Precision Underwater Positioner (PUP) for the Laser Raman Spectrometer

Sheri N. White, William Kirkwood, Mark Brown, Scott Jensen, Rich Henthorn, Karen A. Salamy, Danelle Cline, Edward Peltzer and Peter Brewer

Monterey Bay Aquarium Research Institute, 7700 Sandholdt Road, Moss Landing, CA 95039

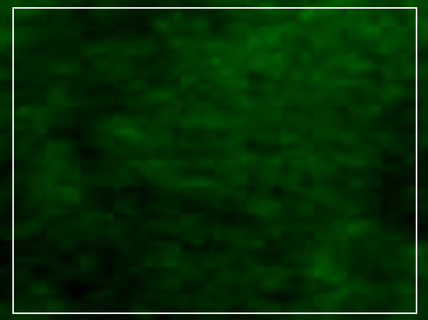
INTRODUCTION

A precision underwater positioner is needed for use with the MBARI Laser Raman Spectrometer (LRS). The LRS uses a 532 nm laser to excite a target of interest and analyzes the spectrum of the returned, Raman scattered light. This spectrum is a "fingerprint" of the chemical and molecular make-up of the target. Raman analysis is rapid, requires little to no sample preparation, is (generally) non-destructive, and can be used on solids, liquids and gases.

The spot size of the laser is less than 1 mm and the focal depth varies from 0.3 mm to 3 mm in water. Thus, precision positioning is required to obtain good quality spectra from the LRS on the seafloor. The two approaches to precision positioning are: 1) present the target to a stationary probe head, or 2) present the probe head to the stationary target. A key advantage of the LRS over other techniques is the ability to non-destructively analyze a specimen *in situ* without any sample preparation. In order to maintain the experimental flexibility that the LRS provides, the "positioning-the-probe-head" approach is favored.

Currently, the LRS probe head is positioned by the ROV manipulator (*see image below*). This is suitable for coarse positioning at transparent targets where focal point location is not as critical. However, the precise positioning required to obtain spectra from opaque targets can not be achieved by the ROV manipulator. Jitter of the manipulator and vibrations from the ROV also pose problems for the long exposure times often required. Thus, a mechanism is necessary to allow the probe head to be positioned precisely and to maintain position and stability over time.

Essentially the Precision Underwater Positioner (PUP) should be an ROV-deployable system that can mount a sensor head up to 30 kg in weight in either a horizontal or vertical orientation, and move it with a precision of 0.1 mm within a range of 15-20 cm in each axis. The PUP should be generic enough to support the LRS in various configurations and able to serve the needs of other types of instrumentation that may require precision positioning.



Above: The LRS probe head is positioned by the ROV *Tiburon*'s manipulator over a pool of liquid CO_2 at 3607 m depth during an April 2002 experiment in Monterey Bay.

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

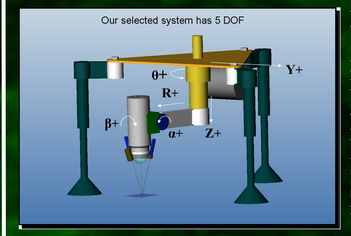
·May accommodate other (non-LRS) sensors

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**

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.

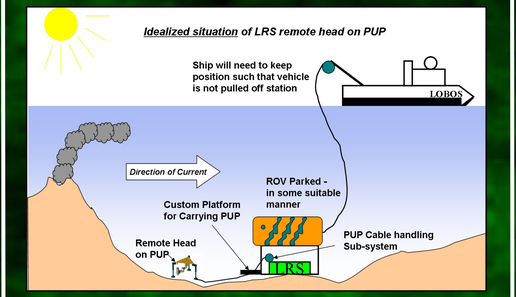
PUP CONCEPT



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 degree- of-freedom system on a tripod base. Three axes (R, Z and θ) 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.

Concept of Operations

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.



Operations Senario:

The PUP is outfitted with the instrument it will carry (the LRS is shown) and then carried on the front of the ROV. This is done as part of the mobilization effort and the system is then checked from end to end for proper operation.

As assessment of the weather conditions is made to determine if weather window, dive depth, and mission bottom time allow for enough margin to prevent the ROV from being pulled by its tether which in turn might topple the PUP. This is due to the two body problem of parking the PUP on the bottom while it is performing delicate science experiments. The PUP cannot jitter or be jostled at all during a Raman data acquisition.

The ROV is launched and carries the PUP along with the instrument to the selected scientific site.

The pilots determine the direction of the current and access the slope and bottom conditions. Coming to the site from the down current side the ROV is positioned within the robotic arms reach of the site. The ROV is landed and held in place by downward thrust.

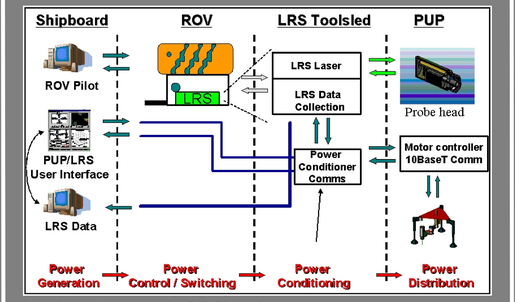
The PUP is lifted off of the carrying cradle and positioned over the site. While still holding on to the PUP, the pilots note the slope readout and determine if the slope is within the acceptable specifications. The PUP is released from the manipulator. The ROV moves back, letting the cable payout, approximately 3 to 5 meters.

The slope readout is monitored to be sure the PUP is not settling into the bottom and tipping. The system is given a final systems check and the lights are turned off in the case of the LRS application. The PUP then executes the mission per the science plan.

After concluding the mission the vehicle lights are turned back on. The ROV is moved back into manipulator distance and parked again on the bottom.

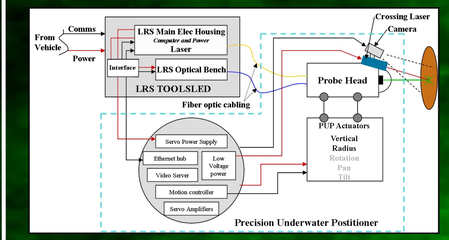
The PUP is put back into the stowed position (or home position) and is lifted by the manipulator back onto the carrying cradle. The cable is gently gathered back the manipulator using previously reinforced areas on the cable allowing the ROV manipulator to safely lift the tether.

The ROV transits to the surface and is recovered.



Above: Integrated system concept for PUP-LRS operations.

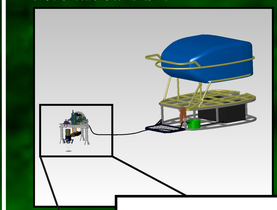
PUP BUILD

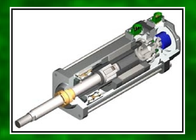


The PUP and LRS system are used as an integrated unit with a single connection to the ROV for power and communications. Two of the LRS pressure housings are mounted in the ROV toolsled, while the probe head is mounted on the PUP for off-loading from the ROV.

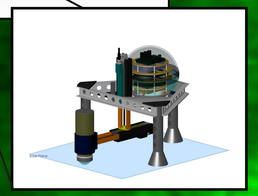
Due to resource and time constraints, the PUP will be built in incremental stages. Phase I will consist of a 2 degrees-of-freedom (R and Z axes) system with non-adjustable legs. All of the electronics for the full 5 degrees-of-freedom system will be installed. A color camera and crossing lasers are also 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.

Mechanical Build

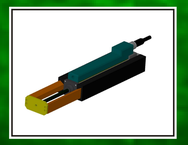




Linear actuators (*left*) from Exlar Corporation were modified for deep water (4000 meter) use. They are rated to exert a force of 1000 lbs. and have a travel distance of 20 cm.



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

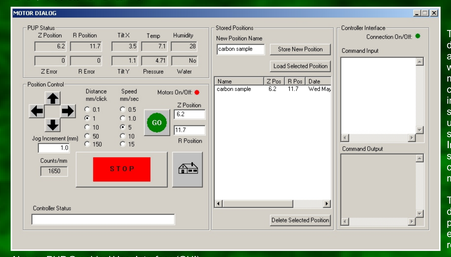


The glass instrument housing (*left*) is made from borosilicate material and rated for 6700m depth. A glass sphere was chosen over a titanium sphere or cylindrical housing due to weight constraints. The base stand is made from aluminum.

Above: Electrical Engineer Scott "Sparky" Jensen tests the integrated electronics.

Two crossing lasers and a color camera on the sensor mount (*right*) will assist users in positioning the probe head.

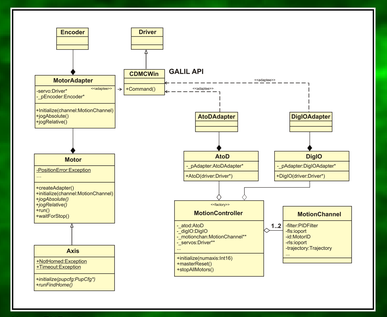
Software Build



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.



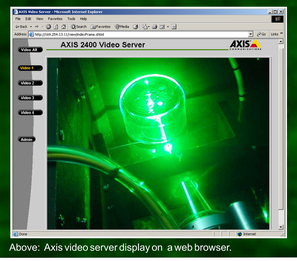
Above: PUP software class diagram.

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.

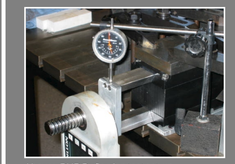
The Galil unit implements all the low-level motor control loops necessary to move the PUP actuators to a desired position. By relying on the Galil controller module, the software developers are able to concentrate on the system's required motions and not on how to control the motion actuators. The Axis 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*).



Above: Axis video server display on a web browser.

PUP TESTING

Above: John Ferreira (mechanical technician) testing deflection of PUP ways.

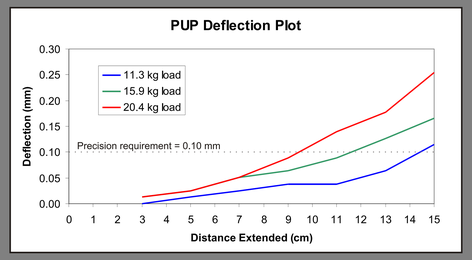


Above: PUP Deflection test set-up.

Sub-Assembly Testing (Load and Deflection)

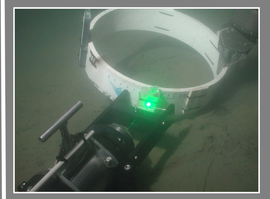
The linear actuator required modifications to the "as-built" mechanism received from the vendor. One of the derived requirements was a stiff assembly capable of carrying the weight of the probe head and future improvements such as more degrees of freedom for the mechanism. This resulted in early prototype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



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.



Left: A murky image of the ROV *Tiburon* manipulator positioning the LRS probe head to analyze a translucent rhomb of calcite at 663 meters water depth. The opaque minerals attached to the PVC corral could not be analyzed due to the lack of precision positioning.

Right: An off-loadable stand was developed to position the probe head over a mesh-topped funnel in which gas hydrates could be collected. This stand was used during the 2003 MBARI Gulf of California expedition. It proved useful, but highlighted the need for a more stable, positionable platform for the LRS probe head.

ACKNOWLEDGEMENTS

We would like to thank the David and Lucile Packard Foundation for their generosity in funding this project, Jill Pasteris (Washington University, St. Louis, MO) for her scientific contributions to PUP and Martin Lee of US Stepper for his consultation during the concept design process.

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