ACOUSTIC, NEAR-VIDEO-QUALITY IMAGES FOR WORK IN TURBID WATER

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ABSTRACT

In clear water and with appropriate lighting, optical systems such as cameras and the human eye can image out to 5–10 m. With increasing frequency, however, underwater work that relies on optical systems is situated in turbid water where optical systems fail. We have developed two sonars that provide near-video-quality images in turbid water out to 10 m. The sonars can be carried by a diver or mounted on a small ROV. The video image can be seen in a color display mounted on a diver's mask or cabled to the surface. The sonars use a multi-element acoustic lens to focus sound on a composite PZT linear array to form multiple acoustic beams each less than 0.4° wide. The images have sufficient resolution that divers can identify and inspect objects without having to resort to tactile means. These sonars can also be used to monitor the work of and provide feedback to an ROV. The sonars operate at 2 or 3 MHz, consume 20–25 W of power, have fast refresh rates from 5 to 11 frames/s, and provide fields of view from 20° to 30°.

INTRODUCTION

In clear water with sufficient light, optical systems (cameras or eyes) can image out to 5–10 m. In many rivers, lakes, harbors, bays, and other coastal areas visibility is a fraction of a meter. There, optical systems have white screens, and divers must resort to tactile means. This paper describes two prototype sonars, the Limpet Mine Imaging Sonar (LIMIS) and the Acoustic, Barnacle Imaging System (ABIS) that bridge the gap between typical sonars and optical systems. Their extremely high (for sonar) resolutions and rapid refresh rates allow these prototypes to substitute for optical systems in turbid water. They consume little power (20–25 W), which makes them useful for diver-held operations and submersibles with power budgets. Although the sonars were designed for specific applications, discussed in the next section, they are quite suitable for these general applications:

Positive identification and inspection: After targets of interest have been located with a side-scan sonar and their locations have been recorded using GPS, the usual procedure is to send a boat to the first location and lower an ROV with a video camera to identify the target. If the water is too turbid and the camera generates a blank screen, the next step generally calls for a diver to find and then identify or inspect the target by tactile means. If ABIS or LIMIS were deployed on the ROV, one would simply switch to its output and make the necessary identification or inspection.

Recovery and construction: ROVs with articulated arms can recover objects or repair structures. Feedback to the operator is generally by video cameras. When the water is too turbid, or when the ROV stirs up silt from the bottom, the cameras do not function. ABIS or LIMIS could provide the needed feedback in those conditions.

Underwater surveillance: Specific objects or areas may require continuous monitoring for security, safety, or scientific reasons. These requirements would normally be met by small video cameras, but in low-visibility, monitoring must rely on acoustic imaging systems.

SONAR DESCRIPTIONS

LIMIS (Limpet Mine Imaging Sonar)

LIMIS has two realizations: hand-held and ROV-mounted. The diver-held version is shown in Figures 1 and 2. The display mounts on the diver's mask and provides him with a color image that can be seen clearly in zero-visibility water[1]. Optics in the display form a virtual image that appears large and at a comfortable distance from the eye. LIMIS was designed to be held by divers as they search for limpet mines attached to the hulls of ships. It operates at 2 MHz and images objects between 1 and 12 m from the sonar. Figure 3 shows three images with a near-video quality that allows divers and ROV

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Fig 1. The hand-held configuration of the LIMIS and its mask-mounted display.

Fig. 2. A diver views images from the LIMIS through its mask-mounted color video display.

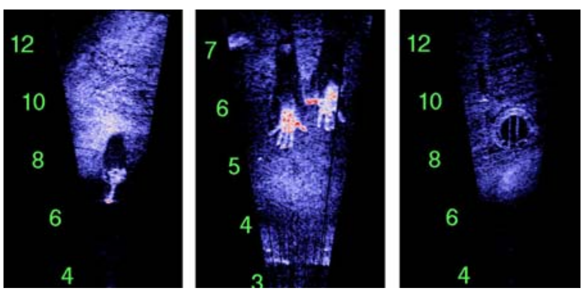

Fig. 3. Three sample images taken with LIMIS. The left image shows a limpet mine on the hull of a ship 7 feet (2.1 m) from the sonar. The center image shows two hands. The right image shows an intake on the hull of a ship. The intake is approximately 46 cm in diameter and is 9 feet (2.7 m) from the sonar. The left and right images were taken in Chesapeake Bay in water with 15-cm visibility.

operators to positively identify objects in turbid water. The mine and intake are 2.1 and 2.7 m (7 and 9 ft) respectively from the sonar. The water visibility was 15 cm. At these ranges, the images update at 11 frames/s and provide a smooth dynamic scene as the sonar moves or objects move within the field of view. Figure 4 shows the image of a cinder block on the bottom of Puget Sound 1.8 m (6 ft) from the sonar. Figure 5

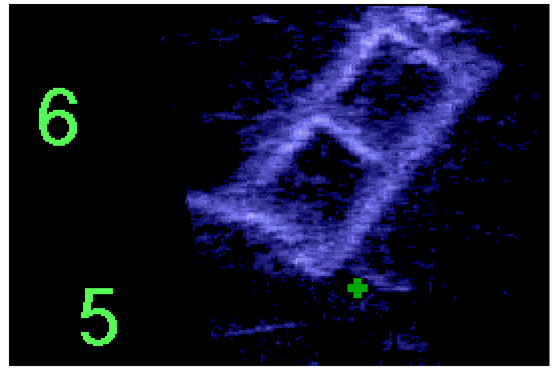

Fig. 4. A cinder block on the bottom of Puget Sound 6 feet (1.8 m) from the sonar.

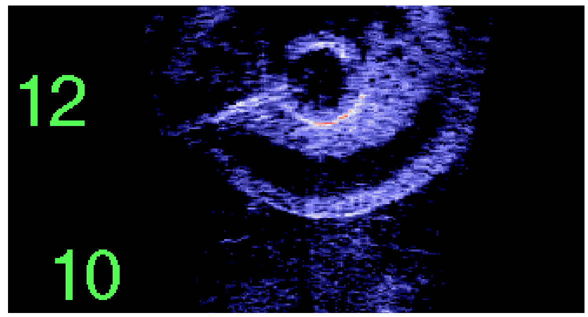

Fig. 5. A railroad car wheel with a chain coming out from the hub. The wheel was imaged in Puget Sound when 12 feet (3.6 m) from the sonar.

shows a railroad car wheel that was used as a weight and has a chain coming out of the hub. The wheel was 3.6 m (12 ft) from the sonar and covered with bottom growth such that it was invisible optically.

The sonar is controlled by an RS-232 link or by thumb switches on the sonar handle. The sonar operates for 3.5 hours on its internal, rechargeable nickel metal hydride batteries. An auxiliary power pack approximately 2.5 cm by 8 cm by 15 cm snaps on the bottom of the unit to give 1.5 hours of additional operation. Alternatively, 15 Vdc can be cabled to the unit for indefinite operation. The ROV version is shown in Figure 6. It outputs data either in NTSC video format or by Ethernet as a series of 64 by 512 byte arrays. LIMIS specifications are shown in Table 1.

ABIS (Acoustic, Barnacle Imaging System)

ABIS was designed to mount on a hull-crawling ROV to detect and grade fouling on the hulls of ships. It is part of a larger program directed by the Naval Surface Warfare Center (NSWC) to autonomously clean hulls of naval ships. It images barnacle-size objects 0.8 m to 4.5 m in front of the sonar. Figure 7 shows the sound-

Fig. 6. The LIMIS model configured for a submersible.

Fig. 7. The ABIS soundhead and electronics module form a forward-looking sonar that mounts on an ROV. The ROV will inspect hulls for fouling and clean selected sections. The images will update 6 times/second and have 1-cm resolution at 3-m range.

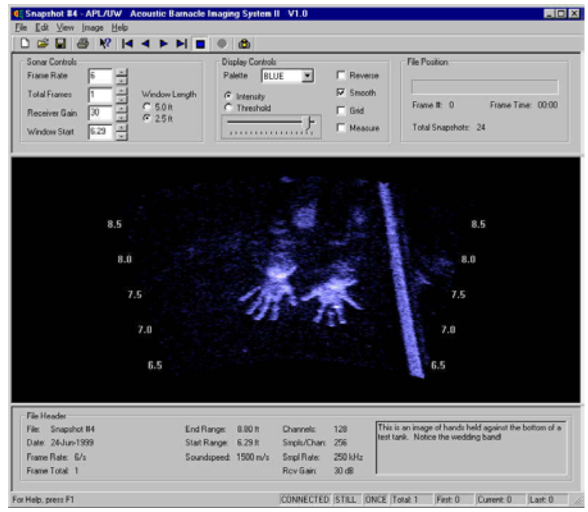

Fig. 8. The display of ABIS showing control and status parameters as well as an image of two hands 7.25 feet (2.2 m) from the sonar. Note the wedding ring on the left hand.

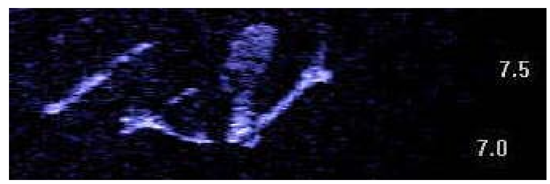

Fig. 9. Image of three tools 7.25 ft (2.2 m) from ABIS. The tools are: screwdriver (left), cutters (center), and end wrench (right). The close end of the end wrench is lying on a patch of unpainted surface.

head and electronics module. The division into two modules gives more flexibility in placement on a submersible. A 500-ft cable with power conductors and fiber optics connects the electronics module with a breakout box on the surface. A PC connects to the breakout box and runs a Windows application that controls the sonar and displays the data. The images in Figures 8 and 9 were made in a test tank 1.2-m wide, 3.6-m long, and filled with water 50-cm deep. Figure 8 shows the topside Windows display with control and status parameters and an image of two hands 2.2 m (7.25 ft) from the sonar. Note the wedding band on the left hand. Figure 9 shows three tools at 2.2 m (7.25 ft) from the sonar. At the left is a screwdriver, in the center is a pair of cutters, and at the right is an end wrench whose end closest to the sonar is lying on a section of bottom with no paint. The unpainted galvanized surface of the test tank is brighter (returns more sound) because it is rougher than the painted surface. At this range, the image is refreshed 6 frames/s. This refresh rate allows the sonar to maintain a smooth dynamic image as it moves or objects move within its field of view. The ABIS refresh rate varies from 4 to 9 times/s. ABIS specifications are shown in Table 2.

BASIC PRINCIPLES

Both sonars use a set of thin, acoustic lenses made of polymethylpentene to focus sound on a 1-3 composite linear array.[2,3] An example of a lens set is shown in Figure 10. Four advantages of acoustic lenses over conventional electronic beamforming are (1) acoustic lenses can form any number of beams in parallel at the speed that sound passes through the lenses, (2) digitization occurs after the beams are formed such that a much lower sampling rate is required, (3) beamforming takes no power, and (4) the sonar transmits and receives narrow beams through the same lens set. Two disadvantages are (1) the lenses and the spaces between the lenses add volume in front of the transducer array, and (2) multiple reflections between lens surfaces cause internal reverberation. The reverberation

Table 1. LIMIS Specifications

Cross-range resolution	1.6 cm at 3-m range
Beamwidth	0.35° horizontal by 13° vertical (one-way)
Number of beams	64
Field of view	19.2°
Range settings	3–15 m, 1.5–8 m, 1–3.6 m, 0.6–2 m
Down-range resolution	2.5 cm, 1.25 cm, 0.6 cm, or 0.3 cm
Frame rate	5.5 (15-m range) 11 (all other ranges)
Source level	211 dB re 1μPa
Operating frequency	2 MHz
Power consumption	25 W (1.75 A at 14.4 Vdc)
Power options	Internal batteries, nominal 3.5-hour duration External battery pack, 1.5-hour duration Cabled power, indefinite duration
Weight (diver-held)	7.7 kg in air, including internal batteries 100 g positive in seawater
Weight (ROV-mounted)	5.0 kg in air and 0.8 kg positive in seawater
Dimensions (diver-held)	18-cm wide, 20-cm high, and 36-cm long
Dimensions (ROV-mounted)	16.8-cm wide, 20.6-cm high, and 29.5-cm long
Output format	NTSC video on a mask-mounted monitor or cabled topside.
Control	Switches on handle or RS-232
Digital Uplink	RS-232 to transfer selected digital images

Table 2. ABIS Specifications

Cross-range resolution	1 cm at a 2.5-m range
Beamwidth	0.27° horizontal by 8.5° vertical
Number of beams	128
Field of view	32°
Start ranges	0.8, 1.9, 2.7, 3.0 m
Window lengths	0.75, 1.5 m
Down-range resolutions	3, 6 mm
Frame rate	4 to 9 frames/s
Source level	208 dB re 1 μpa
Operating frequency	3 MHz
Power consumption (underwater modules)	120 VAC 20 W
Dimensions Soundhead Electronics module	 29-cm long by 18-cm wide by 18-cm high 17.1-cm diameter by 30-cm long
Weight in air Soundhead Electronics module	 6 kg 6.1 kg
Communication link	152 m of fiber optic cable with power conductors. Cable diameter is 1.3 cm. Protocol is 10BaseT Ethernet.

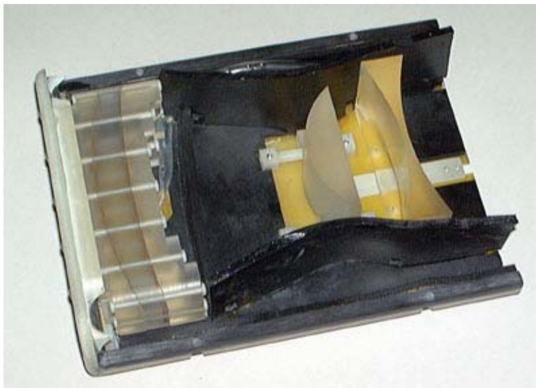

Fig.10. The lens set begins with a triplet plastic-liquid-plastic lens (left side of the photo) followed by two plastic lenses. The transducer array (not shown) fits in the rectangular opening on the right side of the housing. When the sonar is submerged, ambient water fills the spaces between the lenses and the transducer array.

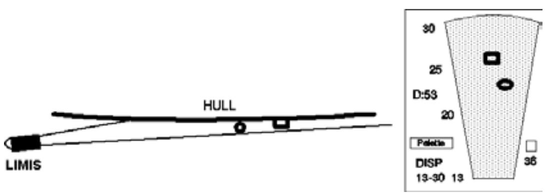

Fig. 11. LIMIS and ABIS are held near the hull to get a small grazing angle. Targets are displayed as if seen from an angle perpendicular to the hull.

inside these sonars is about 40 dB down from the target echoes and scatters to form a slightly brighter background. No range-shifted “ghosts” of target images are seen.

The sonars generate multiple beams that are narrow in azimuth and wide in elevation. The diver or ROV images an area by aiming the sonar as shown in Figure 11. Each beam hits the surface at a small grazing angle and ensonifies a stripe on the surface. The 64 (or 128) beams ensonify contiguous stripes that cover the area of interest. Objects are displayed as if seen from an angle perpendicular to the hull.

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