task 1.5, (5D) Task 1.6, (10D) Task 1.7, (2D) Task 2.1, (1D) Task 2.2, (5D) Task 2.3; (5D) Task 2.4, (5D) Task 3.1, (5D) Task 3.2, (10D) Task 3.3

Rob McEwen, Controls, 70 days total: (10D) Task 1.1, (15D) Task 1.6, (5D) Task 2.1, (15D) Task 2.2, (5D) Task 2.3, (20D) Task 2.4, (10D) Task 3.3

Jon Erickson, ME, 45 Days total: (15D) Task 1.7, (20D) Task 2.3, (10D) Task 3.1

Brian Schlining, SE, 35 Days total: (5D) Task 1.2, (30D) Task 1.3

Mike McCann, SE, 10 Days total: (10D) Task 1.4

Alana Sherman, EE, 45 Days total (10D) Task 1.7, (10D) Task 2.3, (5) Task 2.4, (15D) Task 3.2

Danelle Cline, SE, 26 Days total, all on Task 1.5

Dave Caress, MB Systems No days budgeted
Hans Thomas, AUV Supervisor, No days budgeted

Project lab space

We would like to continue to us the project lab space in room A-244

Data availability outside project team, uniqueness

We plan to release images to the public through the video lab's outreach, and through the Google Earth portal.

Risk matrix (development and infrastructure projects only)

	Technical Risk	Organizational Risk	Tech Transfer Risk	Labor Estimate Risk
High				
Medium	x			x
Low		x	x	

3) MILESTONES (new and continuing projects)

	Milestone 1	**Milestone 2**	**Milestone 3**	**Milestone 4**	**Milestone 5**	**Total Resources**[3] for each resource category for all milestones listed here
Milestone Date	**3-1**	**5-1**	**8-1**	**10-1**	**12-1**	
Milestone Description	**Refine BIAUV**	**Improve Terrain Following**	**Midwater Mode**	**0**	**0**	
EE	**90**	**135**	**225**	**0**	**0**	**405**
SE	**864**	**405**	**135**	**0**	**0**	**1269**
ME	**333**	**297**	**315**	**0**	**0**	**936**
EE Tech	**5**	**10**	**10**	**0**	**0**	**225**
SE Tech	**0**	**0**	**0**	**0**	**0**	
ME Tech	**10**	**20**	**17**	**0**	**0**	
Machine Shop				**0**	**0**	

(See next page for personnel classification

[3] This number should be the same number you entered on the resource requests for this particular resource.