SeaView Systems delivers paper at UI2004

During Underwater Intervention '04 in New Orleans, SeaView Systems' president Matthew Cook presented the following paper during the technical sessions.

Technical and Operational Considerations for Long Distance Pipeline Inspection

1 INTRODUCTION

With much of the potable water and sewer infrastructure that was installed in early 1900's throughout the Western world coming to the end of its working life, there is a large and growing demand for pipeline and tunnel inspection. While many alternatives already exist for short and medium distance (0-300m) vehicle inspections (both free swimming ROV's and crawlers), there are currently few systems able to perform long distance penetrations through pipelines of less then 24" I.D.

This growing application for ROV technology requires the ability to perform very deep penetrations through restricted passages in shallow to moderate depths. This new demand requires a re-think of the ways in which we design and configure ROV's and the umbilicals that support them. Of equal importance is the way in which we present the recorded data and video to the client. For this paper, such vehicles will be described as Long Distance Remotely Operated Vehicles (LDROV's).

2 REVIEW OF PIPELINE INSPECTION DEMAND

The next time you open a faucet in order to drink, cook or wash you might take a moment to consider how that water comes to arrive at your tap. We are all generally aware that much of the Western worlds water flows through a network of underground tunnels and pipelines. In that network are reservoirs, various pumping and filtering stations as well as thousands of miles of buried pipeline. What might be less apparent is that in many cases the very pipeline that carries the water from the reservoir to your glass may be upwards of 100 years old and rapidly approaching the end of its working life.

In the American Water Works Association study "Dawn of the replacement era" the author extrapolates from a study of 20 utilities that project expenditures in the order of $250 billion will be required over the next 30 years. This estimated figure is for potable water only. In addition to this demand that could reach a cost of $10,000 per household (in today's dollars) the water utilities are also required to meet new regulations imposed by the Safe Drinking Water Act.

This all ads up to a great deal of pipeline work and therefore pipeline inspection.

3 CONSIDERATIONS AND OPTIONS FOR LONG DISTANCE EXCURSION OPERATIONS.

Before getting into specific inspection techniques we should consider what the client who is sponsoring the project requires.

Project parameters may be:

- Depth of sedimentation or debris
- Existence of blockages/restrictions
- Location of cracks/leaks
- Effects of corrosion
- Pipeline out-of-round
- Buckling
- Degradation of surrounding support.

Depending on client requirement and budget, these parameters need to be accurately videoed, measured and processed in a timely manner and displayed in a format that allows the engineer to make informed decisions as to what and how rehabilitation should proceed. It is up to the underwater vehicle developer to consider these needs when working up a design for a LDROV or AUV. The operator must not only provide the means of getting the sensor package to the site but also anticipate the needs of the client and ensure that the data will be recorded and presented in a useful manner.

There are currently three basic techniques for penetrating pipeline to any considerable depth: using a free swimming ROV, a crawling vehicle or Automated Underwater Vehicle (AUV).

3.1 TYPES OF INSPECTION VEHICLE

The first two vehicles discussed below are defined as ROV's by the fact that they are controlled from some remote location. The third type of vehicle, the AUV carries any control functionality within its body.

Each of these platforms may carry such sensors as:

- High resolution cameras
- SIT cameras
- Sonic scanning profilers
- Sonic scanning imaging sonar's
- Laser profilers
- Ultra sonic thickness sensors
- Corrosion probes
- Turbidity sensors
- Sample collectors
- Leak detectors
- Sub Bottom profilers
- Range Gated Cameras

3.1.1 FREE SWIMMING ROV:

- First and most obvious is that in order to operate, a free swimming ROV needs to be submerged in water.
- Able to be operated over sediment minimizing any disturbance during inspection.
- Able to be maneuvered through tight, narrow restrictions such as butterfly valves.

3.1.2 CRAWLING ROV:

- Able to operate in flooded, partially flooded and drained pipelines.
- Able to exert very large pull in order to overcome the large drag experienced on umbilical when traversing drained pipelines.
- Unable to easily maneuver through vertical restrictions such as butterfly valves.

3.1.3 AUTOMATED UNDERWATER VEHICLE (AUV)

Until such time as a means of transmitting large bandwidths of data through water can be devised (and much research is being done on this subject) the use of AUV's will be limited to capturing data and then reviewing it post-mission. Options available today range from simply sending a neutrally buoyant camera down a line through to actively controlled vehicles capable of self-centering and recording large amounts of varied data.

The advantage of using a simple, float-through technique for video recording is that the general condition of the pipeline can be assessed at low cost.

The disadvantages of this method are an inability to review points of concern in greater detail, inability to closely locate features, that a floating housing provides and unsteady sensor platform and the possibility of the instrument fouling and causing a blockage.

3.2 TELEMETRY AND DATA HANDLING

In order for all of the sensors described above to be of use, and for the LDROV to be controlled, there must be a means of accessing the large quantities of data that the sensors generate in real-time.

With earlier solutions, these services have been performed with coax and shielded twisted pairs of light copper conductors. With very long distance penetrations however, this method becomes problematic due to the large diameter of umbilical required to contain all of the necessary conductors as well as limitations in data quantity due to bandwidth restrictions.

Underwater intervention technology has benefited immensely with the coming of the information age and today very small and compact fiber optic multiplexers allow all the data that one might ever need to transmit to be handled on one, very small diameter fiber.

3.3 POWER HANDLING

Unlike the ROV's performing the very deep dives that have been done to date which also require long umbilicals, the pipeline inspection ROV does not have the luxury of space. In order to access the pipelines that need to be inspected, the LDROV must be small and compact. When it comes to umbilicals, less is more.

The problem is how best to get the necessary power to the propulsion system and sensors demanding it.

Broken into their most basic elements the options available are to either carry the power onboard in a form of stored energy or to transmit the energy in an umbilical as either electrical or some other easily converted form of energy.

Of the stored power versions some that have been explored especially within the AUV industry are various electrical batteries and hydrogen fuel cells. Stored power methods have the advantage of requiring only an umbilical capable of transmitting control telemetry, data and video to/from the surface. This could be performed by a very small diameter fiber optic umbilical. The problems that these methods present to LDROV operation are complexity of design, necessary size of vehicle to accommodate the stored energy and a potential hazard to water and infrastructure in the event of equipment failure (ie contamination or explosion).

Transmission of energy in the form of electricity is the simplest and most supported by industry in general. The means of transmission is either in the form of AC or DC power each with its advantages and disadvantages. Whichever method is used, in order for the transmission to be understood a quick overview of Ohms Law and some power formula needs to take place.

OHMS LAW : $V=IR$

Where:

V = Electromotive force (Volts)

I = Electrical Current (Amperes)

R = Electrical Resistance (Ohms)

DC POWER FORMULA:: $P = VI$

Where:

P = Power (Watts)

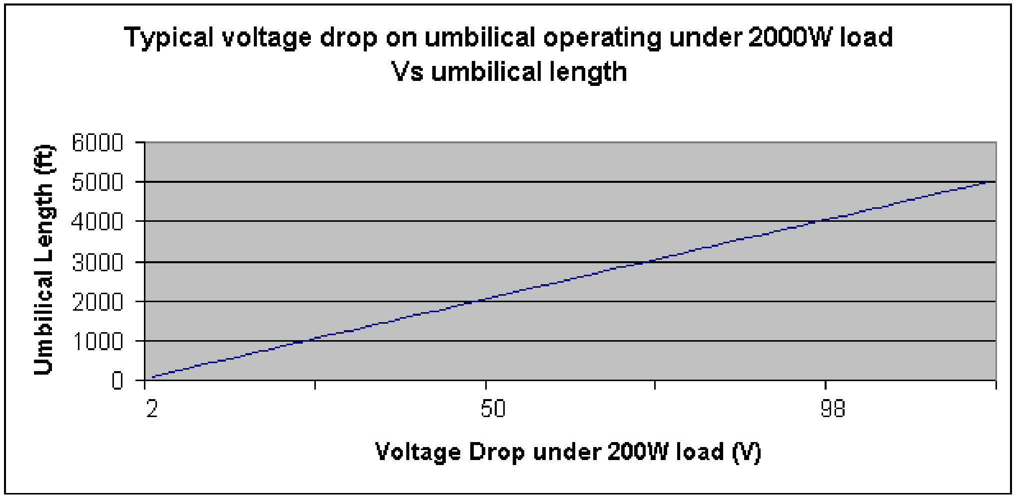
V = Electromotive Force (Volts)

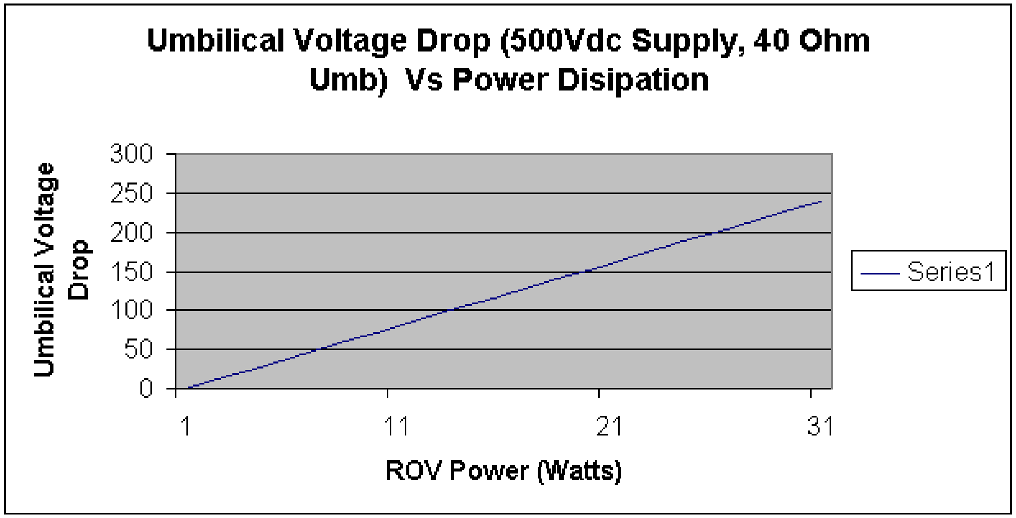
I = Electrical Current (Amperes)

Ohms law and the DC power formula both come into play in understanding voltage drop across a long umbilical.

What these formula tell us is that for a given surface voltage, the voltage drop across an umbilical will be proportional to the power dissipated by the load.

In real terms for an ROV operator this means, double the command on the joystick and you double your voltage drop over the umbilical.





3.3.1 ELECTRICAL POWER TRANSMISSION THROUGH UMBILICAL

In order to capitalize on the fact that we now have the capacity to handle all of our data on a fiber optic line, if we are to use electrical power transmission lines in an umbilical, they should be engineered to be correspondingly small and light. This means using small power conductors that in turn result in relatively high internal resistance in the umbilical.

3.3.1.1 ALTERNATING CURRENT

Alternating current is a common choice for ROV power transmission partly due to the simplicity in which the voltage can be stepped up and down.

The disadvantage of using AC power in a LDROV however is that transformers prove to be too bulky in the LDROV requiring switching power converters be used to step down voltages to usable levels. While by no means impossible, this option is not generally an off-the-shelf item and would require a sophisticated switch mode power supply be developed specifically for the application.

3.3.1.2 DIRECT CURRENT

There is a wide range of DC-DC converters available on the market today. These devices typically have quite tolerant input characteristics. DC power transmission is a simple compact choice for power transmission.

3.3.2 DEALING WITH VOLTAGE DROP

Common to these two methods of electrical power transmission is the concept that higher transmission voltages will facilitate the distribution of higher power for a given conductor size. The limiting factor is the maximum voltage capacity of the conductor's insulation.

3.3.2.1 POWER TRANSMISSION FOR STEADY LOAD

Given a constant load, long distance power transmission is relatively simple: The designer need only set the surface supply voltage to the required load voltage plus the known umbilical voltage drop and the job is complete.

3.3.2.2 POWER TRANSMISSION FOR VARYING LOAD

The issue becomes more complicated when one considers that the load of a LDROV constantly varies as the thrusters or tracks are driven, lights are dimmed and sensors are operated.

The LDROV requires that either the surface voltage be varied to compensate for the swing in umbilical voltage drop or the front-end power supply on the LDROV be designed to handle very large voltage swings.

There are a number of ways that this situation can be handled:

- Use negative feedback from a sensor on the LDROV to control the output voltage of the surface supply.
- Use an algorithm to directly control the surface supply based on instantaneous current demand.
- Use a front-end power supply in the LDROV with a large enough tolerance to the variation in input voltage to accommodate the voltage swings anticipated in the umbilical during normal operation.
- Use a power-sinking device to provide a constant load on the umbilical. i.e. The LDROV presents a constant load to the umbilical by dissipating unused energy in the form of heat.
- A combination of some or all of the above.

4 CONSIDERATIONS AND OPTIONS FOR GENERAL DESIGN OF A LDROV.

In order to think about desirable qualities of the LDROV it is useful to imagine the ideal machine and work towards that goal.

The ideal LDROV would be able to:

- Access any conceivable location within a pipeline or tunnel network while carrying a full suite of sensors.
- Provide a steady platform for sensors and cameras.
- Transmit real time data back to the operator.
- Perform intervention tasks.
- Be accurately positioned throughout its mission.
- Be able to ensure a 100% recovery rate without the possibility of doing harm to infrastructure or contaminating water.

There are no one-shot answers to building such a machine but there are some concepts that can be adhered to in order to achieve close to ideal results.

4.1 ACCESS TO ALL LOCATIONS

This is among the most fundamental problems facing the LDROV designer. Generally, if a ROV is to access all locations it must be very small, have a very high thrust to mass ratio (taking the mass of the umbilical into the calculation) and be able to accept any depths that it will be required to dive to.

These requirements set up a natural conflict. Vehicles were once designed around their propulsion unit (either HPU, electric thrusters or track motors). In order to satisfy demand using conventional power handling techniques, an umbilical was specified to handle the power demand with minimal voltage drop. This inevitably required a large umbilical diameter that in turn required more thrust to pull the umbilical over a long distance. The result tends to be a self-defeating race to build a bigger, more powerful vehicle until it no longer will fit into the pipelines that instigated is original development.

To avoid this vicious cycle the designer will maintain accessibility by concentrating on keeping a vehicle small by capitalizing on the technologies already discussed i.e. fiber optic technology and sophisticated, active, power handling methods. In this manner, the LDROV can be kept very compact, requiring minimal thrust (so therefore power demand) and can send back data from a wide range of sensors.

4.2 STEADY PLATFORM

Often, the idea of providing a steady platform is related to providing a large platform. This need not be the case. What is important is that there be a strong moment arm holding the LDROV rigid in its horizontal plane (i.e. restricting pitch and roll). This is simply achieved by maximizing the size of and distance between the center of buoyancy and center of gravity of the vehicle.

4.3 TRANSMISSION OF REAL-TIME DATA

This problem is largely dealt with by using fiber optic multiplexers carrying both video and serial data on a single-mode or two multi-mode fibers. Data can certainly still be sent over copper but once long distances become involved the mass of the umbilical will begin to effect the vehicles penetrating capacity.

4.4 PERFORM INTERVENTION TASKS

In many cases, a client will not only require that a vehicle record data but will need some form of intervention to take place. Examples may be the collection of samples or removal of surface material to expose underlying structure.

Until AUV technology develops to the extent that a vehicle can negotiate obstacles such as complicated and unforeseen blockages or perform sophisticated intervention tasks automatically, the operator will need to have the ability to view data and video real-time and be able to send control signals back to the vehicle. Until such time that a through-water data transmission technique is developed that will allow the transmission of video or at a minimum high resolution imaging sensor data, such work will need to be carried out by an ROV that is in someway tethered to the surface.

4.5 POSITIONING

A range of techniques exist for the positioning of a vehicle. These will be discussed on order of accuracy beginning with the least accurate.

4.5.1 DEAD RECKONING

Among the simplest methods of performing an inspection is to insert into a flowing pipeline a neutrally buoyant vessel containing some sensor or camera. The time is recorded along with the data or video. A dead reckoned position can be resolved based on the flow rate within the pipe.

4.5.2 MEASURED UMBILICAL OFF OF DRUM

By using some form of counter as the umbilical is spooled off of an umbilical winch and subtracting the distance from the winch to the beginning of a pipe, a reasonably accurate position can be resolved. The disadvantage of this technique is that various errors can creep in to the calculation due to changes in umbilical centenary with changes in tension as well as errors incurred as the umbilical goes around bends.

4.5.3 ACOUSTIC MEASUREMENT

By using some form of acoustic network, very accurate distances can be resolved in a straight line. However, once the vehicle turns a bend or goes behind an obstacle, the acoustic signal strength drops off dramatically. Other possible problems exist in false distances as a result of "ghosting" echoes off of the pipeline.

4.5.4 MEASURED UMBILICAL FROM WITHIN PIPE

By locating an umbilical distance counter within the pipe at a known location at the beginning of a run (after any bends typically found at the start of a run) the problems of centenary error are removed altogether and bend errors are greatly reduced allowing linear position to be recorded with errors in the range of better then 0.1% of penetration distance.

4.6 100% RECOVERY RATE / NO HARM

There is no ultimate solution to this requirement. Any time that equipment is inserted into an unknown pipe both the pipe and the equipment are put at some risk and there is a chance that unforeseen problems could result. The best one can do is to control the risk and reduce to an acceptably low lever the likelihood of this occurring. Some items to be considered are:

- Familiarize thoroughly with pipeline details such as speed of water flow, expected turbidity, likely obstructions (special attention taken to valves) and previous work performed.
- Consider the ability of another vehicle or diver accessing the LDROV in the event of equipment failure.
- Consider the ability to remove a dead-sub by hauling in on the umbilical.
- If the LDROV comes upon an unexpected feature, stop and consider the ramifications of continuing. Is there a better, less risky way?
- If the LDROV does get "stuck" will this effect water production until a rescue operation can be conducted?
- Consideration must be given at the design stage for minimizing the impact of complete failure.
- Reduced size means less chance of complete blockage.

5 INSPECTION REPORTING CONSIDERATIONS AND TECHNIQUES

The best vehicle and data-set imaginable is of little use if the information cannot be presented in a manner that is of use to the client.

The operator must consider the client's needs and objectives and present a report in a format that will make the recorded information meaningful. In particular, the client not only needs to know that a certain condition exists but where it exists.

One key to making this possible is to "timestamp" all data as it is recorded. This means that each data record, whether it be video, sonar, distance etc be recorded along with a record of the exact time that the data was gathered. By handling the information in this manner, the individual pieces can be co-coordinated during post-processing for later review.

5.1 VIDEO

The advent of digital recording technology and the DVD has allowed large amounts of video data to be easily recorded onto a medium that is simple to transport and facilitates access to specific features. Video logs showing time and features can accompany the DVD and chapters set up on the introductory pages allowing the reviewer to go directly to an item of interest rather then searching through hours of featureless information.

5.2 IMAGE CAPTURE

An added advantage of digital recording is that still images can be pulled off of the video and displayed in a written report with no reduction in quality. Rather then filling a report with the clutter of multiple images, hyperlinks can be used to bring up an image that is of particular interest to the reviewer.

5.3 3D WALKTHROUGH

Often, the data that a client will require is not just video but they will require dimensional information of the inside of the pipe. This data can be recorded using a scanning profiler among other instruments.

Scanning around the fore/aft horizontal axis, a profiler delivers a series of X and Y points that make up the cross section of a pipe. Without the Z component this information is quite meaningless. The exact dimensions of that cross section are known but not where in the pipeline is that cross section is located. By using the timestamp discussed earlier, the recorded penetration distance can be correlated with the recorded profiler data to give X,Y & Z components.

In the case of a scan taken every 10ft, this will give a good general indication of the overall condition of the pipeline, depth of sediment etc. but it wont cover localized problems in the majority of the pipe lying between the 10 ft scans. By recording data constantly, a much larger dataset is recorded reducing the size of any anomaly that could go undetected. This data can be displayed as a 3 dimensional model.

5.4 OTHER DATA

Data from other sensors such as pipeline depth, corrosion potential sensors and ultrasonic thickness sensors can be displayed in similar graphical images.

6 CONCLUSION

It can be seen by the topics touched on in this discussion that while initially seeming to be a very specific topic, the act of performing long distance pipelines requires the integration of quite a wide range of technologies and methodologies.

With the decay of existing water infrastructure we see that this country has a big job ahead. Happily, for the inspection portion at least, technology has come along just in time to make the task of performing sophisticated long distance inspections achievable. Concentration must be on maximizing the benefit of the available technology and keeping vehicles small with low power demands.

Finally, in order to capitalize on available technology and provide the client with the best product possible, thorough understanding of the problems and available solutions needs to be achieved. Only then will we do justice to the investment being put into our projects and to the effort and labor of those that laid the pipes and dug the tunnels a century ago.