USE OF LASER SCANNING SYSTEM ON MOBILE UNDERWATER PLATFORMS

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Abstract - An underwater Laser Based Synchronous Scanning System which produces high quality images, through turbid waters, is described. A prototype system has been developed at Spectrum Engineering Inc. to demonstrate the operational feasibility of Synchronous Line Scan architecture. This prototype system incorporates an Argon Ion laser operating at 488 and 514.5 nanometers. Operational systems could incorporate a frequency doubled Nd:YAG solid state laser operating at a wavelength of 532 nanometers. Both laser configurations operate at wavelengths attractive for use in underwater systems due to minimum light attenuation at these wavelengths. Operational platform results presented here were performed on a research submarine and a towed body.

## INTRODUCTION

Producing useful imagery in the underwater environment is a difficult challenge. In most underwater imaging systems there is not sufficient ambient light available to produce images. Thus, artificial illumination is a primary component in nearly all underwater imaging systems. The propagation of light through sea water suffers from two primary effects, absorption and scattering.

Absorption is the loss of optical energy as light propagates through water. A primary reason for this increased absorption in sea water, versus air for example, is the increased density of suspended particles in the sea water medium. The concentration of these particles varies from less than 0.1 $mg/m^3$, in deep open ocean water to greater than 1 $mg/m^3$, in coastal waters and bays. This higher density increases the probability that a propagating photon will interact with suspended particles. This interaction absorbs energy from the light beam, thereby reducing the signal available to an imaging sensor.

A second problem of great importance in underwater imaging is scattering. The scattering function is the process by which the direction of photons in the propagating light beam are deflected from the original path. If scattering occurs at an angle of less that 90 degrees, it is called forward scattered. If the angle is greater than 90 degrees it is referred to as backscatter.

The backscatter process has the effect of masking the image. Since backscatterd light typically travels a shorter distance and therefore suffers less attenuation than the "reflected light from target", it has a higher intensity. Therefore the "signal light" is masked by the backscattered light.

The forward scattering process has two effects. The first effect is that, as the light propagates from the source, scattering causes the light beam to spread and increases the area illuminated by the light source. This decreases the optical intensity per unit area illuminating the target, as well as illuminating areas outside the region of interest. The second effect of forward scattering is evident as the light reflected from the target, "the signal", is forward scattered as it propagates back to the imaging sensor. This forward scattering causes light received at the imaging sensor to appear to have originated at a different location in the object plane than it actually did, thereby potentially blurring the image.

## OPTICAL ARCHITECTURE

As described above, the absorption and scattering processes make underwater imaging, at extended ranges, a difficult problem. Throughout the history of underwater imaging, numerous optical architectures have been developed to address these difficulties. These include separated source and receiver, indirect illumination[1], range gating[2] and synchronous scanning[3,4]. Typical operational ranges of various optical architectures are shown in Figure 1. This paper reports on a synchronous Laser Line Scan Imaging System developed by Spectrum Engineering Inc.

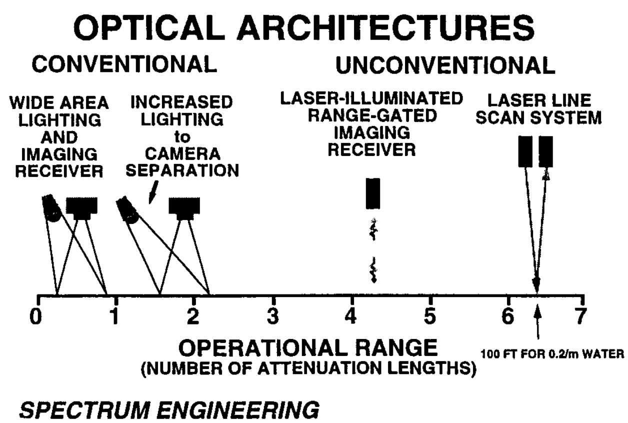


Figure 1
Operational Ranges Underwater Imaging System

Synchronous Scanning relates to family of optical systems where the field of illumination and the field of view of the receiver are overlayed and scanned together. The system developed by Spectrum Engineering Inc. utilizes one of the synchronous scanning architectures referred to as a line scanner.

Figure 2. shows a conceptual sketch of the Laser Line Scan System (LLSS). Two mirrors are rigidly mounted to a common motor shaft. The laser output is incident on one of the mirror facets and reflected toward the object being scanned. As the motor rotates, the laser beam is scanned across the object. Since the two mirrors are mechanically coupled, the receiver aperture is always pointing

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in the same direction as the laser beam. The field stops in front of the sensor (PMT) control, the field of view of the receiver, and make it coincident with the field of illumination.

The primary advantage of the LLSS architecture over conventional imaging systems is that it minimizes both backscatter and forward scatter. As shown in Figure 2, the field of illumination and the field of view of the receiver have a small common volume which reduces the effect of backscatter. Also, since the LLSS produces a reflectance map of the object, rather than an image, forward scattered light has a less severe impact. in the LLSS, all light that originated in the receiver field of view, is a useful signal whether it has been forward scattered or not. Therefore, only light which originated outside the receiver field of view, and was forward scattered into this field of view, is considered noise. In a conventional imaging system all light that is forward scattered while returning from the object to the receiver contributes to noise.

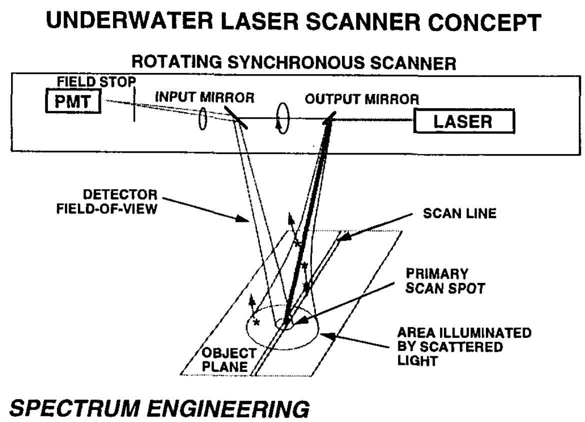


Figure 2
Laser Line Scan System Conceptual Sketch

The output of the PMT is proportional to the reflectance of the object being scanned. Generation of the reflectance map in the LLSS is accomplished by sampling the output of the PMT at periods that are synchronized to mirror rotation. The sampled PMT output is digitized and used for generating a video display. The digitzation and video display generation are accomplished using a commercially available frame grabber operated in a variable scan mode. The timing signals required by the frame grabber are generated by the LLSS to establish a 1:1 aspect ratio for the pixels along the center line of the swath. The sample rate calculated is directly proportional to the sensor speed over the bottom, and inversely proportional to the desired pixel spacing. As the sensor passes over a stationary object the display is built up a pixel at a time until an entire line is generated. The new line is displayed at the top of the monitor, and all previous lines shifted down sequentially, with the bottom line no longer in view, resulting in a "waterfall" effect.

## TEST RESULTS

Since the summer of 1990 the Laser Line Scan System has undergone field testing. The testing has been performed on a research submarine as well as a towed body. The following is a discussion of these test results.

### Dolphin Test Results

During the summer of 1990, the Laser Line Scan System was deployed on the research submarine USS Dolphin (AGSS-555). The July 1990 at-sea testing was performed off the coast of San Diego, CA.

During the LLSS test program on the USS Dolphin, the LLSS was compared to an intensified CID (ICID) camera system and an Electronic Still Camera (ESC) utilizing an intensified CCD (ICCD). The illumination for the ICID camera was provided by two 500 watt thallium iodide lights. In order to minimize the the effects of backscatter, the lights were located 45 feet aft of the camera. The illumination for the ESC is provided by strobe lights with an output of 300 watt-seconds. Comparisons of the LLSS to these two imaging systems are shown in Figures 3 and 4.

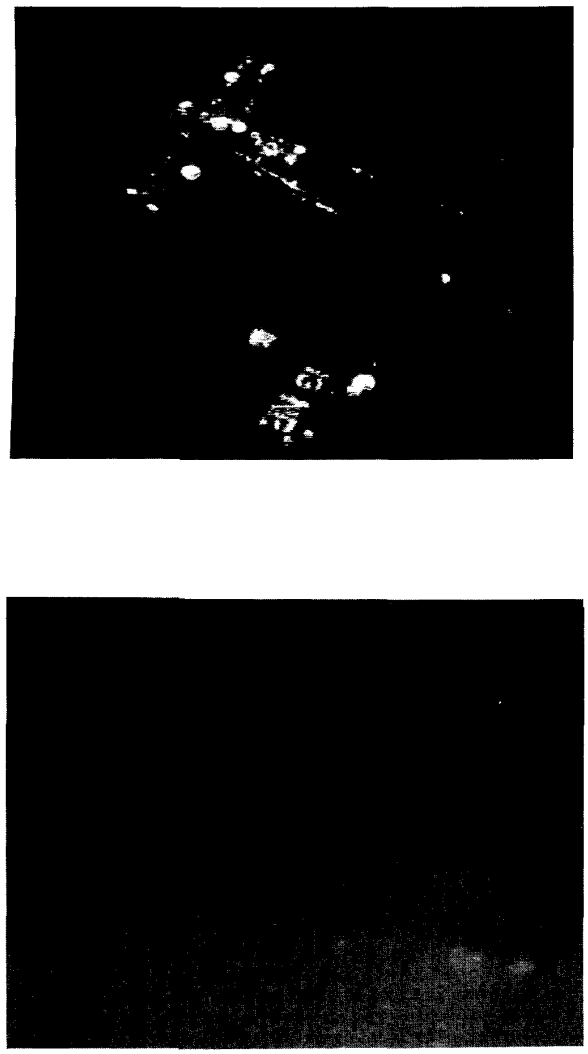

Figure 3
Comparisons of images of a sunken WWII torpedo bomber generated by the ICCD and LLSS under nearly identical conditions.

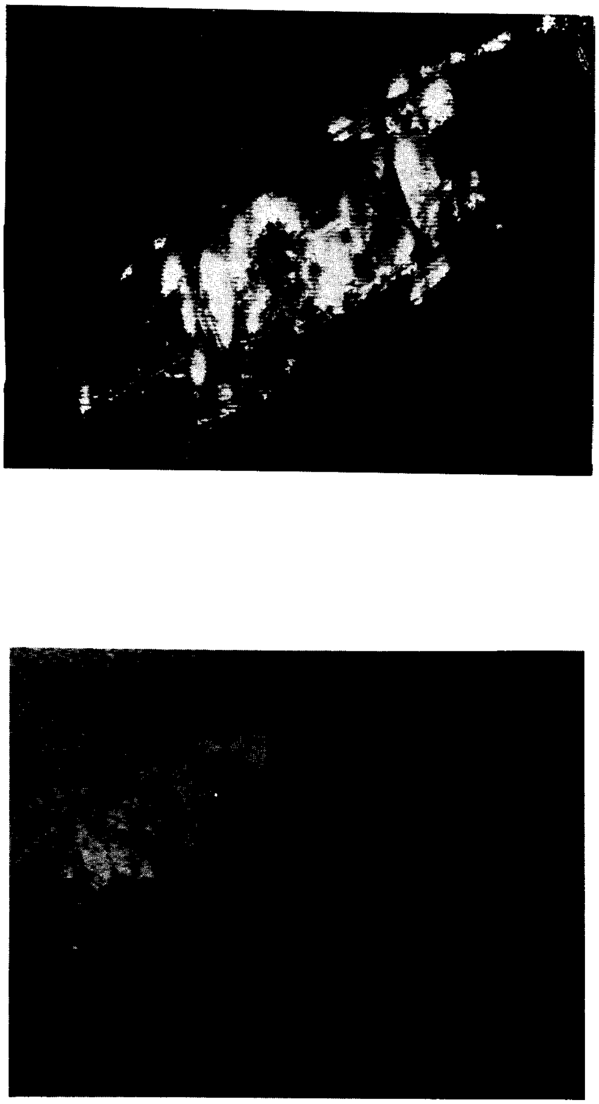

Figure 4
Comparisons of images of a sunken sailboat generated by the ESC and LLSS under identical conditions.

The results obtained during the testing on the USS Dolphin demonstrated that improved imagery is achievable using a synchronous scanning system. While these results are an indication of the potential of the synchronous scanning system the question of platform stability was not addressed because the USS Dolphin is a very large and stable platform. The concern for platform stability is due to the fact that the LLSS generates a one dimensional image, with the second dimension being produced through the forward motion of the host platform over the object.

Towed Body Test Results

From November 1991 through February 1992 a towed body test program was implemented with Saches Engineering Associates (SEA). The primary purpose of this test program was to evaluate the LLSS performance on a more dynamic platform such as towed body. The towed body developed by SEA was a heavy "fish" with fixed vertical and horizontal stabilizers. During the majority of testing the effects of towed body motion were not noticeable, and high resolution imagery was produced, as shown in Figure 5. In Figure 6 an image shows the effect of towed body motion but demonstrates that useful imagery is possible even on more dynamic host platforms. If the host platform motion is measured, post processing of the imagery could be performed to remove the effects of platform motion.

Figure 5
High resolution imagery produced by the LLSS on a towed body showing the 8 inch difussers of the San Diego Sewer Outfall

Figure 6
Imagery produced by the LLSS on a towed body showing the effects of host platform motion

## CONCLUSION

The Laser Line Scan System is capable of generating high quality images at extended ranges as shown during tests performed on the USS Dolphin and the SEA towed body. The towed body testing shows that while images generated by the LLSS will show effects of platform motion, extraordinary efforts to stabilize the platform are not required ot support generation of high quality imagery.

The prototype Laser Line Scan System utilizes an Argon Ion gas laser which requires a large power budget. While this power budget is not a limitation on towed bodies, ROV's submarines or large AUV's an LLSS configured with a solid state laser would be attractive for use in more general AUV/ROV applications.

## REFERENCES

(1) W.H. Wells, Tetra TEch Data Systems Inc. "Indirect Illumination to Reduce Veiling Luminance in Seawater", Proc. SPIE vol. 1537-01, 1991 San Diego, California Conf. on Underwater Imaging Photography, and Visibility, pp. 2-9, July 1991.

(2) B.A. Swartz, Sparta Laser Systems Lab, J.D. Cummings, Applied Remote Technology, "Laser Range-Gated Underwater Imaging Including Polarization Discrimination", Proc. SPIE vol. 1537-04, 1991 San Diego, California Conf. on Underwater Imaging Photography, and Visibility, pp. 42-56, July 1991.

(3) B.W. Coles, "Recent Development in Underwater Laser Scanning Systems", Proc. SPIE vol. 980 San Diego, California Conf. on Underwater Imaging, pp. 43-51, August 1988.

(4) P.J. Heckmen, P.D. McCardell, "Real Time Optical Mapping System", U.S. Patent No. 4,143,400, 6 March 1979.