# Remotely Operated Vehicles for Restricted Access Hydrographic Surveys

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*The technological advancements in the field of ROV have greatly simplified the inspection process in complex environments. The article below enumerates the advantages of using ROV in performing sophisticated inspection in various fields. It kindles our thought process to find ways and means in which it can be adapted to inspection of complex pipelines.*

## Introduction

Over the last 10-15 years the ROV industry has enjoyed the benefit of a number of technological advancements that have enhanced the capability of smaller, inspection class ROVs. By understanding the potential benefits that these new technologies may provide their clients, a system operator can configure an inspection class ROV to perform survey tasks that were previously either unachievable or cost prohibitive. This paper does not attempt to suggest that inspection class ROVs can compete with the work class ROV for performing all but the most basic manual intervention tasks but rather attempts to highlight the unique capabilities and advantages of the well equipped inspection class ROV for performing sophisticated survey tasks.

The enhanced capability enjoyed by this class of ROV is of direct benefit to the Oil and Gas industry in a number of ways. Their relatively small size allows them to not only reach tight locations such as the interiors of downed platforms and other subsea structures that prohibit the use of large vehicles but when equipped with Inertial Navigation Systems (INS) they are able to perform detailed surveys in locations where acoustic positioning systems are not applicable. Relatively new technologies allow the inspection class ROV to perform sophisticated subsea survey tasks such as three dimensional modeling, high resolution multi-beam bathymetric surveys and high definition video surveys. In many cases these vehicles provide equal or better survey results then their larger cousins while bringing other benefits to the market including ease of mobilization and lower operational costs.

Specific advancements that the ROV industry has enjoyed over the last 15 years include the commercialization of DC-DC converter technology, fiber optic data transfer technology, magnetically coupled brushless DC thruster technology, the miniaturization of precise Inertial Navigation Systems and the marinization and miniaturization of high definition video cameras. These technological milestones have brought inspection class ROV's from being a somewhat useful but problematic shallow water tool to being an able sensor platform capable of being operated reliably in real world conditions and of delivering survey data of quality and density comparable to the best examples in the industry.

We have on a number of occasions been presented with scenarios which require that we push our inspection class ROV's capability to its extreme. By exploiting the available technology we have been able to set up our fiber optic inspection class ROV to meet our challenges and by doing so convert the relatively small size of the ROV from a liability into an advantage.

This paper describes three such examples and how technology has been exploited to enhance the ROV's capability to meet the challenges of the project. The paper suggests ways in which the lessons learned on these operations could benefit offshore oil and gas applications.

## Restricted Access Hydrographic Survey

Performing a hydrographic survey requires that a sensor, whether single beam echo sounder, multi-beam sonar or scanning sonar, be accurately positioned and its attitude measured in order to project the true position of the sensors return data points. Traditionally, such surveys are performed from the water surface from a vessel with the sensor transducer rigidly mounted to the vessel's hull or deployed from a pole over the vessel's side. The absolute position of the transducer is measured (typically with some form of DGPS device) along with the vessel's heading, pitch and roll. Being rigidly mounted to the vessel, the vessel's heading, pitch and roll are transferred directly to the sensor head. All these data are recorded and processed in real time using sonar data acquisition software in order to position each sonar or echo sounder data point in space.

Though the use of acoustic positioning is accepted and used by the onshore and offshore underwater intervention community as a means of projecting DGPS resolved geographical positions into the underwater space, such positioning methods assume a free path for acoustic signals between the roving transponder or responder mounted on the ROV and either a surface transducer (in the case of Ultra Short Base Line (USBL) acoustic positioning) or to other bottom transponders (in the case of Long Base Line (LBL) acoustic positioning). This requirement for a direct path for the acoustic beam prohibits the use of acoustic positioning systems in restricted areas where no direct line-of-site to reference beacons is possible. At times the environment is such that multipath issues prevent the successful use of these technologies.

One of our major clients was presented with such an environment when tasked to perform draft surveys under two decommissioned aircraft carriers, USS Saratoga and USS Forestall both moored in Newport Harbor, Rhode Island. The client proposed to adapt the use of the CDL MiniPos Tunnel Mapping System to provide the required position and attitude of a relatively small, inspection class ROV under the carriers which would then be used to deploy a 360 deg scanning profiling sonar and so provide a 3-dimensional model of both the underside of the aircraft carrier and the seabed terrain directly below the vessels hull.

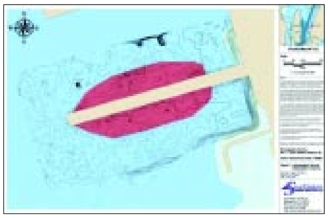
The CDL Mini-Pos Inertial Navigation System provides dead reckoned positions relative to a pre-surveyed start point by taking linear accelerations and performing a double integration computation in order to resolve displacement (acceleration integrated once provides velocity, velocity integrated again provides displacement). Deployed in a custom chassis bolted to the bottom of the ROV, the MiniPos INS not only provides a tight, absolute position but also provides accurate vehicle attitude (heading, pitch and roll) needed to resolve the absolute position of the sonar returns.

**Seaeye Falcon DR equipped with an under slung survey skid. The survey skid was custom designed to accommodate the CDL MiniPos Inertial Navigation System as well as a RDI Doppler sonar. Other equipment included a 360 degree scanning profiling sonar and a forward looking obstacle avoidance sonar.**

Other equipment deployed and fed into a Kalman filter in support of the INS derived dead reckoned position was a bottom tracking Doppler Sonar and a precision depth sensor. The Doppler sonar was used to provide constant velocities and thus reduce the tendency for position drift inherent in INS dead reckoned position solutions over time. The precision depth sensor provided depth which provided a constantly updated vertical component to the solution when corrected for tide.

ROV set up near the stern of the USS Forrestal. Heavy weather mooring lines and the hull itself prevented the survey of the bottom under the carrier using a surface vessel.

Thus equipped with real-time absolute position in space and accurate attitude, the ROV becomes much like the vessel working on the water surface. By mounting a 360 degree scanning profiler onto the ROV we were able to resolve absolute positions for the profiler data points. When the profiler shot down we recorded the bottom bathymetry, when the sonar shot up we recorded the underside of the aircraft carriers hull. Altogether, we were provided with a 3 dimensional "point cloud" model the space below the hull of the carriers.



The vessel-based hydrographic survey at Pier 1 Naval Station Newport, was used to develop 1-ftelevation contours in the berths surrounding the pier. The area in red represents the footprints in both berths where the aircraft carriers or their mooring hardware restricted access by the survey vessel (image courtesy SeaVision Marine, LLC).

As a primary requirement of this effort was to provide accurate bathymetry of the berth spaces, in addition to using the profiling sonar data, we also recorded elevations using the elevation feature of the Doppler sonar and added this elevation to the depth derived using the precision depth sensor. This provided the equivalent of a single beam echo sounder survey and was used to generate charts of the berthing space.

The actual survey was performed by accurately positioning a sunken deployment cage at the end of the pier by use of RTK DGPS and a plumb bob. The ROV was parked in the deployment cage and the INS was allowed to settle on that position. Once settled, the ROV was flown out of the cage and proceeded to make runs back and forth longitudinally and laterally along the length and breadth of each ship's berth. Once the survey of each berth was complete the ROV was returned to the garage where its position was checked to ensure that no gross degradation in position had occurred.

## Navigation in Virtual Space

Navigating a ROV in low visibility is never an easy activity but when the space in which you are operating is a recently flooded mine, cluttered with debris and equipment some 1600ft below surface and there is no hope for rescue in the event of entanglement, the need to know one's position relative to surrounding obstructions and to know that position in real-time is all the more urgent.

So, in October 2006, when the uranium mining company Cameco suffered a roof cave-in in their Cigar Lake mine in Northern Saskatchewan, resulting in the mine flooding, we were presented with an opportunity to again demonstrate the MiniPos INS system when we were subcontracted by Nuytco Research to support them with providing Cameco with flood re-habilitation services.

The mine had been designed to contain such a flooding event with the installation of two 12 foot diameter high-pressure bulkhead doors located within the shaft so that when closed they would isolate the mine's ore body area from the mill/production facility area, allowing the mine to flood, but positioned so to protect the mill/production assets. During evacuation, one door was closed successfully but the other failed to seal despite heroic efforts on the part of the miners concerned to make it do so. After several attempts and with frigid water flooding through the door and increasing in volume at an alarming rate, it became apparent that the door was not going to able to be closed in the given time. Reluctantly, the miners, with water at thigh level, took the last 1600ft elevator ride to the surface loosing the entire mine until such time as the leak could be stopped and the mine dewatered and rehabilitated.

Part of the rehabilitation effort required that we demonstrate the ability to robotically access the failed bulkhead door and assess the feasibility of robotically sealing and closing the door. Nuytco Research contracted SeaView Systems, Inc to provide our Seaeye Falcon DR ROV. Together the two companies took a 'white paper" development approach with the only restriction to the problem being the state-of-the-art of applicable underwater technology.

As visibility was expected to be near zero, the need for accurate navigation and the best available real-time remote imaging equipment was identified as being a critical requirement for the successful completion of the project.

Having had earlier experience with deploying guided Inertial Navigation Systems on the ROV during the aircraft carrier Restricted Access Hydrograpic Survey described earlier, we recommended that the ROV be positioned using a CDL Minipos INS system.

Other identified equipment was a Didson imaging multibeam sonar, RDI Doppler Velocity Log, CDL Minipulse profiling sonar, Imagenex 881a imaging sonar, two Outland Technology P&T cameras and two 150W DSPL halogen lamps to be deployed in addition to the standard low light Seaeye Camera.

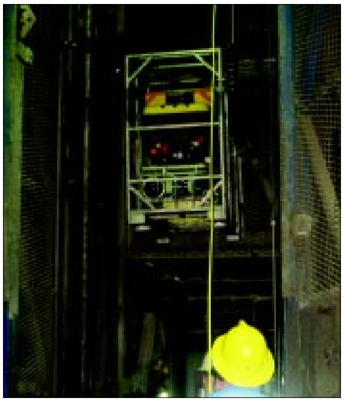
Due to the low visibility, it was necessary that a means of navigating the ROV be developed that would not only position the ROV real-time but also provide an expedient

**Seaeye Falcon DR configured for operation in the Cigar Lake mine. Note CDL minipos and RDI Doppler sonar mounted on survey skid. Also on skid are two Outland Technologies Pan and Tilt cameras and CDL Minipulse profiling sonar. Mounted directly below the center camera is a Didson Multibeam imaging sonar on a platform mechanically slaved to the center camera. Note additional syntactic foam blocks fitted to maintain neutral buoyancy.**

means of mapping any debris or obstructions as they were identified in order to minimize the risk of entrapment. To this end, using Hypac software our client built a virtual 3-dimensional model of the mine system based on drawings provided by Cameco. Within this model, a basic model of the Falcon DR was placed and fed the model with position information derived from the CDL Minipos. Using this information, the ROV was to be flown through the virtual space much like a video game, using sonar primarily for obstacle avoidance and tunnel mapping duties. The deliverable product to the customer would potentially be an updated 3D model of the mine showing it as it exists now complete with geo-reference features such as implements, tool boxes and other solid debris.

The mission was to dive the ROV in its deployment cage to 1600ft, fly straight out 100ft, turn right and travel a further 250ft recording profiling sonar data all the while. Accomplishing this required that the ROV negotiate past a Bobcat skid steer tractor, a number of cables, pipelines and other infrastructure hanging from the tunnels roof, and finally maneuver past a scoop loader (low profile tractor used in mines) that the miners had been using to try to pull the bulkhead door shut immediately prior to evacuation from the flooding mine. Finally, the ROV was to take a video survey of the bulkhead door which, due to the poor visibility, required that the camera be positioned very close to the door and associated slings.

The Falcon DR was lowered in its cage to the mine drift some 1600ft below the surface where the INS was given the final position from where it would dead reckon throughout the investigation. Visibility at this point was in the order of 2 feet. Leaving the cage, it soon became apparent that the 3D virtual guidance was a great aid to the pilot and lived up to its promise in allowing the mission to be flown in virtual space as the ROV traveled in real space. The navigation and obstacle avoidance was complimented by the three sonars including the Didson multibeam imaging sonar also carried aboard the ROV.



The Falcon in deployment cage about to be lowered into the 1600ft vertical shaft.

The most important achievement of this project was the demonstration that a small vehicle fitted with a very dense suite of survey equipment and operated by a suitably qualified operational crew, was capable of operating in virtual space in order to reach its objective and once there was able to perform work.

Air freight-able lifting umbilical winch fitted with 4200ft of Kevlar reinforced umbilical cable. Photo also shows 24" sheave wheel which when fitted with a strain sensor provides feedback to winch control processor to provide heave compensation capability.

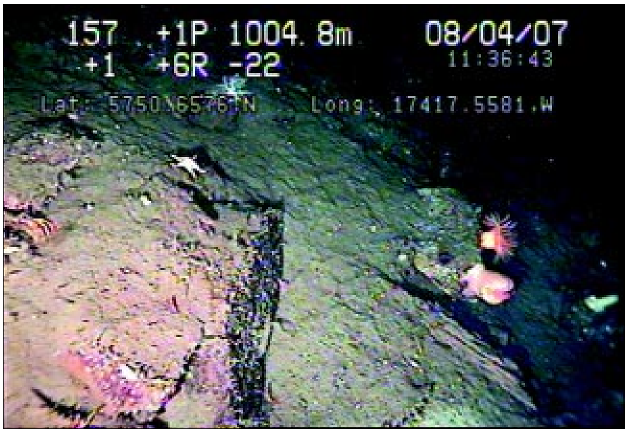
## Fly-away 1000M Deployable Vehicle

In the past, the ability to deploy a vehicle to depths of up to 3300ft has meant the deployment of an armored umbilical and lifting umbilical winch. This equipment often represents more then 4 times the mass of the ROV itself. This hefty equipment results in prohibitively expensive mobilization costs limiting the type of projects that a deep water vehicle can be considered for. The added mass may also limit the size of vessel of opportunity onto which the equipment may be safely mobilized.

In order to work around the problem of excessive mobilization costs and deployment weight, SeaView has developed a lifting umbilical winch system that uses umbilical with a relatively light Kevlar strength member rather then wire armor.

It is of no help to the customer if, after all the cost and effort undertaken to mobilize a system onto location, the ROV is still unusable due to an overly narrow weather window. In an attempt to widen this operational weather window, we developed a heave compensation winch system that renders and retrieves umbilical in response to strain experienced by the umbilical during dive operations.

Operations are performed by using a folding hydraulic A-frame and lifting umbilical winch assembly to lower the ROV in its deployment garage to within approx 30ft of seabed or the target working depth. Once at the optimum depth, the system measures a strain gauge embedded into the overboard sheave wheel. This strain signal drives a powerful servo system to either render cable to reduce umbilical strain such as when the vessel rolls away from the deployment side or to retrieve umbilical as the vessel rolls




**This image is a screen shot taken from video recorded with a Seaeye Falcon DR ROV. The video was recorded on a 2007 science research project. Note the video overlay showing water depth of 1004.8 meters (3293ft).**

towards the deployment side. The degree of retrieval is governed in order to keep the garage close to its optimum altitude above seabed. By working the winch in this dynamic manner, the mass experienced on the umbilical caused by ship generated accelerations is minimized leaving the umbilical to only experience the relatively low mass of the deployment garage and ballast.

This system not only allows for minimal mobilization costs and more tolerance to heave and roll but also allows more ballast to be attached to the deployment garage which helps to keep the garage plumb from the vessel when working at depth in moderate currents.

## Future Applications for Oil and Gas

When combined together, the technologies that we have demonstrated in the projects above; INS systems, multibeam sonars, deploying to depths of 3300ft and innovative data acquisition and display methods, we believe that the inspection class ROV represents an often under exploited option to offshore Oil and Gas operations.

The following list highlights some applications in which the methods and equipment discussed in this document could be directly adapted to provide cost effective solutions to Oil and Gas survey challenges:

- Performing high resolution multibeam site surveys
- Spool-piece metrology using Inertial Navigation Systems
- Pre-lay multibeam bathymetric route surveys and as-laid surveys
- Debris field mapping (especially in low visibility situations)
- 3 dimensional modeling of downed platforms and other subsea assets
- High Definition video pipeline surveys
- Multibeam pipeline surveys

## Conclusion

In the three case studies discussed in this paper we have describe how the fiber optic inspection class ROV, properly equipped and operated, presents a very capable, reliable and cost effective sensor deployment package.

The advent of DC-DC converters, fiber optic video and data transmission, magnetically coupled brushless thrusters, Inertial Navigation Systems, computer aided systems control and sophisticated data acquisition and display software has empowered the inspection class ROV to demonstrate comparable, and in many cases superior, survey capabilities to many more traditional ROV systems.

The case studies described here are just a small sample of the ways in which innovative exploitation of commercially available technology may be used to enhance the capability of relatively in-expensive ROVs in order to lower operational costs while providing the end user with superior survey products.

## Acknowledgements

Special thanks to:

Mr. Jeff Snyder of SeaVision Marine, LLC for the use of the bathymetry chart of the Newport Naval Station.

Michael Reay and David Porter at Nuytco Research, LTD, for their excellent project management of the Cigar Lake investigation project.

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Matthew Cook was originally trained as a Weapons Systems Engineering Technician by the Royal Australian Navy. Upon leaving the Navy in 1991, Matthew entered the offshore oil and gas industry, working first as a seismic survey navigator and then moving into the ROV industry in 1993. He has worked throughout South East Asia, the North Sea, and the Gulf of Mexico. In 2003, Matthew left the offshore industry to start his own business, SeaView Systems, Inc. based in Michigan, USA. Through SeaView, Matthew has developed several small, fiber optic ROV systems as well as other associated electro-mechanical systems and software.