Vision in Turbid Water

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INTRODUCTION

In clear water, divers use their eyes for spatial feedback and ROVs use optical video systems. In turbid water where there is little or no visibility, divers resort to tactile examinations and ROVs are generally grounded. Conventional imaging sonars make images in turbid water, but not with the detail provided by optical systems. This article reviews a technology that provides dynamic, near-video-quality acoustic images that allows work to continue in zero-visibility conditions.

WORKING IN TURBID WATER

A significant amount of underwater work takes place in seas, rivers and coastal areas were visibility is limited and optical systems are ineffective – sometimes generating only blank screens. Operating an ROV or other remotely operated equipment in these conditions is very dangerous and generally causes such work to slow or halt until conditions improve. If the water temperature and depth allow it, divers may be sent down to work "by Braille" to identify objects, determine the extent of damage, or do some simple construction work.

ACOUSTIC MOVIE CAMERA

In 1999, The Applied Physics Laboratory, University of Washington, developed an acoustic movie camera that was designed to provide images with sufficient detail that the U.S. Navy could identify swimmer-intruders detected by a large harbor surveillance sonar.[1] The acoustic movie camera bridges the gap between medical ultrasound, which images the fingers of a fetus at a range of 10 cm, and a conventional sonar that images a shipwreck at ranges of 100's of meters. The camera uses acoustic lenses that refract sound waves and focuses them in a similar way as light is focused with optical lenses. The result is an "acoustic movie" with more clarity and detail than seen in conventional imaging sonars. Acoustic movie cameras operate using a combination of high frequencies, acoustic lenses, very narrow beams, and high sampling rates to increase image detail. The operating acoustic frequencies range up to 3 MHz. High-frequency sound more quickly absorbed in water than low frequency sound and thus the maximum range or these high frequency acoustic movie cameras is limited to 130 feet (40 m) when operating at 1.1 MHz and to 50 feet (15 m) when operating at 1.8 MHz. The acoustic movie camera generated interest outside of the military in areas of inspection, security, and fisheries. In the 1990's, the research team that worked on the acoustic camera concept at the University of Washington tried to interest industry in this technology. However none was interested to obtain a license from the University. One required a guaranteed order of 40 units. In 2002, the research team formed Sound Metrics Corp. and obtained an exclusive license to manufacture and sell the Dual-Frequency Identification Sonar (DIDSON). The standard system focuses from 1 m to its maximum range at 40 m and has a 29° field of view. Due to its limited range, DIDSON is a good identification tool but not a good search tool. The following examples show applications of DIDSON.

Fig. 1. U.S. Coast Guard boat with DIDSON (in circle) intercepts and verifies detected swimmer-intruders. (Courtesy of Space and Naval Warfare Systems Command.)

SECURITY

Deployment in Harbors: The United States Coast Guard is deploying an Integrated Anti-swimmer System (IAS) at a number of harbors. The IAS has four primary components: The Kongsberg SM2000, The WQX-2 ACAP processor, the Security System Guidance System and the Dual-Frequency Identification Sonar. The SM2000 detects targets that may be swimmer-intruders. The WQX-2 ACAP ranks the many potential targets. When one exceeds a threshold, a small boat is sent to that target location and a DIDSON is lowered in the water to verify that they are divers, how many, and in some cases if they are carrying anything (Fig. 1).

Forward Looker on AUVs: DIDSON also has an LR (longer range) version that operates at frequencies of 0.7 MHz and 1.2 MHz. This version detects objects out to 80 meters is used as a forward looking sonar on AUVs. It has three duties: 1) to detect objects that should be avoided, 2) fill the gap not covered by the right and left side-scan sonars mounted on the sides of the AUV, and 3) use the higher frequency to identify an object. The Office of Naval Research purchased a DIDSON LR to mount on the front of a Bluefin Robotics AUV to test and demonstrate the new technology. A DIDSON-LR also went to the German WTD-71 Navy Department for integration in an AUV operated by WTD-71. The DIDSON-LR will be used for obstacle avoidance and navigation of the AUV.

Search Hulls: In March 2006, the Space and Naval Warfare Systems Command in San Diego hosted a Hull Unmanned Underwater Vehicle Localization System demonstration. Twenty-six ROV and AUV manufacturers and system integration teams responded. Five of the systems used a DIDSON for an underwater imaging sensor to detect and identify mines and IEDs on the hulls of ships. This paper briefly describes three of them. 1) A team from the University of South Florida designed an inspection system called the Mobile Inspection Package (MIP)[2]. The MIP uses a combination of acoustic and optical sensors. For long range detection, they obtain 3D imagery with the Coda Octopus Echoscope. At short range they use a laser line scanner in clear water and a DIDSON acoustic movie camera for turbid water applications. The MIP was also successfully demonstrated at the NATO Undersea Research Centre, La Spezia, Italy in April 2006. DIDSON clearly imaged the targets placed on a ship hull for the demonstration. 2) Faculty and students from the Mechanical Engineering Department, Massachusetts Institute of Technology (MIT) working with Bluefin Robotics designed the second system[3]. They developed a Hovering Autonomous Underwater Vehicle (HAUV) as a test-bed for a number of sensors. DIDSON was used on this vehicle to detect and identify objects on the hulls of ships as the platform "mowed the lawn" over the hull surface. 3) Lockheed Martin Perry Technologies demonstrated a Cetus II AUV equipped with a DIDSON to conduct a conformal hull search. A mosaic of the collected DIDSON data used both the Novint DIDSON data evaluation tool and the Sound View Systems, Inc. super-resolution software.

Fig. 2. Diver with mask-mounted display and diver-held model DIDSON DH. (Courtesy of Dave Elliott.)

Diver-Held: The acoustic movie camera also comes in a version that can be held by divers. Two of these systems are used by the Naval Facilities Engineering Command (NAVFAC). NAVFAC manages the planning, design and construction of shore facilities for U.S. Navy activities around the world and uses the DIDSON Diver-Held to support their work in underwater construction. The Galveston Police Department purchased a DIDSON-DH to aid their work in homeland security around the docks. Fig. 2 shows a NOAA diver testing a unit off the coast of Georgia.

INSPECTION

Working in Glory Holes: It is very expensive when time is lost because of a slow down or halt to work due to turbid water conditions. To reduce that loss, Oceaneering Canada, Mount Pearl, Newfoundland, has used a DIDSON for over two years in glory holes off the coast of Nova Scotia**.** Glory holes are depressions in the ocean floor, excavated to protect the sub-sea wells from iceberg scour. Every glory hole contains several drill centers, with production and water and gas injection wells located at each center. A glory hole is typically nine meters deep, and measures 25 meters by 25 to 65 meters in size. When part of a mud wall collapses, the hole is filled with turbid water and optical systems have blank screens for possibly hours. The DIDSON continues to give visual feedback in those conditions as shown in Fig. 3.

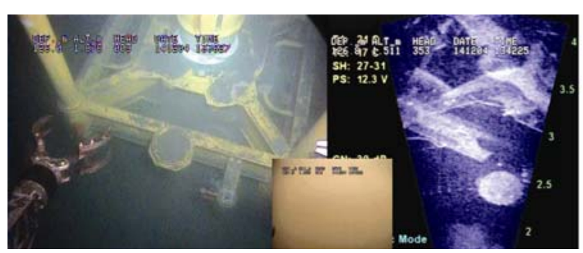

Fig. 3. Optical feedback in a glory hole changes from left image to center image after a wall partially caves in. A DIDSON image (right) allows work to continue in turbid conditions. (Courtesy of Oceaneering International, Inc.)

Laying Pipe: The low visibility water near the bottom of the Bay of Campeche, Mexico prompted Oceaneering International, Inc., Houston, Texas, to use a DIDSON instead of optics for visual feedback. Sections of pipe are welded together on a lay boat then pushed off the stern as the boat moves forward. The work is done in 150 feet of water. Fig. 4 shows

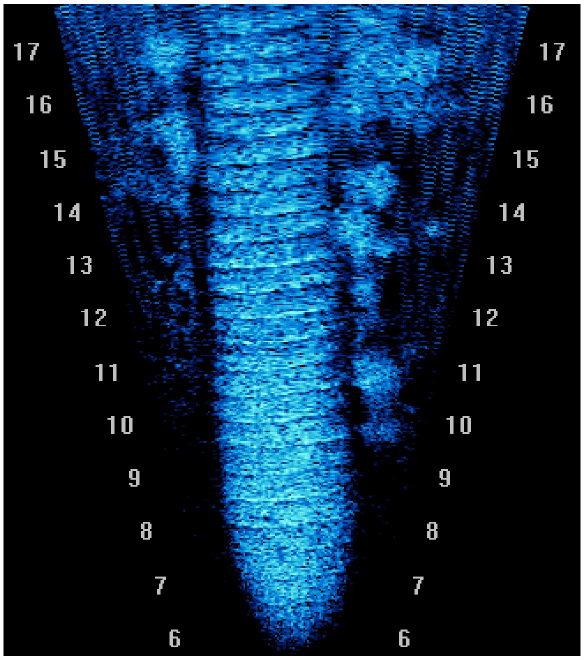

Fig. 4. A DIDSON image of a 36-in pipe as it bounces at touchdown and stirs up sediment. (Courtesy of Oceaneering International, Inc.)

the "touchdown," the point where the pipe finally rests on the bottom 900 feet behind the work boat. The monitoring crew on a different ship follows the touchdown point with an Oceaneering Sealion 38 ROV just above the pipe. The crew uses a DIDSON mounted on the ROV to inspect the pipeline for abnormalities such as buckling at the field joint (Fig. 5) or damage to the concrete coating. At touchdown the pipe bounces and stirs up sediment reducing the low visibility to zero. The movies from the acoustic camera allow continuous inspection of the pipe and the field joints as well as the immediate terrain. When pipes cross on the sea bed, flexible, protective mats are laid between them (Fig. 6). The mats measure 8 feet by 20 feet and are made of 6-in. square concrete blocks held together by a mesh of steel cable. The mats are deployed by suspending them on a down-line from a barge or boat.

At the bottom, divers or an ROV correctly place two mat corners. The topside crew then lowers the rest of the mat to the bottom. The ROV team or divers make sure the mat falls correctly. DIDSON is used throughout this process.

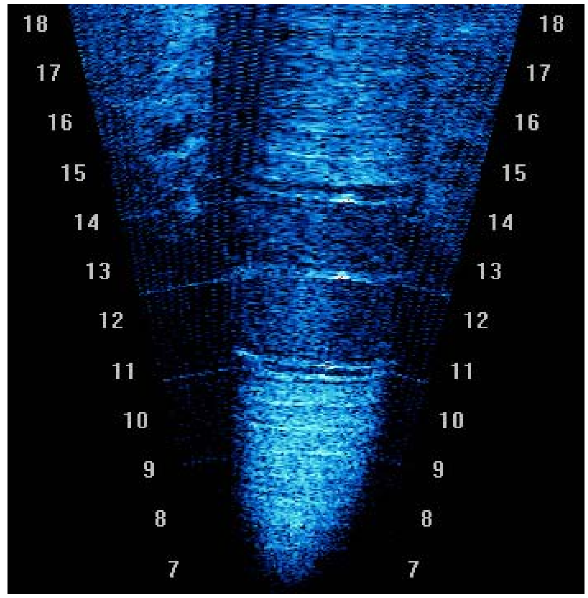

Fig. 5. A field joint on the pipeline. The three half-inch bands binding the sheet metal are visible. (DIDSON image courtesy of Oceaneering International, Inc.).

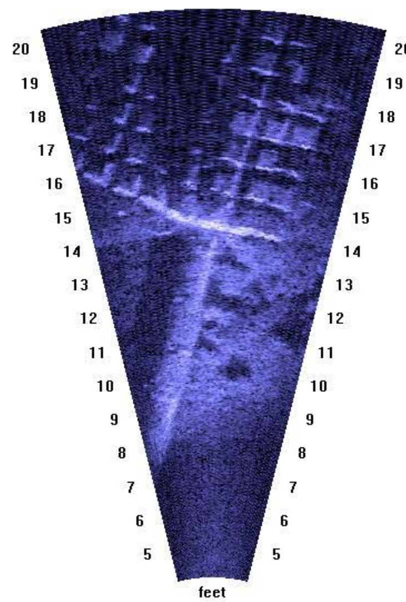

Fig. 6. A protective, flexible mat lies over a pipe that will soon be crossed by a second pipe. (DIDSON image courtesy of Oceaneering International, Inc.)

Salvage Work: The hurricanes in 2005, wrecked havoc on oil rig structures in the Gulf of Mexico. Detailed maps locating wellheads, pipes, and other structures in the turbid water are of little use after the hurricanes scattered and reshaped these objects on the ocean floor. Salvage work continues in the northern area of the Gulf of Mexico by the Submersible Systems, Inc., Patterson, Louisiana. The team works from the MV Toisa Proteus with a DIDSON mounted on a Comanche ROV (Fig. 7). The acoustic movie camera provides images for detailed seabed surveys. It helps determine best locations to position cutting equipment and rigging to remove downed oil rig platforms. It also helps find well-heads and pipes where they disappear into the seabed.

Fig. 7. The Submersible Systems, Inc. Comanche ROV uses a DIDSON for a salvage operation on a downed oil rig platform. (Courtesy of Submersible Systems, Inc.)

Rental of Acoustic Movie Cameras: Three companies in the Gulf Coast area rent acoustic movie cameras. They are 1) Come Monday, Inc. (Houston, TX), 2) Harvey-Lynch (Stafford, TX), and 3) Royal Service and Rentals (Broussard, LA). Typical applications are feedback for navigating ROVs, inspecting pipelines, surveying platform structures, and monitoring divers. Their arsenal includes acoustic cameras that are depth rated to 300 m, 1000 m, and 3000 m.

Fig. 8. Salmon are imaged with DIDSON and counted when swimming upriver to spawn in an Alaska river laden with glacial silt. (Photo courtesy of Alaska Department of Fish and Game.)

FISHERIES

Acoustic movie cameras have been quite useful to fisheries both for enumeration and behavioral studies. For enumeration, their contribution has been the ability to work in shallow water (sometimes only 2 feet deep) and to be able to distinguish fish among rocks on the river bottom and debris in the water column. Over the last four years, the Alaska Department of Fish and Game installed 22 DIDSONs as shown in Fig. 8 to count fish in rivers laden with glacial silt. These systems have been sent to very remote sites and have distinguished themselves with a very low failure rate.

Fig. 9. The mouths of trawl nets are designed to reduce catching non-target species (bycatch). DIDSON images the fish behavior at the mouth of nets and provides needed feedback to improve the design. (Photo courtesy NOAA/NMFS/Northwest Fisheries Science Center.)

Acoustic movie cameras allow unprecedented study of behavior in turbid and dark waters where optical systems are ineffective. For example one study concerned spawning frequency at night in different flow conditions (related to how much water was spilled by a dam). Before DIDSON, they would have had to use lights with video and no longer have a dark environment. Another example is predation. Sometimes structures that are meant to help preserve fish around various water intakes or in fish passages at dams also harbor predators that then prey on the very fish they are trying to preserve. DIDSON monitors the predation events and provides information to better design these structures. Additional applications (Fig. 9) use DIDSON to monitor behavior of fish at entrances to bypass or screening systems designed to keep them out of harm's way from turbines, bycatch in trawl nets, irrigation systems, or drinking water processing systems. The acoustic movie camera provides important information to evaluate the effectiveness of these entrances and provides insight to make them more effective.

CHANGE FROM NOVELTY TO WORKHORSE

Since 2001, over 150 acoustic movie cameras have been placed in the field. They are used in shallow rivers and as deep as 3000 meters in the oceans. They are mounted on ROVs, AUVs, fixed bottom mounts, and held by divers. The almost-video quality images have allowed unprecedented vision in turbid water for a wide variety of tasks. A major benefit of the acoustic movie camera is its video stream of images. To better appreciate this, one can check out www.soundmetrics.com and view numerous "movies" from the camera.

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