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Technologies for Positioning and Placement of Underwater Structures

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Technologies for Positioning and Placement of Underwater Structures

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Preface

The work described in this report was authorized by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as part of the Innovations for Navigation Projects (INP) Research Program. The work was performed under Work Unit 33141, "Positioning and Placement of Underwater Structural Components," managed at the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. Dr. Robert G. Mann, ERDC Topographic Engineering Center (TEC), was the Principal Investigator.

Dr. Tony C. Liu was the INP Coordinator at the Directorate of Research and Development, HQUSACE. Dr. Reed L. Mosher, ERDC Structures Laboratory (SL), was the Laboratory Manager for the INP Program, and Dr. Stan Woodson, ERDC SL, was the INP Program Manager.

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1 Introduction

Background and Purpose

Initial research conducted as part of the Innovations for Navigation Projects Research Program, Work Unit 33141, "Positioning and Placement of Underwater Structural Components," has identified currently available positioning and placement technologies and navigation systems of possible use to the U.S. Army Corps of Engineers for positioning large underwater structures in river environments.

Technologies for positioning large underwater structures are categorized by their primary mode of operation, including optical, acoustic, electromechanical, inertial, and passive. The most dramatic improvement in positioning this century has been the development of the global positioning system (GPS). Coupling this technology with newly developed sensors and improved computer-processing capabilities provides extremely accurate surface and subsurface positions. These sensors include acoustic transducers and transponders, multibeam and side-scan sonar, acoustic cameras, lasers, video cameras, gyrocompasses, inclinometers, and motion sensors. Telemetry of data via radio link enhances the versatility of the sensors in remote locations.

Navigation and Positioning Applications

Navigation and positioning in its simplest form is taking measurements to help one determine his current position or where he is going. Today's navigation and positioning applications are grouped into six basic categories: area surveys, the primary application; route surveys, which are similar to area surveys but usually of shorter duration; inspections, typically for cables and pipelines; target location, a small but critical application; positioning, which calls for high accuracy and repeatability; and static measurements, which are generally low-cost operations and comprise only a small segment of the market.

More specific applications are found by looking at the markets that use these tools. The shipping industry, for example, uses the technology for navigation charts. Oil and gas industry applications include exploration, site surveys, construction support, and pipeline placement. Applications by the military and the civil government include mine countermeasures and environmental surveys. Fisheries draw from the environmental monitoring and fish stock assessment capabilities, while coastal engineering applications include dredging and prospecting for minerals. Cable placement uses positioning technology. Search, salvage, and solid waste disposal round out the primary markets.

Subsea applications include construction support, route surveys, seafloor mapping, seismic surveys, and automated positioning surveys for exploration rigs, ships, and platforms. Positioning technology enables remotely operated vehicles (ROVs) to better perform services such as construction support and intervention, drill rig support, platform and pipeline inspection, and site cleanup.

Acoustic or sonar-based systems represent another prominent type of navigation and positioning system used today. Sonar systems transmit high-frequency sound waves in water and register the vibrations reflected from the object. Sonar triangulation describes a positioning or surveying method that provides precise coordinates in reference to “baseline stations” that act as markers or reference points for navigation. These baseline stations can be placed in the water, carried by the diver, or mounted on ROVs.

2 Positioning and Placement Technologies

Satellite Positioning

The most dramatic improvement in positioning and navigation methods of the past 50 years has been the development of the global positioning system (GPS). This system consists of 24 satellites orbiting approximately 19,000 km (12,000 miles) above the earth in six polar orbits. The Department of Defense operates the system, and the signals are available to anyone with a receiver.

Two frequencies are transmitted and certain restrictions are placed on users without the proper military clearance for specific receivers. The signals are degraded for security purposes and, thus, accuracies from GPS for civilian use are approximately 100 m. However, a technique known as differential GPS (DGPS) has proven to be extremely useful in achieving accuracies of a few centimetres in real time and less in a data post-processing mode.

Equipment for this technique consists of a base station with receiver, antenna, and transmitter and a rover station with receiver and antenna. The base station receives satellite signals, applies corrections to the data, and transmits them to the rover or mobile station. The mobile station receives satellite signals and corrections from the base station and computes a very accurate position in real time. This use of GPS is commonplace and is used in virtually all high-accuracy surveying and positioning, including hydrographic surveying, topographic surveying, some cadastral surveys, and point positioning. In general, any accurate positioning requirement will use DGPS alone or with other surveying methods described later in this report. Several large construction projects around the world have used this method for bridge section placement, tunnel location, and levee and dike positioning.

Several software packages are available for reducing data and applying corrections. The U.S. Army Engineer Research and Development Center's Topographic Engineering Center and the Corps' St. Louis District used this method in a field evaluation of placing the steel cell at Lock and Dam 24 (Mann and Fehl 1998; http://crunch.tec.army.mil/information/publications/Lock_Dam24/cell.htm).

Several companies also use their own satellites and ground network for positioning and surveying applications. These systems consist of a receiver and antenna along with proprietary software for data reduction. Coverage is not as extensive as with GPS satellites, but in some cases this is not a determining factor for the local surveyor.

Manufacturers of satellite positioning equipment include Trimble, Ashtech, Leica, Magellan, Javad, and Sokkia. They also provide service and, in some cases, will perform the surveys. However, usually, survey companies with expertise in DGPS surveying handle this.

Satellite Positioning with Acoustic Ranging

One of the drawbacks of using GPS is that, for underwater surveys and positioning, it is limited since the signals cannot penetrate the water surface. For accurate measuring of movement on the seafloor, a method has been developed that uses acoustic transponders on the seafloor combined with GPS technology on the sea surface.

Scripps Institution of Oceanography has been the lead in developing the system for measuring crustal plate movements with centimetre accuracy. Taken at a much smaller scale, this method could be used to monitor movement of large underwater structures in river or coastal environment. The system consists of three or more acoustic transponders located in a circle on the seafloor with the radius approximately equal to the water depth. On the surface, the ship (or structure) has three well-separated GPS antennas mounted on the highest part of the superstructure and an acoustic transducer mounted underwater on the same rigid structure. Onshore, one or more GPS receivers at known reference points are needed to complete the system.

The exact position of the transponders is calculated using acoustic ranges collected from a transducer towed near the seafloor. Near the circle's center the ship is then positioned, and data are collected from the GPS antennas on the ship's position. Since the GPS antennas above the water are not collocated with the transducer underwater, the offsets must be applied to the transducer. By applying the GPS antenna positions with the acoustic ranges from the transducer, the horizontal position of the transponders' array is calculated. This position can then be continuously monitored, and any movement of the array is correlated with the movement of the seafloor (or structure).

For application to the placement of underwater structures, the transducer is placed on the structure being positioned. After the positions of the transponders are calculated, the position of the transducer on the structure is calculated in real time. The movement of the structure after final placement is then monitored as settling occurs. Although this method has been used only in deep water to monitor crustal plate movements, the accuracies obtained by it could be useful for monitoring structural movement in shallow water.

Acoustic Sensors

For most underwater positioning applications, acoustic transducers and transponders are used. Depending on the water depth and type of position service needed, several options are available.

Long-baseline (LBL) systems secure three or more baseline stations (cylinders with transmitters and receivers in them) to corners of the targeted area, tracking a diver or ROV's position relative to those stations. Short-baseline systems use sonar antennas mounted aboard surface vessels as reference points, with positioning tracked relative to the vessel. This system is used primarily for ROV piloting.

In ultrashort-baseline navigation, positioning is again tracked relative to a vessel. However, in this method, a single transducer ray is used in one location as a reference point—typically in a rod mounted on the side of the boat. The system uses the movement of sound waves in the water with reference to the starting point to track positioning. The mounting convenience afforded by this method is offset by the tendency to be less accurate than other methods, resulting in a lower quality of positioning data (Baker 1997).

For LBL acoustic positioning the frequencies are generally between 5 and 15 kHz. These are used for deep-water operations in the petroleum industry. Also available are medium frequencies (18 to 36 kHz) and extra-high frequencies (EHF, 50 to 110 kHz). The higher frequencies are used for shorter baseline operations and give much higher accuracies. In general, the transponders take direct baseline measurements between pairs of transponders and transmit these data using an acoustic telemetry link, either to a surface-deployed or ROV-mounted transponder. Other instruments, such as inclinometers, gyrocompasses, and STD (salinity, temperature, depth) sensors, can be mounted within the housing. A personal computer interface with visual display at the surface is used to control and monitor the system.

Originally used by the petroleum industry for locating drill sites, acoustic sensor technology could possibly be used for pile location and placement in remote areas or where direct GPS signals are obscured. This would not require fabrication of a subsea template for the piles, and would result in cost savings. In addition, this eliminates the need for a large crane for template installation, which would further reduce costs and save time. Using the EHF, accuracies of better than 5 cm are achievable.

Manufacturers of acoustic positioning systems include Sonardyne International, Ltd., International Transducer Corporation, SonaVision, and Aquatec Electronics, Ltd. (Figure 1). Several service companies use the equipment for their clients' positioning needs or lease it to clients for their use.

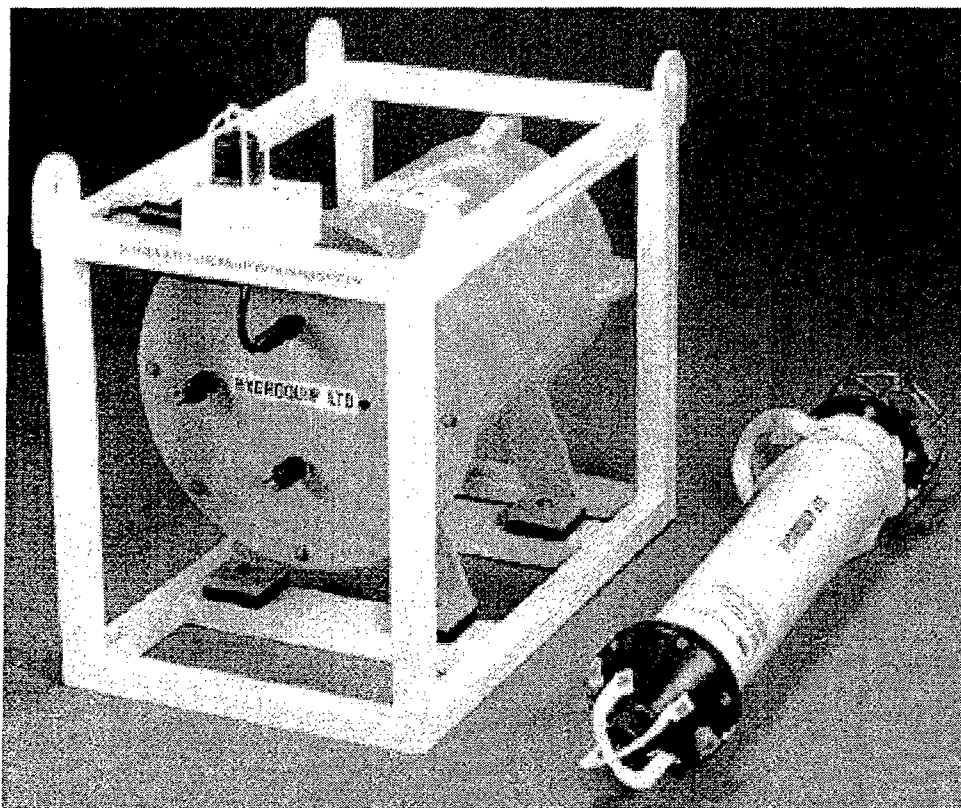


Figure 1. Sonardyne transducer for underwater positioning

Multibeam and Side-Scan Sonar Transducers

An integral part of positioning structures is the imaging of the bottom where placement of the structure is planned. Recent advances in the development of low-profile acoustic transducers and in the processing capability of computers have made possible high-resolution images of the seafloor. Technology such as digital side-scan sonar, multibeam sonar, and underwater laser imaging provides complete coverage of the bottom for hydrographic survey operations. These surveys are also used for investigations of underwater hazards to navigation, target identification, condition reports, and dredge payments.

Although side-scan sonars do not give geositions of an image, they provide an image of the bottom that resembles an aerial photograph. The "fish" is towed behind the boat and transmits sound waves toward the bottom in a fan shape (Figure 2). The bottom becomes ensonified when the sound waves are reflected back to the receiver. The resulting image is from an area of the bottom that ranges from 20 m to over 1,000 m on each side of the fish.

Figure 3 is an image from a high-resolution side-scan sonar showing a bicycle on the bottom of a shallow river. In this example, the light-colored areas are ensonified, while the dark areas are the acoustic shadows or areas where no sound waves have reached. Some displays have the reverse characteristics. Figure 4

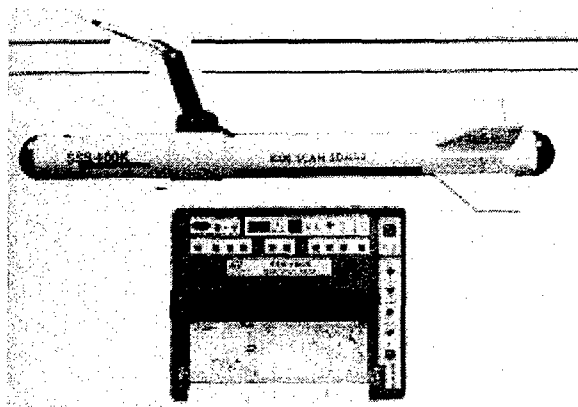


Figure 2. Side-scan sonar fish and recorder
(J. W. Fishers Manufacturing, Inc.)



Figure 3. High-resolution side-scan sonar image of
a bicycle (Marine Sonic Technology, Ltd.)

shows crab pots (approximately 0.6 m per side) on the bottom. These examples show the detail that can be derived with high-frequency side-scan sonar used for object detection. Other geologic and hydrographic features that can be detected with these instruments include sand waves and ripples denoting current direction and speed, biological populations, scour holes from erosion, as well as manmade debris larger than about 1 ft³ (0.03 m³) in volume.

Multibeam sonars are capable of giving accurate depth data along with horizontal positions. The transducers create narrowly focused beams that are directed toward the bottom in a fan-shaped array. This swath can range in width from 90 to over 150 deg. The result of this is complete coverage of the bottom and very efficient data acquisition. The processing and display capabilities of the software today allow the multibeam data to reveal dramatic features on the seafloor. Figure 5 shows the Wilmington channel surveyed with multibeam sonar.

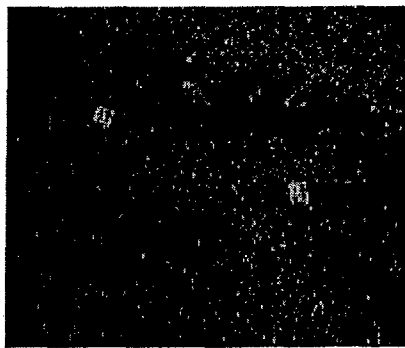


Figure 4. Side-scan sonar image of crab pots on river bottom (Marine Sonic Technology, Ltd.)

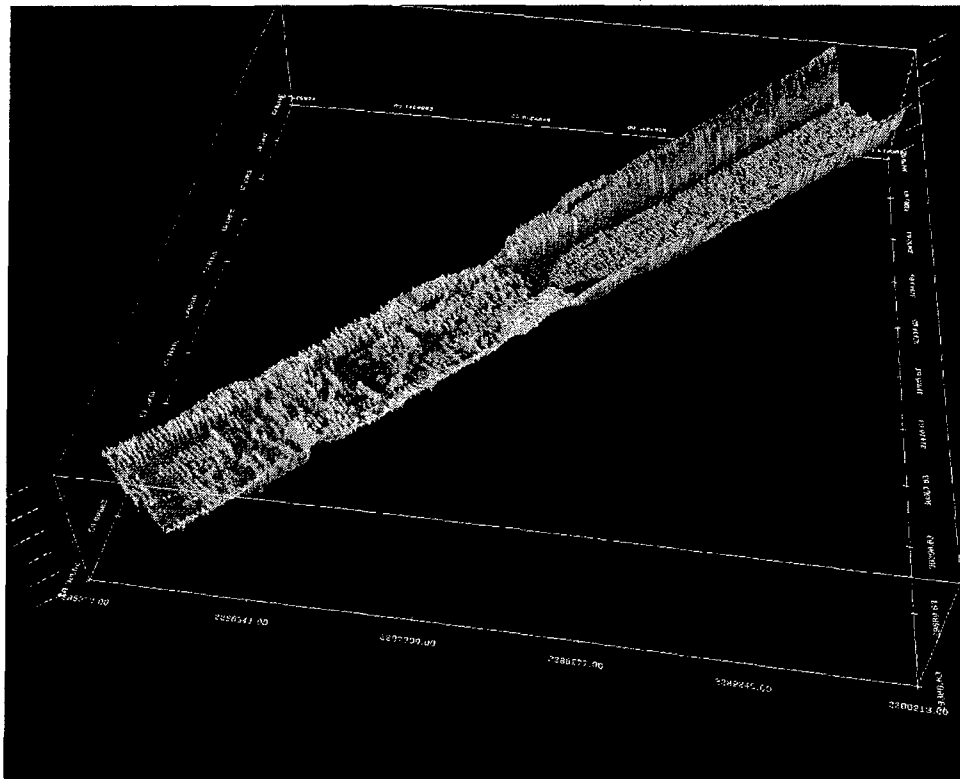


Figure 5. Wilmington channel showing shallow areas needing dredging

Acoustic Cameras

Often it is desirable to have a continuous video or photo of the structure or conditions in the water when performing construction operations. Unfortunately, the conditions in the water may be such that optical photography is not effective at ranges greater than a few centimetres. One advantage that acoustic methods of subsea positioning have over optical methods is that they are not dependent on

water conditions or visibility. Sound waves in water are not affected by turbidity in the water column, but only by temperature, pressure, and salinity. These parameters can be accurately measured, and thus the velocity of sound can be calculated. Positioning using acoustic methods generally refers to a signal transmitted by a transponder and received by another, or reflected off an object and received by the original transponder. The distance (and thus position) is then calculated by the travel time in the water from transmit to receive.

By using a scanning acoustic beam and displaying the return signal, an acoustic camera captures an image similar to an optical camera, provided the scan rate is high enough. The Echoscope, manufactured by the Norwegian company OmniTech, is basically a multibeam sonar with several hundred beams generated on a single acoustic pulse (Figures 6 and 7).

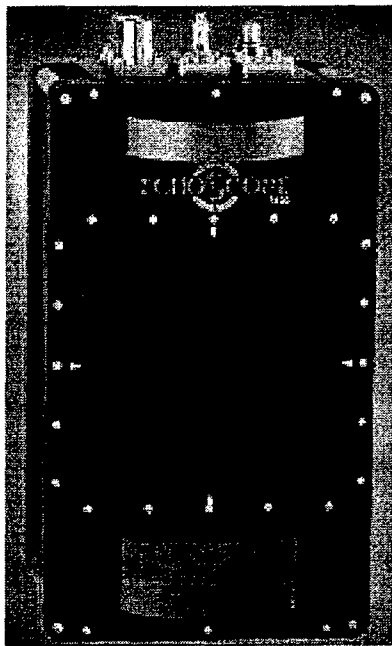


Figure 6. Echoscope used for underwater imaging of features of interest (OmniTech AS)

The pulses are transmitted in a cone-shaped geometry, and the reflected pulses are detected in a two-dimensional (2D) array. The Echoscope has three frequencies, each with a specific opening angle. At 150 kHz, the opening angle is 90 by 90 deg, at 300 kHz the opening angle is 50 by 50 deg, and at 600 kHz the opening angle is 25 by 25 deg.

The images are transmitted via fiber optic cable at 160 Mbits per second and displayed on a surface monitor at a rate of between 2 and 10 per second. One 3D image consists of a number of lateral 2D images—one per distance slice representing a time window. The finest range resolution is 5 cm, which is the



Figure 7. Image of sunken ship from Echoscope
(OmniTech AS)

minimum thickness of a slice. The complete 3D image includes x , y , z and intensity for each reflector. Although presently this is a diver-held instrument, it could possibly be adapted to a remote sensing technique.

Another similar instrument was developed by the Applied Physics Laboratory of the University of Washington for use by the U.S. Navy. Termed LIMIS (for limpet mine imaging sonar), this is basically a scanning sonar used for detection of limpet mines attached to ship hulls. Also called an "acoustic flashlight," the diver-held instrument displays the image on a mask-mounted screen, allowing the diver to identify the target in zero visibility. In addition, the image can be transmitted to a computer onboard the surface vessel or shore site.

The LIMIS has a resolution of 0.7 in. (18 mm) at a 10-ft (3-m) range. It forms 64 beams, each 0.3 deg horizontal by 7 deg vertical. There are four ranges, from 50 to 2 ft (15 to 0.6 m). The instrument has a frequency of 2 MHz and requires only 25 W. The acoustic lens technique uses a PZT array to form the 64 narrow beams that transmit and receive the 0.3- by 7-deg rectangular beam. The advantage of this instrument is its small size and minimum power requirements.

Applications for placing large structures would use the acoustic camera to obtain real-time photographic images of the attitude and position of the underwater structure in turbid river conditions. The acoustic camera would provide images of the condition of the structure and the surrounding environment while installing the structure.

Laser Positioning

The use of lasers in positioning and surveying has been commonplace for many years. With the addition of DGPS and geographic information system (GIS) capabilities, laser ranging has become a more robust tool in the surveyor's suite of instruments (Figure 8). Basically, these lasers consist of a low-power laser gun that computes the distance to an object by the travel time it takes to transmit and receive the light signal.

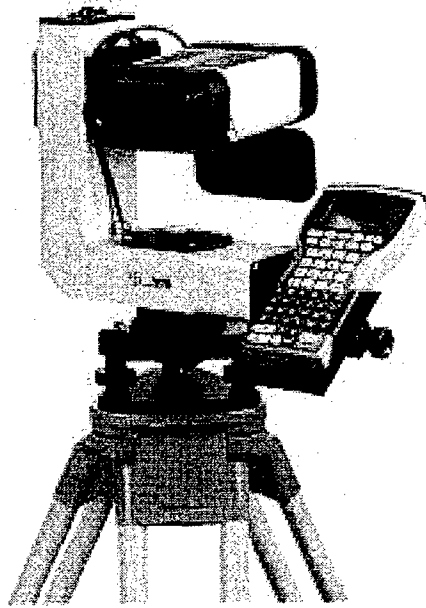


Figure 8. Laser rangefinder (Reigl Laser Measurement Systems)

The position of the laser is derived from a mounted GPS antenna on the laser range-finder. The laser calculates and displays the range, azimuth, and inclination to any target, without prisms or reflectors. Other sensors mounted with the laser are the digital compass and accurate inclinometer. The laser range-finder permits the user to acquire remote targets without requiring a GPS antenna at each point.

The utility of this technology in positioning large structures is apparent. The user could stand on the riverbank and collect data on the position of the structure in an almost continuous mode without attaching any sensors to the structure. Also, the fact that no cables are used on the structure is an advantage. The data would be fed directly into a GIS for further processing if needed.

Video Camera

Another possibility for using cameras comes in the form of a "smart" video camera. This is a video camera that generates digital image data that are

automatically tagged with georegistration metadata to indicate the precise position and attitude of the camera when the image was taken. This streamlines the processing of the digital image data and reduces the time needed to correlate common features in different images. It enables the derivation of the precise 3D coordinates of features in the images.

Developed by NAVSYS Corporation, the "GI-Eye" includes a GPS receiver, inertial sensors, and a digital video camera (Figure 9). The inertial sensors include an accelerometer and a fiber-optic gyroscope. The digital image data are recorded in bit-map file format and can be stored on a CD-ROM. The georegistration metadata are in a database, where they are cross-referenced to the image bit-map filenames to facilitate retrieval and processing of the image data.

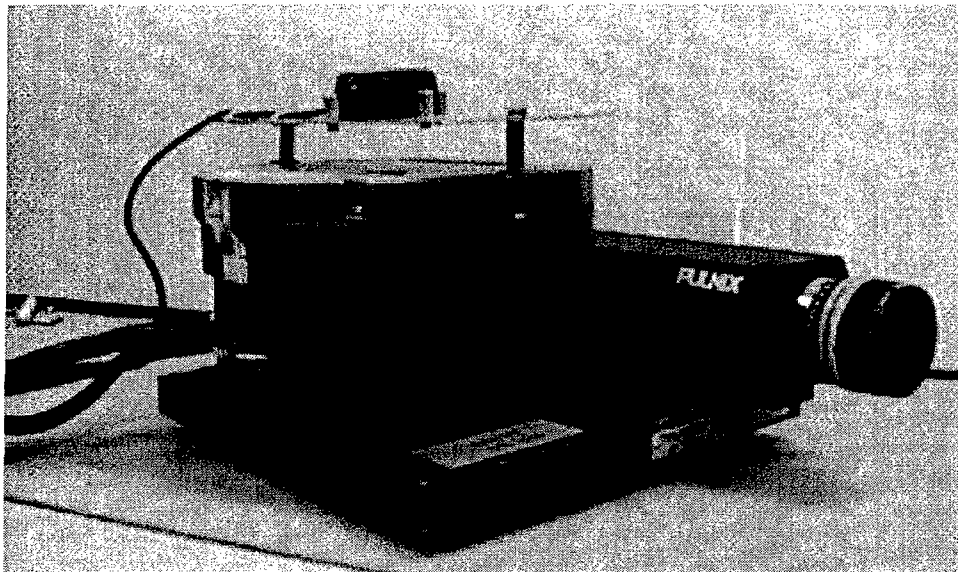


Figure 9. GI-Eye video camera with GPS receiver (NAVSYS Corporation)

The software package is designed to ease the processing of the GI-Eye digital image data and to generate 3D coordinates of the features of interest from the image database. When multiple views of the same feature are selected, the software (GI-View) automatically computes the 3D coordinates of that feature. The accuracy has been proven to be better than a few centimetres relative to the location of the camera. This system has been demonstrated by the U.S. Navy to provide real-time coordinates on the battlefield.

This technology could have potential application for use in positioning large underwater structures. For rapid assessment of the location of the structure, this camera could be especially efficient in remote areas where attaching a sensor on the structure is not feasible or desirable.

Passive Sensors

This is a generic name for sensors that do not require any outside interaction other than a power source. These sensors generally provide auxiliary information to another system. They are useful because they provide key data on a specific parameter. Included in this category are the gyrocompass, inclinometers, inertial navigation systems, and motion reference units and displacement transducers.

Gyrocompass

These instruments are extremely accurate compasses used to provide directional or azimuthal information for survey projects. They use a small gyroscope for stability and consistency. Although they are expensive, they provide supplemental information when navigating and positioning is required.

Inclinometers

These dual-axis sensors provide information on the vertical and horizontal attitude of an object. They are generally small and easily attached to a structure. They require a cable to send the information to the processing software in the computer. Update rates are up to 50 times per second, accuracies are 0.01 deg, and ranges are between 0 and 50 deg.

Inertial navigation

A complement to precise acoustic positioning is found in inertial navigation systems. The Position and Orientation System/Marine Vessels, manufactured by TSS Corporation, is a GPS-aided inertial navigation system that computes a real-time position (latitude, longitude, and altitude) and orientation (roll, pitch, and heading). The system uses a Kalman filter-based aided inertial navigation algorithm with a GPS receiver as the primary aided sensor. The result is a system that maintains heading, roll, and pitch accurate to 0.05 deg at any latitude and in all dynamic conditions.

Motion sensors

This is a generic term for accelerometers that measure the movement and displacement on a structure in three dimensions. These instruments are sometimes referred to as heave, pitch, and roll sensors or motion reference units. Motion sensors are essential instruments on hydrographic vessels with multibeam transducers, due to the large range of motions to which a small vessel is submitted. The information provided by the sensors is used to correct for the vessel motion, and thus place the received acoustic signals in their correct geospatial position. Motion sensors are expensive but necessary instruments.

Table 1 shows a summary of the various instruments that can possibly be used for positioning of large structures in river environments (Chiarito, McVan, and Savage, in preparation). It should be noted that the limitations of some instruments would require modifications to be made, although these may not prove feasible under the scope of this project. In addition, several sensors will operate only above water and thus can be used only on structures above water, or would need waterproofing. Table 2 gives the specifications for several multibeam sonar transducers for imaging the river bottom where construction will take place. These instruments should always be used in conjunction with side-scan sonar for optimum imaging.

Table 1

Equipment for Monitoring Positioning and Placement of Underwater Structural Components

Equipment	Manufacturer	Uses	Limitation	Range	Accuracy
Displacement transducer		For detection of movement of structural elements.	Attached as integral part of the structural element; power/signal cable requirements must be part of the construction plan; waterproofing required.		
Biaxial clinometer	Applied Geomechanics, Inc.	For detection of pitch, yaw, or roll of structural element; submersible sensors are available.	Attached as integral part of the structural element; power/signal cable requirements must be part of the construction plan; waterproofing required.	±20 or ±50 deg	0.1 deg of angle
Laser distance sensor	Acuity Research, Inc.	For measuring distance. Can be applied to level and position measurements, autonomous vehicle navigation, and 3D imaging.	Cannot be used in an underwater environment.	0 - 15.24 m	2.55 mm
Gyroscopes	Lifton Guidance and Control Systems	For detection of angular rotational movement and direction of structural elements.	Attached as integral part of the structural element; power/signal cable requirements must be part of the construction plan; waterproofing required.	???	???
3D point positioning – Odyssey	Arc-second, Inc.	Laser-based 3D position information.	Uses a wand as a receiver, which must touch the point in question. It is not a remote system.	30 -50 m	3 mm
Level control device sensors	Lundahl Instruments, Inc.	Ultrasonic monitoring and control of liquid and/or solid levels.		Varies with model series: 0.3 - 7.6 m and 0.6 - 15.24 m	2.54 mm
Inclinometers	WPI Instruments, Inc.	For detection of changes in angular position.	Attached as integral part of the structural element; power/signal cable requirements must be part of the construction plan; waterproofing required.	±14.5, ±30, ±90 deg	<0.0005 deg
(Continued)					

Table 1 (Concluded)

Equipment	Manufacturer	Uses	Limitation	Range	Accuracy
Accelerometer	WPI Instruments, Inc.	For detection of changes in velocity that can be converted into displacement.	Must convert output into displacement. Attached as integral part of the structural element; power/signal cable requirements must be part of the construction plan; waterproofing required.	±0.5 G, ±2.0 G, ±5 G	<10 microG
	Litton Guidance and Control Systems				
	Patriot Sensors and Controls Corp				
Multi-axial accelerometers					
Submersible displacement transducer	RDP Electrosense	For detection of movement of structural elements.	Attached as integral part of the structural element; power/signal cable requirements must be part of the construction plan.	±12.5 to ±100 mm	±0.5% of full scale
	Patriot Sensors and Controls Corp.				
Rotary capacitive displacement transducer	RDP Electrosense	Measures angular position of a shaft with respect to the body.	Must convert output into displacement. Attached as integral part of the structural element; power/signal cable requirements must be part of the construction plan; waterproofing required.	0 to 300 deg	±1% of full scale
	Patriot Sensors and Controls Corp.				
Potentiometer	Patriot Sensors and Controls Corp.	For monitoring of a travel element.	Attached as integral part of the structural element; power/signal cable requirements must be part of the construction plan; waterproofing required.	0-5.08 mm through 0 - 50.08 m	±0.1% of full scale
Position/velocity transducer	Patriot Sensors and Controls Corp.	For monitoring element movement in distance and speed of movement.		0-5.08 mm through 0 - 5.08 m	±0.1% of full scale
Digital compass module	Honeywell	For positioning of underwater structures or drilling /boring equipment and is integrated with GPS.		±45 deg	±0.2 deg

Table 2 Multibeam Sonar Sensor Specifications						
Manufacturer	Frequency, kHz	Range Resolution, cm	Number of Beams	Beam Geometry, deg	Swath, deg	Ping Rate
Reson (SeaBat 8124)	200	1	40	3.0 x 2.5	120	30/sec
Odor (Echoscan)	200	2.5	30	3 x 0.7	90	14/sec
Simrad (EM3000)	300	1	128	1.5 x 1.5	120 to 190	50/sec
Seabeam (1180MKII)	180	5	126	1.5 x 2.8	20 to 150	15/sec
Triton Elrics (Hydrosuite)	200	2.5	128	1.5 x 1.5	90 to 150	15/sec
OmniTech AS (Echoscope)	150-600	5-10 cm	1,600	0.6 x 1.2 to 2.5 x 4.8	25 to 90	5-10/sec

3 Conclusions and Recommendations

Conclusions

The initial search of instruments and sensors available for positioning has led the investigators to enthusiasm about the possibilities ahead. There are several instruments that could potentially be used to position large structures in remote settings. Most of these instruments have been used in the petroleum industry for several years. At least two more demonstrations are planned to evaluate the merging of acoustic and GPS technology with laser and acoustic technology.

In the near future, several adaptations are possible, including the following: further integration of total tracking systems and solutions; integration of GPS with acoustics for greater ease of use and lower cost; integration of GIS data with real-time navigation and 3D graphics to assist in subsea navigation; development of pseudo-random noise acoustic systems for use in extremely high noise environments; simplification of software and systems, making equipment more user-friendly while continuously improving accuracy; improved interface with integrated packages; and higher accuracy at any depth for substantially lower prices, thanks to a continued cross-discipline use of underwater equipment.

Recommendations

Positioning large structures will require both above-water and submerged sensors, preferably with telemetering capabilities for real-time positioning. Based on this preliminary review of the available technology for positioning structures in river environments, the recommendations are as follows:

- a. Use differential GPS or real-time kinematic for positioning structures when an antenna on the structure is possible.
- b. Use multibeam sonar and/or side-scan sonar for imaging the bottom immediately before placement of the structure.
- c. Use passive sensors (such as tiltmeters, inclinometers, and gyrocompasses) when possible for accurate orientation prior to placement.

- d.* Determine tolerances of construction modules well in advance of deployment, allowing necessary modification of positioning sensors.
- e.* Use, where possible, remote data access to avoid using data cables in positioning structures.
- f.* Include monitoring the position of the structure after placement in any installation plans and perform this using the same equipment as for initially installing the structure.
- g.* Incorporate positioning data into a GIS for use as an "as-built" structure.

Require coordination among the surveyors, construction operations, and engineers at the earliest stages of planning to ensure a successful placement using any electronic positioning instruments.

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