Development of a precision underwater positioner for in situ spectrographic applications

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ABSTRACT

MBARI has developed and deployed a precision underwater positioner for use with its laser Raman spectrometer (DORISS Deep Ocean Raman In Situ Spectrometer). The DORISS instrument is capable of obtaining chemical and structural information in situ from gaseous, liquid or solid targets in the deep ocean. However, when analyzing solid, opaque objects, the instrument probe head must be positioned with a precision of ~0.1 mm. Additionally, the probe head must be free of vibration and other motions induced by the ROV, and stable for tens of minutes for data acquisition.

The Precision Underwater Positioner (PUP) was developed as an off-loadable platform to meet the stringent positioning requirements of the DORISS instrument. The functional requirements call for a positioner that can be carried and deployed by an ROV; is off-loadable onto the seafloor to decouple the sensor head from ROV-induced motion or vibration; is stable on various types of seafloor terrain; incorporates a camera, lights, and crossing lasers to help with proper positioning; is controllable by a shipboard scientist via a GUI which provides position feedback; has variable speeds; and has a full range of 15 cm in each direction with a precision of 0.1 mm. While the PUP was designed to meet the needs of the DORISS instrument, it is a stand-alone system that can also be used with other sensors that require similar positioning requirements.

The Precision Underwater Positioner is 5 degree of freedom positioner on a tripod platform Z, R, q, and pan & tilt at the sensor head. Adjustable legs allow it to accommodate uneven seafloor. Phase I of the PUP consists of only 2 degrees of freedom (Z and R), and has rigid legs. It has been built, tank tested, and deployed on the seafloor (~175 m depth) for at-sea tests. This testing has verified that the PUP meets the stipulated requirements and is capable of providing the stability and positioning necessary to collect quality Raman spectra of solid and opaque targets on the seafloor (to depths as great as 4000 m).

FUNCTIONAL REQUIREMENTS

GENERAL REQUIREMENTS

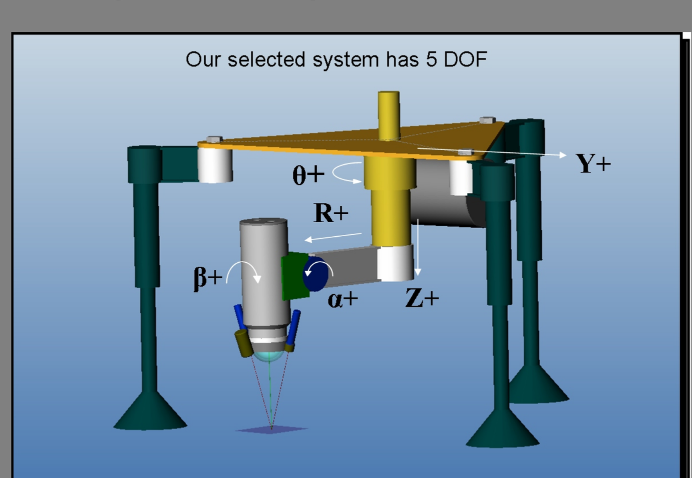
The PUP system:

Shall be capable of operating in stand-alone mode (in air or water) for in-lab use and testing
Shall be deployed on the seafloor by an ROV
Shall maintain stability over full range of motion
Shall accommodate uneven ocean floor (e.g. slopes up to 30 degrees), a variety of seafloor surfaces (e.g., rocks, sediment, mud) and a sensor head in either the horizontal or vertical orientation
Shall be placed in the appropriate location (with the sensor head facing the target) and such that the target is within the operational work space of the sensor head by the ROV manipulator
Shall have an external camera, lighting, and crossing lasers mounted to the sensor mount for positioning
Shall be controlled by a shipboard scientist via a GUI with position feedback
·May accommodate other (non-LRS) sensors

PERFORMANCE REQUIREMENTS

Minimum position travel of the beam spot (each dimension)	**15 cm**
Maximum travel increment of the beam spot (each dimension)	**0.1 m**
Maximum time to travel full range (each dimension)	**1 minute**
Relative precision (each dimension)	**0.1 mm**
Relative accuracy (each dimension)	**1 mm**
Pan and tilt range (for either horizontal or vertical orientation)	**+/- 45 degrees**
Maximum sensor weight allowed on mounting surface (in air)	**30 kg**
Maximum sensor size allowed on mounting surface	**60 x 20 x 20 cm**
Maximum weight of complete system (in air)	**100 kg**
Maximum stowed size (excluding drawer space)	**122 cm W x 61 cm H x 61 cm D**
Maximum available drawer space for stowage	**61 cm W x 30 cm H x 91 cm D**
Power	
Input power (Tiburon)	**240 VDC, 5 kW**
Input power (Ventana)	**110 VAC, 2 kW**
Environmental	
Operating depth	**4000 m**
Operating temperature (ambient)	**0 to 50 degrees C**
Operating current (water velocity)	**0 to 0.5 knots**

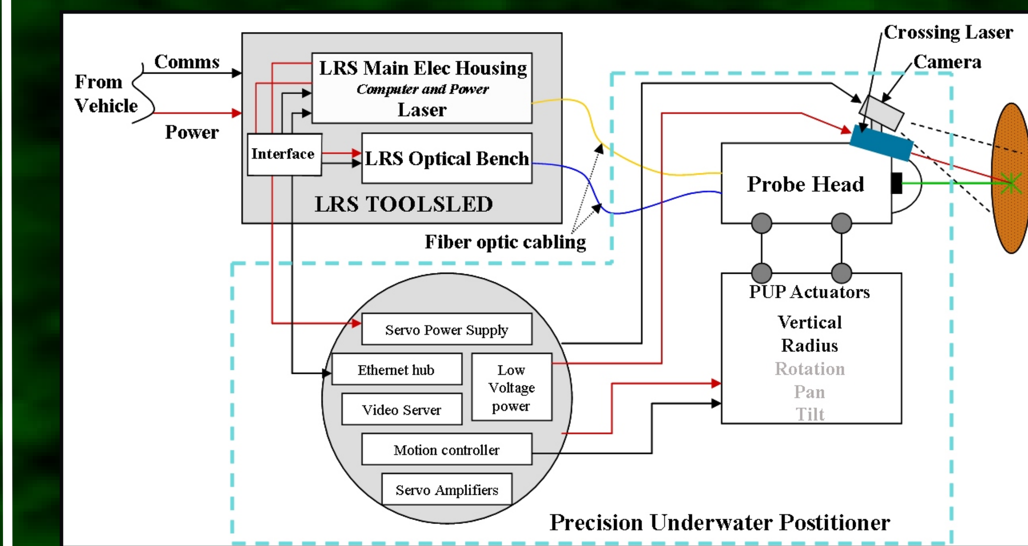
Design Concept



The PUP team looked at a variety of concepts that would satisfy the project's functional requirements including a purely XYZ system and a hexapod. Our selected concept was a 5 DOF system on a tripod base. Three axes (R, Z and q) would provide movement within the working envelope (see image at left). A pan and tilt device would allow the laser beam to be positioned at an optimal angle to the surface to provide maximum signal. A tripod base would provide stability, and adjustable legs would allow the PUP to accommodate an uneven sea- floor.

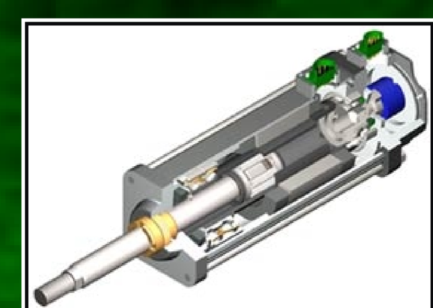
PUP Technical Specifications

The PUP system is primarily built around the LRS sensor requirements but it is also intended to be available for additional instruments. In-situ microscopic instrumentation, microscopic photography, and other applications have been included in the functional requirements. The concept of operations is developed from those requirements while also considering the platforms and limitations of the ROVs (*Ventana* and *Tiburon*) that will carry the system. The first concept priority is to keep the minimum number of wires and connections between the ROV toolsled and the PUP. The second priority is to minimize weight change effects to the ROV when the PUP is deployed.



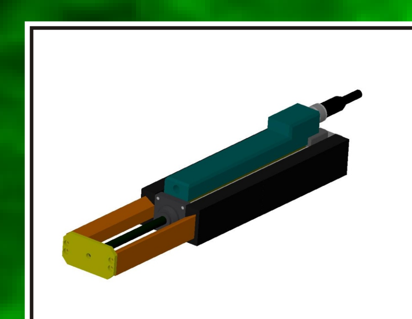
The PUP and LRS system are used as an integrated unit with a single connection to the ROV for power and communications. Two of the LRS pressure housings are mounted in the ROV toolsled, while the probe head is mounted on the PUP for off-loading from the ROV.

Due to resource and time constraints, the PUP will be built in incremental stages. Phase I will consist of a 2 degrees-of-freedom (R and Z axes) system with non-adjustable legs. All of the electronics for the full 5 degrees-of-freedom system will be installed. A color camera and crossing lasers are also a part of Phase I. This enables the PUP to be deployed on schedule for test dives in August 2003 and will provide additional capabilities for the LRS. Subsequent phases will include the addition of the remaining degrees-of-freedom, adjustable legs, and a cable management system for stand-off distances greater than 2 meters.

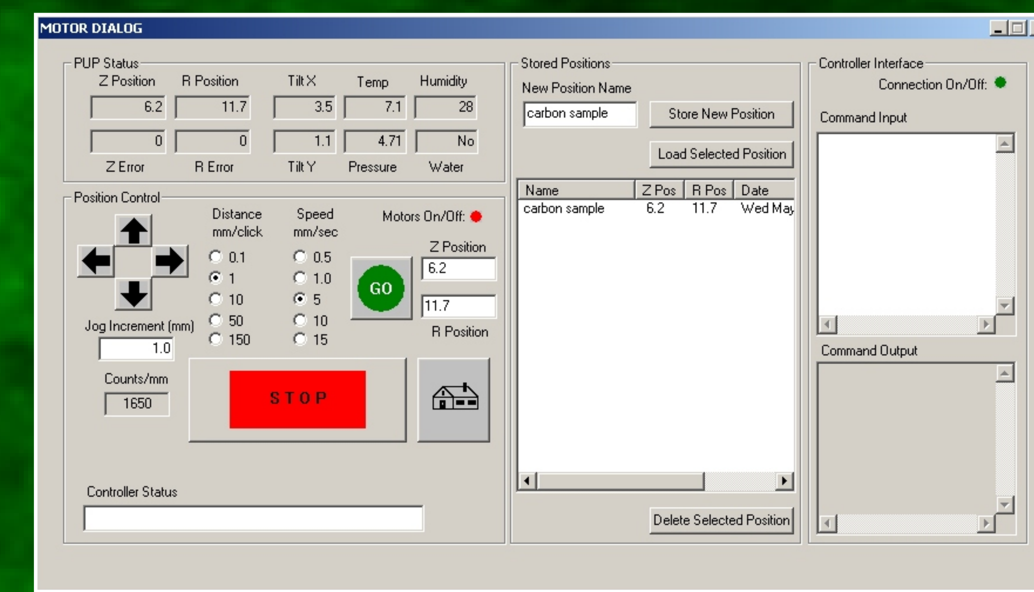


Linear actuators (*left*) from Exlar Corporation were modified for deep water (4000 meter) use. They are rated to exert a force of 1000 lbs. and have a travel distance of 20 cm.

Dovetail ways (*right*) are used to provide precision travel. The dovetails are mounted directly to the actuator housing which provides stiffness without adding weight.



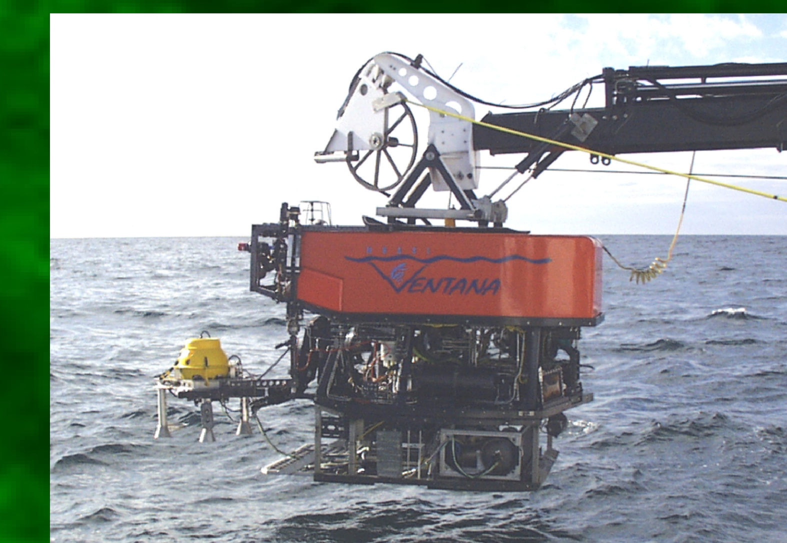
PUP Software Build

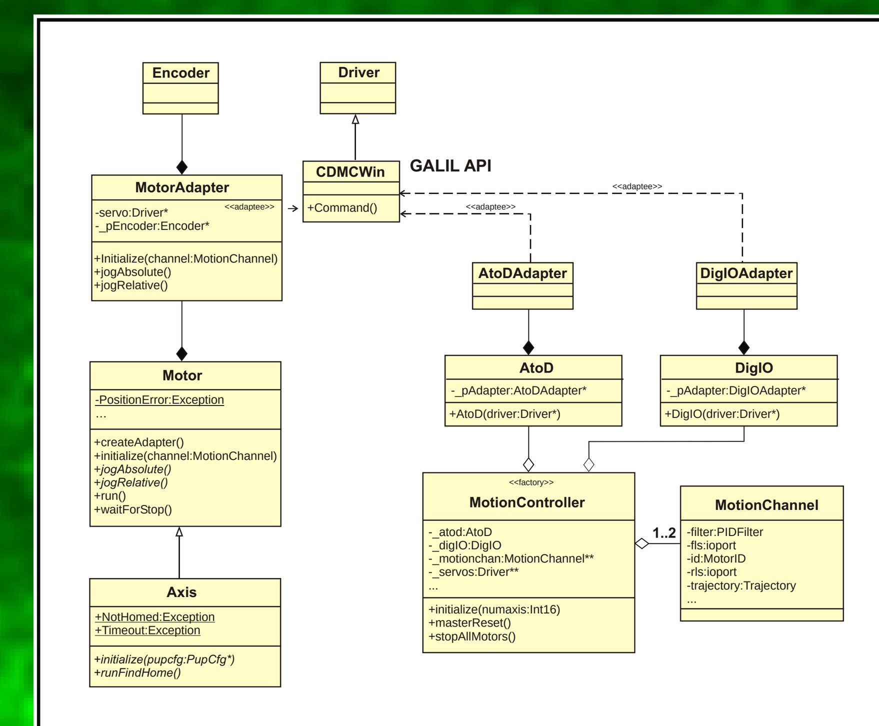


Above: PUP Graphical User Interface (GUI).

The graphical user interface (GUI) was designed to present all the motion control and critical data to the user in a single window. The controls available include moving to arbitrary and previously visited coordinates and moving in variable increments and motor speeds. After storing positions of interest by name, the user can return those positions simply by selecting the name from a list. Incremental control allows the scientist to step through a plane at step sizes of their choice. Variable speeds are useful when moving relatively long distances.

The data section displays critical data during a PUP mission. Current motor position is displayed along with environmental data such as temperature, relative humidity, and X-Y tilt angles.





Above: PUP software class diagram.

The motor control program was built re-using a successful design from the Environmental Sample Processor (ESP) project. Approximately 90% of the code for the PUP motor control was recycled from the ESP project. With a solid foundation of motor control code available, a more aggressive schedule for the PUP has been pursued.

Some of the GUI design style for the PUP interface has also been borrowed from ESP. In particular, the event loop used to poll for information was lifted directly from ESP. The "look-and-feel" of the PUP interface, however, is new and reflects the high level of interaction necessary during deployment (*see image at left*).

The PUP project leveraged off-the-shelf components to hasten development. Two purchases in particular, the motion controller board from Galil and the video server from Axis, helped to lower the software development time and cost for the project.

The Galil unit implements all the low-level motor control loops necessary to move the PUP actuators to a desired position. By relying on the Galil controller module, the software developers are able to concentrate on the system's required motions and not on how to control the motion actuators. The Axis video server provides a standard internet video feed that can be displayed directly on the PUP computer screen in any web browser (*see image at right*).

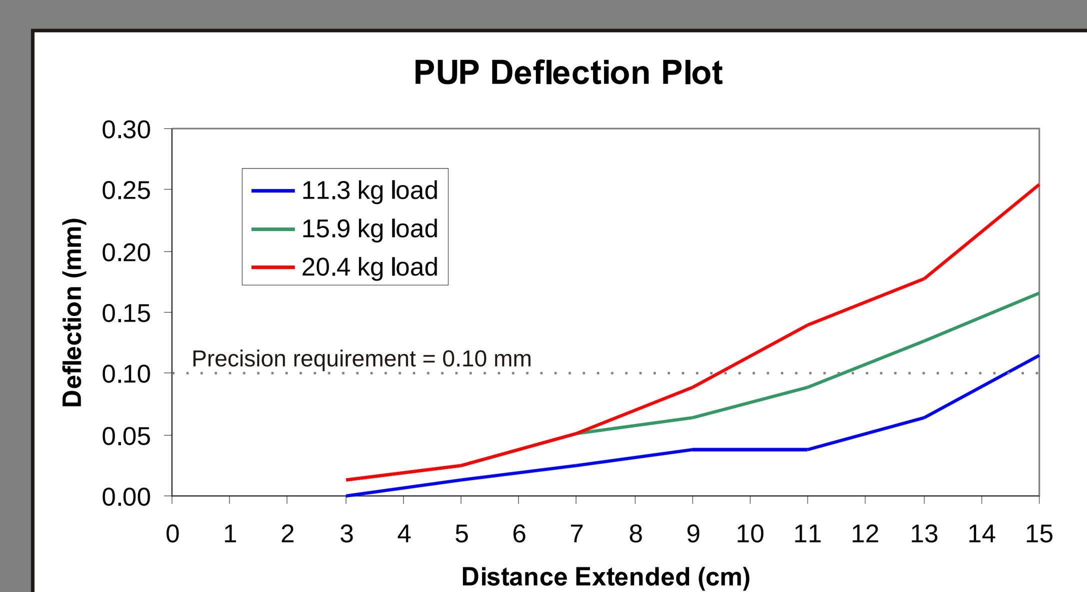
PUP TESTING

Sub-Assembly Testing (Load and Deflection)

The linear actuator required modifications to the "as-built" mechanism received from the vendor. One of the derived requirements was a stiff assembly capable of carrying the weight of the probe head and future improvements such as more degrees of freedom for the mechanism. This resulted in early prototype testing of the slide sub-assembly under various load conditions.

The load testing was conducted for 1 cm incremental extensions of the slide mechanism up to 15 cm (~5.9 inches). Loads were increased in 20 lb. (9.1 kg) increments from 25 to 85 lbs (11.3 kg and 38.5 kg, respectively). The data revealed a system that could be characterized linearly. For a 25 lb (11.3 kg) load (i.e., the weight of the LRS probe head in water), the deflection is within our precision requirement of 0.10 mm (*see figure below*).

Above: PUP Deflection test set-up.



CONCLUSIONS

A precision underwater positioner is necessary to obtain quality Raman spectra from solid, opaque targets on the seafloor. The incremental development approach the PUP team is taking will allow an early, reduced-feature system to be put into operation in the near future. This is will allow scientific progress to be made with the LRS and will provide important operational feedback to ensure a useful final product. The full 5 degrees-of-freedom system decided upon in the concept phase will greatly enhance the ability of the LRS to collect quality data from a variety of targets and deep-sea environments. Although, designed primarily for the Laser Raman Spectrometer, the PUP will be of use to any instrument requiring precise positioning.

ACKNOWLEDGEMENTS

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Background Image: The 532 nm green laser of the LRS illuminates a cube filled with natural gas hydrate from a deep-sea gas vent at Guaymas Basin during the 2003 MBARI Gulf of California Expedition.

Compiled by Karen A. Salamy and Sheri N. White for MBARI, December 2003