Project Number: 901717

Project Start: Jan. 1, **2017**[1] **Project Duration (in years):** **1**[1]

Please indicate if proposal includes requests for any of the following (mark all that apply).

X			X	
Ship Time	**ROV**	**AUV**	**Wave Glider**	**Mini ROV**

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

	X			
Feasibility/Scoping [Less than 100 days effort]	**Development**[2]	**Research**	**Infrastructure**[2]	**Education**
	Time Series	**Institute Initiative**		

Project Manager[3]: Brett Hobson

Principal Investigator: Brett Hobson

Lead Scientist: Francisco Chavez, Chris Scholin, and Yanwu Zhang

Lead Engineer: Brian Kieft

Project Title: Long Range AUV Operations Support

[1] This date and number should remain the same for the duration of the project. If your project start date for 2017 is not January 1, please indicate the start date in the first cell of the milestone chart. Format for duration example: “Year 2 of 5”.
[2] Development and infrastructure projects must complete the risk matrix (see item #5 at the end of the proposal form).
[3] 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)

This is an abstract for a new, multi-year proposal to support the continued operations and refinement of MBARI's Long Range AUV. There are three distinct sections of the proposed work:

1. Continued operations support and training for Science and DMO staff.
2. Refinements to the LRAUVs and their software to facilitate the transition of operations from the development team to the users.
3. New payload integration and testing.

Routine LRAUV operations for the Monterey Bay Time Series are now conducted mostly by the science team, and as soon as the ESP team begins routine operations during 2018 we expect they too will quickly begin conducting vehicle operations on their own. However, we expect there will be a steady need for new missions and capabilities as the science focus of these operations evolve. Also during 2017 we will have a third set of LRAUV users at the University of Hawaii coming on line with a new science focus which will undoubtedly require engineering support.

Adaptive sampling, where the vehicle adapts its behavior based on evolving sensor readings has proven to be a powerful capability that was demonstrated by Dr. Zhang for front following. Instead of tightly integrating these complex behaviors into the LRAUV flight code as we did with Dr. Zhang, a separate computer should be used that feeds basic driving instructions to the flight system through a "back-seat driver" interface. During 2017 and 2018 we are planning to begin integrating a bioacoustics sensor with Dr. Benoit-Bird that will be combined with adaptive behaviors on a separate computer that could also guide the LRAUV to biological hotspots through the back-seat interface. We propose to develop this during 2017.

Many refinements to the LRAUV software were planned for 2017, but the absence of Jordan Stanway for at least ½ of the year has set those plans back considerably. We have scaled back the scope of much of the work, but important features like the data structure middleware, streamlined mission authoring, automated compass calibration, automatic ballasting, and a robust acoustic modem interface will not all be completed this year and therefore we will be requesting support for many of these tasks in 2017. In addition, we also propose to develop the capability to tow a LRAUV with the Wave Glider. We believe this should include an existing low-power energy transfer device to ensure the vehicle arrives on-station, ready to work with a full battery. We expect the resource request for 2017 to be about ¾ of the 2016 request.

2) PROPOSAL

a) New Projects

Statement of the problem, why it is important

The scales of spatial and temporal variability of the microbial ocean are poorly understood, but what we do know is that they are very high compared to the physical ocean, and most likely the chemical ocean as well. This creates a fundamental challenge: how can one make measurements of micro-organisms in their natural environment which allow unambiguous extraction of cause and effect? To do so, it we must be able to observe how organisms respond to their environment. This challenge is at the heart of the CANON activity, and a number of laboratories at MBARI are contributing to efforts to develop such an observational capability. The LRAUV provides an enabling capability for the desired observational capability, providing a platform that simultaneously has the endurance to observe microbial communities from boom to bust, and the payload capabilities to carry the payloads to make the desired measurements.

How does it relate/contribute to MBARI's mission and strategic plan?

This effort addresses the Strategic Plan in that it constitutes an innovative technology for observing the ocean specifically tailored to address topics in the third theme (Ecosystem Dynamics). The scientific relevance of the LRAUV will initially be through the CANON initiative, which will use the LRAUV as a key adaptive observational element for quantitative biological process experiments.

How does it relate/contribute to the Packard Foundation's Ocean Visions Grant making policies?
(See http://mww.mbari.org/oed/OED_Documents.htm#Packard for documents.)

Our effort directly supports the goal of "Enhance scientific understanding of the functioning of marine ecosystems." The linkage via the CANON project, which seeks to develop new methods for understanding and predicting the dynamics of marine microbial ecosystems, provides one clear linkage. However, the general capabilities of this vehicle extend beyond CANON goals, in we believe the vehicle can also be used for monitoring capabilities, and indeed time-series activities at MBARI are beginning to explore use of the LRAUV as a low-cost tool for high-value observations far from shore.

Does it relate to the Technology Roadmap? If so, please describe how.
(See http://mww.mbari.org/oed/TechnologyRoadmap.pdf.)

Operation of LRAUVs for extended missions aligns well with the three engineering initiatives outlined in the Technology Roadmap. The LRAUV is 'taking the lab into the ocean' (Init. #1), algorithms running onboard the AUV will be performing targeted sampling (Init. #2) and the multi-week missions easily qualify as advancing a persistent presence (Init. #3).

b) <u>Continuing Projects</u>

Current status of project and results to date

Over the past year the original LRAUV Tethys has been the workhorse running routine operations to support the Monterey Bay Time-series. As part of these operations more end users from the Chavez lab have been stepping up to operate the vehicle. Much of our work described in this proposal builds on the momentum to put these vehicles into the hands of the scientists and make it easier for the end user to safely operate them.

Currently we have just over 12,000 hours (Table 1) across the three vehicles to date consisting of just under 200 individual deployments/recoveries. We are pleased that the number of deployments still matches the number of recoveries!

Table 1: Vehicle Runtime Hours

	2016 to date (.55 year)	**Lifetime**
Tethys	652	7345
Daphne	0	4383
Makai	40	943
Total	**692**	**12,671**

Tethys also makes a cameo in one of the auditorium shows “Mysteries of the Deep” at the Monterey Bay Aquarium and was filmed for the Discovery Channel film “Blue Serengeti”.

Tethys and *R/V Paragon* being filmed by a drone for the show at the Monterey Bay Aquarium.

Tethys and *R/V Paragon* being filmed for "Blue Serengeti". Courtesy of Kip Evans.

In 2016 Tethys has also achieved the highest Mean Time Between Critical Failure (MTBCF) in its lifetime with science missions nearly doubling the value. This metric describes the average time a user would have to view the dash to potentially intervene due to a fault in the system. This year saw record runs of over 200 hours straight with no user intervention needed. System reliability is critical as Tethys is operated further offshore and by more end users.

Significant changes from previous project proposal

There are no significant changes from the previous proposal.

Publications based on the results of this project only

1) Stanway, M.J., Kieft, B., Hoover, T., Hobson, B., Klimov, D., Erickson, J., Raanan, B.Y., Ebert, D. & Bellingham, J., "White Shark Strike on a Long-Range AUV in Monterey Bay", In *Proceedings of OCEANS*. MTS/IEEE. Genova, Italy. May 2015.,

2) Zhang, Y., Bellingham, J.G., Ryan, J.P., Kieft, B. & Stanway, M.J. "Autonomous 4-D Mapping and Tracking of a Coastal Upwelling Front by an Autonomous Underwater Vehicle", *Journal of Field Robotics*. 2015. (in review)

3) Stanway, M.J., Zhang, Y. & Bellingham, J.G. "Interpolating through time and space with empirical orthogonal functions", In Ocean Sciences Meeting. ALSLO. Honolulu, HI, February, 2014.

4) M Jordan Stanway, Brian Kieft, Thomas Hoover, Brett Hobson, Andrew Hamilton, and Jim Bellingham Acoustic Tracking and Homing with a Long-Range AUV in Proceedings of OCEANS MTS/IEEE St. John's, Newfoundland, Canada September 2014

5) Y. Zhang, J. G. Bellingham, J. P. Ryan, B. Kieft, and M. J. Stanway, "Two-Dimensional Mapping and Tracking of a Coastal Upwelling Front by an Autonomous Underwater Vehicle," Proc. MTS/IEEE Oceans'13, pp. 1-4, San Diego, CA, U.S.A., September 2013.

6) Bellingham, J. G., Zhang, Y., Kerwin, J. E., Erikson, J., Hobson, B., Kieft, B., Godin, M., McEwen, R.,Hoover, T., Paul, J., Hamilton, A., Franklin, J., and Banka A., "Efficient Propulsion for the Tethys Long-Range Autonomous Underwater Vehicle," IEEE AUV, pp 1-6, Monterey, CA, Sept 1-3, 2010.

7) M. A. Godin, J. G. Bellingham, B. Kieft, and R. McEwen. "Scripting language for state configured layered control of the Tethys long range autonomous underwater vehicle." In OCEANS 2010, pp. 1-7. IEEE, 2010.

8) B. Kieft, J. G. Bellingham, M. A. Godin, B. W. Hobson, T. Hoover, R. S. McEwen, and E. C. Mellinger, "Fault Detection and Failure Prevention on the Tethys Long-Range Autonomous Underwater Vehicle," 17th International Unmanned, Untethered Submersible Technology Conference, Portsmouth, NH, Aug. 2011.

9) M. A. Godin, Y. Zhang, J. P. Ryan, T. T. Hoover, J. G. Bellingham, "Phytoplankton Bloom Patch Center Localization by the Tethys Autonomous Underwater Vehicle," IEEE Ocean, Kona, Hawaii, Sept 2011.

10) Y. Zhang, M. Godin, J. G. Bellingham, and J. P. Ryan, "Ocean Front Detection and Tracking by an Autonomous Underwater Vehicle," IEEE Ocean, Kona, Hawaii, Sept 2011.

11) J. Das, T. Maughan, M. McCann, M. Godin, T. O'Reilly, M. Messié, F. Bahr, K. Gomes, F. Py, J. Bellingham, G. Sukhatme, and K. Rajan, "Towards mixed-initiative, multi-robot field experiments: Design, deployment, and lessons learned." In Intelligent Robots and Systems (IROS), 2011 IEEE/RSJ International Conference on, pp. 3132-3139. IEEE, 2011.

12) Y. Zhang, M. A. Godin, J. G. Bellingham, and J. P. Ryan, "Using an Autonomous Underwater Vehicle to Track a Coastal Upwelling Front," IEEE Journal of Oceanic Engineering, Vol. 37, No. 3, pp. 338-347, July 2012.
13) Y. Zhang, J. G. Bellingham, M. A. Godin, and J. P. Ryan, "Using an Autonomous Underwater Vehicle to Track the Thermocline Based on Peak-Gradient Detection," IEEE Journal of Oceanic Engineering, Vol. 37, No. 3, pp. 544-553, July 2012.
14) B. Hobson, J. G. Bellingham, B. Kieft, R. McEwen, M. Godin, and Y. Zhang, "Tethys-Class Long Range AUVs - Extending the Endurance of Propeller-Driven Cruising AUVs from Days to Weeks," Proc. IEEE AUV'2012, pp. 1-8, Southampton, U.K., September 2012.
15) Y. Zhang, J. G. Bellingham, J. P. Ryan, B. Kieft, and M. J. Stanway, “Two-Dimensional Mapping and Tracking of a Coastal Upwelling Front by an Autonomous Underwater Vehicle,” *Proc. MTS/IEEE Oceans'13*, pp. 1-9, San Diego, CA, U.S.A., September 2013
16) J.P. Ryan, M.A. McManus, R.M. Kudela, M. Lara Artigas, J.G. Bellingham, F.P. Chavez, G. Doucette, D. Foley, M. Godin, J.B.J. Harvey, R. Marin III, M. Messie, C. Mikulski, T. Pennington, F. Py, K. Rajan, I. Shulman, Z. Wang, and Y. Zhang, "Boundary influences on HAB phytoplankton ecology in a stratification-enhanced upwelling shadow," *Deep Sea Research II*, Vol. 101, pp. 63-79, 2014.
17) Cheriton, O. M., McPhee-Shaw, E. E., Shaw, W. J., Stanton, T. P., Bellingham, J. G., and Storlazzi, C. D., “Suspended particulate layers and internal waves over the southern Monterey Bay continental shelf: An important control on shelf mud belts?” *J. Geophys. Res. Oceans*, 119 2014.
18) Ben Yair Raanan*, James Bellingham†, Yanwu Zhang*, Brian Kieft*, M. Jordan Stanway*, Robert McEwen* and Brett Hobson*, *Monterey Bay Aquarium Research Institute, Moss Landing, California 95039, and † Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, “A Real-time Vertical Plane Flight Anomaly Detection System for a Long Range Autonomous Underwater Vehicle,” in *OCEANS ’15 MTS/IEEE*, Washington, 2015.
19) Stanway, M.J., Kieft, B., Hoover, T., Hobson, B., Klimov, D., Erickson, J., Raanan, B.Y., Ebert, D. & Bellingham, J., “White Shark Strike on a Long-Range AUV in Monterey Bay,” in *Proceedings of OCEANS*, Genova, Italy, 2015.
20) Y. Zhang, J. G. Bellingham, J. P. Ryan, B. Kieft, and M. J. Stanway, “Autonomous 4-D Mapping and Tracking of a Coastal Upwelling Front by an Autonomous Underwater Vehicle,” *Journal of Field Robotics*, vol. 33, no. 1, pp. 67–81, Jan. 2016.
21) Ben Raanan, James Bellingham, Yanwu Zhang, Mathieu Kemp, Brian Kieft, Hanumant Singh, Yogesh Girdhar, “Automatic Fault Diagnosis for Autonomous Underwater Vehicles using Online Topic Models,” IEEE/MTS Oceans’2016, (abstract accepted, full paper due in August 2016).

c) <u>New and Continuing Projects: Plans for 2017</u>

Research Activities

Specific deliverables for research activities:

1. Support for science operations

1.1. **Monterey Bay Time Series (901112) and CANON (901009) –**
Kieft (10), Hobson (10), Stanway (10), Raanan (10)
24 days of 1 vehicle operations during 12 cruises between C1-M2-M1 with water sampling at M1. These will be run as one week missions combined with development and CANON objectives before the time series tasks. CANON is planning 57 days with 1-3 vehicles combined with MBTS deployments plus a 14 day, 3-vehicle experiment in the fall. Watch-standing hours are to be requested in respective proposal, but mission writing, launch/recovery, inter-group communications and contingency is requested here

1.2. **Surf Center Makai/3G ESP (901205)** - Kieft (20), Hobson (20), Stanway (10)
20 days of single vehicle operations during 10 deployments for the development and testing of various incarnations of the 3G ESP with a couple of new analytical modules. Watch-standing hours are to be requested in respective proposal, but mission writing, launch/recovery, inter-group communications and contingency is requested here.

1.3. **Targeted Sampling** (901513): Kieft (10), Hobson (10), Stanway (10)
20 days of tests are planned for new feature tracking and sampling methods and algorithms, based on the previously developed algorithms of front tracking, thermocline tracking, chlorophyll-peak tracking & sampling, and isothermal tracking & sampling. One important component is multi-vehicle collaboration, utilizing succinct acoustic communications between vehicles. We will also develop adaptive sampling algorithms to support animal acoustic tagging work. See 901513 proposal for details of development items. Watch-standing hours are to be requested in respective proposal, but mission writing, launch/recovery, inter-group communications and contingency is requested.

1.4. **Bioluminescence Operations with Haddock and Messié** - Kieft (10), Hobson (10), Stanway (10)
These proposed operations are described by Haddock and Messie in Haddock's proposal.

1.5. **MiVEGAS Vehicle testing and science operations in Monterey** - Kieft (40), Hobson (30), Mellinger (30) Stanway (10)
These shared engineering resources are requested to test out the 3G-ESPs and capitalize on the opportunity to possibly operate six LRAUVs together. In June the MiVEGAS vehicles will be shipped for Hawaii and are not expected to come back to MBARI.

1.6. **MiVEGAS Operations in Hawaii** - Kieft (80), Hobson (80), Stanway (10)

This is operations support for the SURF center LRAUV operations before, during and after the expedition.

1.7. **Development Testing** - Kieft (20), Hobson (10), Mellinger (30), Stanway (20)
This is the task that carries the operational overhead of performing test missions and in the case of the ET (Paul) and MT (Jim S.) where their lab support is logged to assist with vehicle maintenance.

2. Vehicle improvements

2.1. Electrical Refinement and Support

2.1.1. **Low-power improvements for transit –** Kieft (40), Hobson (10), Mellinger (490). Improvements including modification of propulsion controller/ power path, vehicle control algorithms enhancements, and components drivers' improvements enabling battery pack standby mode, as well as power optimization of other sensors in transit mode.

2.1.2. **Battery support and troubleshooting –** Klimov (20). Efforts include bring-up of new battery pack controllers; verification of battery pack stand-by / remote activation mode for purpose of energy saving; and magnetics components signature characterization as needed for navigation purposes.

2.2. Sensor Upgrades

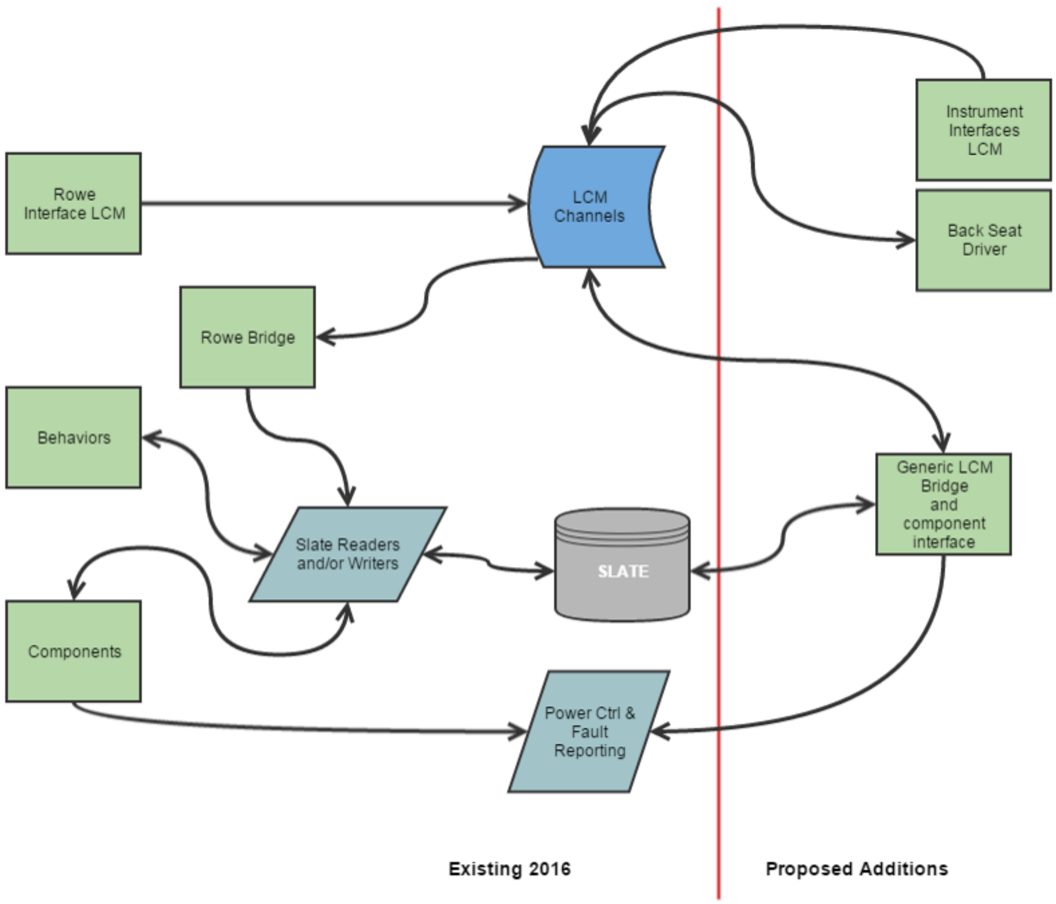
2.2.1. **Bathyphotometer payload integration –** Kieft (15), Erickson (120), MT (50), Machine Shop (50). Bioluminescence Assessment Tool (UBAT) from WetLABS is going to be installed into LRAUV forward wet bay. Efforts include design of bracketry/ mounting, design if the water intake, electrical integration consisting of 12V power path and serial port control; as well as appropriate software improvements.
(NOTE: Acquisition of WetLABS UBAT is budgeted elsewhere, or possibly is shared with the DMO AUV)

2.2.2. **Bioluminescence sensor for open propeller –** Erickson (180), Klimov (280), MT (25), ET (30), Machine Shop (30). Plans for 2017 integration of WetLABS UBAT bathyphotometer offers excellent opportunity of validation and calibration of a method of measuring bioluminescence on an open propeller potentially allowing continuous dusk-to-dawn measurement using vehicle propulsion energy. Two optical detectors are going to be combined into one compact pressure housing just forward of propeller, in order to pick up bioluminescence from the tips of the propeller blades in one channel, and background light from outside of the propeller in another channel, as a reference. The differential signal is going to be amplified and sent to appropriate LCB in LRAUV dry bay. To reduce material cost, the electrical interface of the bioluminescence sensor is going to be unified with existing PAR sensor as much as possible, so they could be used interchangeably.

2.3. **Data Architecture Middleware Implementation –** Stanway (200), O'Reilly (150)
Currently, components consist of the instrument interface and also handle power control, fault reporting, and writing to the slate (and occasionally reading if necessary). An LCM interface for the Rowe, Wetlabs, and CTDs exists and publishes data to various LCM channels. There is no power control or fault reporting from the LCM interface.

A Rowe bridge component was created based on the old Rowe driver. This bridge component invokes the LCM interface and also handles power and fault management. It subscribes to the LCM channel(s) and writes the instrument data to the slate.

<u>2017 proposed improvements for data architecture:</u>
Create the above architecture on the right-hand side of the red line. This architecture requires that new instruments have an LCM interface that publishes data expected by the LRAUV application. One could conceive the basic interface being written by an end user while MBARI engineering could supply the request for any specific data handling. However, many science related instruments won't require intervention from MBARI (e.g. a new brand of CTD) to create a new instrument interface. Configuration files will inform the generic LCM bridge component what channels to subscribe to and what to write to the slate. Basic power control and fault reporting will be provided via LCM channels. While this approach doesn't implement the entire LCM middleware as originally proposed, it does provide stakeholders with the basic ability to write their own interfaces. The foundation for an LCM driven backseat driver API would also be available.



2.4. **Wave Glider Towout –** Kieft (20), Erickson (168), MT (80)

For the initial demonstration of towing out, a towing behavior will be required to keep the vehicle at neutral buoyancy and to monitor depth. This behavior will be called by a mission and will rely on the acoustic watchdog functionality that's already implemented for extended neutral buoyancy drifting missions. Release will occur with human intervention from the waveglider in coordination with the acoustic watchdog.

2.5. **Acoustic Communications** – Stanway (350/20), Klimov (80)

The following section is a summary of the separate effort previously crafted under different proposal; and added here for purposes of project coordination.

Note: to be moved into 901605 if supported

This section describes details of 2 distinct applications for acoustic gear: (1) localization by means of detecting range and direction; and (2) acoustic channel data transfer. The appropriate combination of hardware, software, firmware, and software, is what we refer to as “toolkit” in the following text; as well as action plan for development under this section.

Localization toolkit:
The software components in the localization toolkit will be portable to other systems, in an effort to break the cycle of constantly “reinventing the wheel” every time another project needs to geolocate an asset by means of USBL, LBL, range-only, or direction-only measurements. We plan to achieve this portability by defining an interface based on the generalized observations required for each localization method, then writing each solver as a process or daemon with input and output handled by a well-defined open-source middleware like LCM. Since this will let us write the basic solvers once and use them many times, we should be able to move on to more sophisticated solvers that explicitly handle real-world challenges like changing soundspeed, multipath, measurement delay, and fusing observations from different platforms. This would also include moving from combining single measurements from a few asynchronous sensors (what we do now) to leveraging probabilistic frameworks like Kalman filters, information filters, particle filters, and pose graphs. These improvements will make tracking more robust in real-world field deployments. Some of these capabilities can be found in commercial systems (e.g., Sonardyne) but those systems are too bulky require too much power for our smaller unmanned assets. Other capabilities are still areas of active research, and not available in commercial systems (some versions of range-only or direction-only localization, one-way travel time localization, explicit delay treatment, etc.). We hope that by developing this localization toolkit in a modular fashion, we will produce a new open-source package that is useful to the larger oceanographic community.

Communication toolkit:
The software components of the communication toolkit will also be portable to other systems, and also be designed to handle input and output via an open-source middleware. We plan to leverage current work toward enabling acoustic communications in the LRAUV project, which is initially focused on the Benthos acoustic modem hardware and evaluating the open-source projects goby and DCCL.

Specific actions plan:

- Revisit Kalman filter solutions to acoustic localization with explicit delay treatment (Stanway, 2010 & Stanway, 2012), working toward including these in the localization toolkit.
- Coordinate with Wave Glider Hotspot project (901411) and external collaborators from SARTI on improved and automated range-only localization solvers. We plan to develop these first in postprocessing, but then incorporate them into the localization toolkit using defined interfaces.
- Survey and prioritize research directions for asynchronous sensor fusion applied to acoustic localization using probabilistic frameworks like Kalman filters, information filters, particle filter, and pose graphs.
- Coordinate with other projects – most notably Targeted Sampling by AUVs (901503) – to define message types that enable effective information transfer for

decision making, guidance, and coordination using minimal actual bytes (time for this task is requested under 901503).

Getting fix from external source into the platform internal navigation would need to be under main part of LRAUV project (Stanway - 20 hours). Zero-update style with max change (xx meters) would not be difficult. More correct probabilistic treatment would take more time. Incorporating external position aiding would be helpful for under ice, long-term drift.

2.6. **Configuration Streamlining** – Kieft (10), Stanway (10), Rueda (150)
Further improvements beyond what was basically accomplished last year include the ability for end users to easily alter the volume and type of data being sent to shore on a given communication channel.

2.7. **Resolve Outstanding JIRA Issues** – Kieft (50), Rueda (100)
Approximately 50 issues still remain open in JIRA that need to be completed in 2016. They have been recently reorganized and scoped to provide a more accurate estimate in the proposal. Some of the issues will be resolved in 2016 and this section only represents tasks that will carry over into 2017. To date, about 485 issues have been closed since 2009.

2.8. **Auto-Ballast –** Ranaan (90)
We propose that a behavior and mission be authored to allow for automatic ballasting and trimming of the vehicle at sea. Currently we are using a proof of concept mission level ballast and trim that is fairly inaccurate, takes much longer than necessary, and involves a human to actually make adjustments. The final behavior based ballast and trim will automate the process quickly and simply report to the end user what it has done. This should make for much easier ballast and trimming of vehicles in locations where users don't have a test tank

2.9. **Configuration Management Simplification** – Stanway (80)
GIT sub-repositories are currently cumbersome when it comes to tagging and building. We propose fixing these issues to allow for ease of use.

2.10. **Buoyancy System 300 meter upgrade –** Kieft (10), Erickson (120)
Upgrading the existing buoyancy system pump will allow for drifting down to 300m instead of being limited to 100m as the system is now. This will be particularly useful for areas of operation where the chlorophyll maximum is deeper (e.g. Hawaii). A minor change to the EZ Servo motor interface will also be needed.

3. Export to Non-expert Users

3.1. **Operational Enhancements**

3.1.1. Checklists and documentation – Kieft (30), Hobson (10), Stanway (30), Rueda (100)

The team's checklists have proven many times to catch what could be costly problems before they become issues. These checklists are currently stored in the dash interface and are in need of updating. Combined with automation of tasks (see below) we propose to update the checklists to maximize success for teams other than LRAUV who are operating vehicles.

3.1.2. Pre/Post deployment Automation – Kieft (30), Stanway (30), Rueda (60)

Much of the pre/post work of deployments is done by hand which is time consuming and tends to introduce errors. We propose to simplify this process by allowing the vehicle to run more of the checklists automatically. A new command will be required, as well as some minor automation code.

3.2. **Mission Planning and Alteration –** Kieft (50), Rueda (140)

We propose to build on the work of Carlos and his intern Elijah Meckler have done in 2016 regarding a Domain Specific Language (DSL), called "TethysL", to significantly improve the authoring of mission files so it is much more user-friendly and less error-prone. The scope of this prototype work will be broadened so the translation tool supports basic operators, incorporates all behaviors defined in the current schemas, as well as existing standalone commands and aggregate flags (e.g. sequence, progression, wait, etc). Also, along with improvements in error reporting and code assistance, the user interface will be enhanced and integrated with other LRAUV systems (TethysDash, FleetStatus) as deemed necessary and according to other overall planned LRAUV software work.

3.3. **Dash API Initial Requirements Definition –**Stanway (20), O'Reilly (170), Rueda (140)

Provide an API to a graphical front end mission planner that is being selected in 2016. Currently NEPTUS is being examined. The API would provide for basic command structure transmission to the vehicle for a select group of behaviors.

3.4. **Backseat Driver API –** Kieft (20), Stanway (20), Consultant time

To allow for the integration of standalone embedded targets for more complex data processing and instrument specific control we propose a limited application program interface (API) to allow supervised command and control of the vehicle. Similar to the Waveglider/Hotspot interface, we envision a standalone computer being able to ingest instrument data and command basic vehicle behaviors. Definition of the API will preferably be based on existing third party designs and only modified if necessary. The LRAUV software application will require implementation of this API which will preferably be LCM based. Specific commands and control variables will be routed to the applicable behaviors.

3.5. **MTBF and Data Plotting Automation –** Raanan (112)
Using output from STOQS, refine the existing suite of "quick plot" python scripts to offer more comprehensive plots. Implement the MTBF and runtime calculations on an automated run and publish schedule.

3.6. **Automated Compass Calibration** – Kieft (80)
We propose that a behavior and mission be authored for the at sea calibration of both PNI compasses. The primary will be via direct load control connection while the secondary will use pass-through communications via the ADCP.

4. Project Management

4.1. **Overhead for meetings, etc –** Kieft (75), Hobson (50), Mellinger (25), Erickson (25), Stanway (75), Klimov (25), ET (75), Rueda (50)
This task allocates time for weekly meetings, scheduling, etc. for the team.

4.2. **Contingency to respond to issues –** Kieft (50), Hobson (30), Stanway (50).
In addition to the many successes of 2016 the team also spent time responding to failures and newly discovered bugs. For example, Ben Raanan implemented a new onboard fault detection algorithm under ONR grant N00014-14-1-0199 which identified a problem with the mass shifter. Wear on the leadscrew caused backdrive at typical yo-yo angles and unintentionally changed the center of mass of the vehicle during flight. The fix involved a new mechanical design, a change to the software interface, and qualification of the new system.
While no specific issues can be listed here, the team anticipates responding to similar issues in 2017 (e.g. ground faults, control surface overloads, environmental alarms, communications failures, incident reports, etc.).

4.3. **Project Management –** Hobson (170)
This task covers general overhead related to project management and includes tasks like board updates, budget reviews, scheduling, etc.

Engineering/technology development

See above

Field programs (detail ship requirements/deployments/diver requirements)

See above

Isotope Usage
Project teams must provide details regarding any planned isotope use on shore, on ships, in the Sanctuary, etc. Please review the guidance on isotope usage at http://www.mbari.org/at-sea/cruise-planning/hazardous-materials/ and policy at

http://mww.mbari.org/safety/SafetyManual/Isotope_Use_Policy.pdf, and then provide details on plans below.

None

Specific deliverables

See above appropriate sections

Milestones (see personnel classification list)

2017 Project Start Date: 01/01/2017	**Milestone 1**	**Milestone 2**	**Milestone 3**	**Milestone 4**	**Milestone 5**	**Total Resources**[4] for each resource category for all milestones listed here
Milestone Date	**Category 1**	**Category 2**	**Category 3**	**Category 4**	**-**	
Milestone Description	**Category 1**	**Category 2**	**Category 3**	**Category 4**	**-**	
EE	**30**	**870**	**-**	**50**	**-**	**950**
SE	**270**	**1205**	**920**	**300**	**-**	**2695**
ME	**170**	**598**	**10**	**275**	**-**	**1053**
EE Tech		**30**		**75**	**-**	**105**
SE Tech					**-**	
ME Tech		**155**			**-**	**155**
Machine Shop		**80**			**-**	**80**
Research Specialist					**-**	**212 (Raanan)**
Divers					**-**	

Budget justification

Item	**Description**	**Cost**
1	Replacement pressure tube due to shark bite and corrosion	$8,000

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

2	Replacement endcaps due to corrosion	$11,000
3	Parts for construction of Waveglider tow out mechanism	$800
4	Components for in house bioluminescence sensor	$900
5	Instrument calibrations for 3 vehicles	$5,300
6	Iridium, Argos, and cellular airtime	$15,000
7	Miscellaneous spare parts for 3 vehicles	$12,000
8	Miscellaneous lab supplies	$4,000
9	Oceans IEEE Domestic	$630
10	Travel Domestic (Oceans ’17)	$2,665
	Total	**$60,295**

Project team

Brett Hobson (440 hrs) – PI and PM
Brian Kieft (620 hrs) – Primary SE and lead engineer
Jordan Stanway (1015 hrs) – Software
Carlos Rueda (740 hrs) – Software
Tom O’Reilly (320 hrs) – Software
Jon Erickson (613 hrs) – Primary ME
Paul Coenen (105 hrs) – Operations and lab support
Jim Schofield (155 hrs) – Mechanical maintenance, upgrade support
Ed Mellinger (545 hrs) – Primary EE
Denis Klimov (405 hrs) – Electrical
Ben Raanan (212 hrs) - Research

Project lab and office space requirements
In addition to any changes to current space usage, please also include anticipated office and lab needs for students, postdocs, collaborators, etc.

We plan to continue using the LRAUV lab space in B221 and B224 for the remaining year of this project.

Data storage requirements (see Todd Ruston for assistance)

200 GB/year

Data availability outside project team, uniqueness

Field experiment data will be accessible through ODSS (Oceanographic Decision Support System) and STOQS (Spatial Temporal Oceanographic Query System).

R/V *Paragon* Requests
If the project team will be requesting time for the R/V Paragon, please specify the operators in the group and provide estimates of their availability to operate the vessel.

Hobson, Kieft are available captains for this project.

Export Regulation
Does the project team anticipate any foreign collaborations or international travel? If so, please identify collaborators by name, institution, and country.

No

Does the project team plan or anticipate export controlled purchases, shipments, or transfers of items (e.g., research instruments, proprietary data, hand-carried tools or samples) outside the U.S. temporarily or permanently? If yes, please identify country or countries and indicate whether these items will remain under MBARI control while abroad or controlled by others. Will the items be exported to more than one country? Please include foreign collaborator information as described above.

No

Monterey Bay National Marine Sanctuary (MBNMS)

General Permit
Projects teams need to indicate if any work will be performed that is either: (1) currently authorized under our general permit; or (2) will require that we obtain authorization. The current permit can be viewed at http://mww.mbari.org/pco/permits/mbnms-2015-002_feb2015.pdf. Please see Mandy Allen for questions.

Is a permit with MBNMS required for your work?

Yes. LRAUV is covered under the existing MBNMS permit for 2017.

SESAs (General map)
*Projects will need to indicate whether or not work will be conducted within one of the Monterey Bay National Marine Sanctuary's Ecologically Significant Areas (SESAs). An interactive map can be found on the Sanctuary's SIMoN webpages at http://sanctuarysimon.org/maps/sesa/. (*Note: It may take a moment for the page to load, so please be patient. Also, if prompted for a login, hit “Cancel” and then you will be able to access page.*) To determine if your work will occur in a SESA, specific coordinates can be entered using the locator function (click on the red "target" button in the toolbar at the top of the map). If your work will be conducted in one of these areas, please indicate which area, by number.*

None

Authorizations/Permits from other Agencies or Organizations

Is the project team aware of any other permits or authorizations that will be necessary to perform the proposed work? If so, please list below along with status of authorizations (obtained, pending, need to apply, etc.). Please see Mandy Allen if you have questions.

None

Active Acoustics
We are compiling information on active acoustic use at MBARI. If the project involves using active acoustic instrumentation, please describe plans.

All acoustic devices listed below have been previously captured in the MBARI general acoustic asset spreadsheet listing details like SPL, etc. The LRAUV uses the following acoustic devices:

1.) 600 kHz ADCP (used constantly for navigation)
2.) 18 kHz acoustic modem (used occasionally for tracking)
3.) 29 kHz transponder (used to locate missing vehicle underwater if necessary)

Risk matrix (development and infrastructure projects only)

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