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Underwater Laser Imaging System (UWLIS)

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ABSTRACT

Practical limitations of underwater imaging systems are reached when the noise in the back scattered radiation generated in the water between the imaging system and the target obscures the spatial contrast and the resolution necessary for target discovery and identification. The advent of high power lasers operating in the oceanic transmission window of the visible spectrum (blue-green portion) has led to improved experimental illumination systems for underwater imaging. The properties of laser beams in range-gated and synchronously scanned devices take advantage of the unique temporal and spatial coherence effect of common volume back scatter to reduce or eliminate noise, increase signal to noise levels.

Synchronously scanned systems rely on the highly collimated nature of the laser beam for spatial rejection of common volume back scatter. A synchronous, raster-scanning underwater laser imaging system (UWLIS) has been developed at Lawrence Livermore National Laboratory. The present UWLIS system differs from earlier synchronous scanners in its ability to scan in two dimensions at conventional video frame rate (30 Hz). The imaging performance of the present UWLIS was measured at distances of up to 6.3 AL (at a physical distance of 15.2 meters) during an in-water tank test and 4.5 to 5.0 AL (at a physical distance of 30 meters) during open water oceanic testing. The test results indicate that the UWLIS system is already capable of extending the underwater imaging range beyond that of conventional floodlight illuminated SIT cameras. The real or near real time frame rates of the UWLIS make possible operations in a mode in which the platform speed is randomly varied. This is typical of the operational environment in which the platform is often maneuvered above and around rugged seafloor terrain's and obstacles.

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INTRODUCTION

Scatter produced in the overlapping volume of illumination source and the field-of-view (FOV) of the imaging device (common volume back scatter) limits conventional systems, composed of wide-beam floodlights and video cameras, to imaging targets at approximately 2 attenuation lengths (AL). This corresponds to approximately 15 meters in deep ocean water and less than 1 meter in coastal waters where turbidity is much greater due to pollutants and sediment. Deep ocean applications involving remotely operated vehicles (ROVs) could include salvage and environmental monitoring operations. Shallow water applications could include detecting beach obstacles, mines, or waste canisters as well as drill rig or pipeline inspections.

Range-gated systems use a time of flight technique to discriminate target reflected signal from common volume backscatter. Nanosecond duration laser pulses are used to illuminate the target. Back reflected signals are imaged by a time-gated electronic camera. The camera gate is triggered to open after one round-trip time-of-flight of the laser pulse and remains open for a time equal to the laser pulse duration. Scattered light that has traversed longer path lengths arrives outside the time window and is therefore discriminated against. If laser powers and, therefore, return signals are high enough , single shot two-dimensional illumination and imaging is feasible. If laser power is not sufficient, signal averaging of consecutive pulses is necessary.

Synchronously scanned systems rely on the highly collimated nature of the laser beam for spatial rejection of common volume back scatter. A continuous-wave (CW) laser beam illuminates a target at a single point. Back reflected radiation from the point of interrogation is collected in the well-collimated instantaneous field of view (IFOV) of a single-element detector. The overlap zone between the illumination and detection volumes is the small overlap length of these two beams. The small size of this overlap length results in a dramatically reduced common volume between the two beams and consequently a minimization of common volume back scatter. The overlap region is scanned in a line or raster fashion across the target to create a video image of the target.

CURRENT UWLIS

The present UWLIS incorporates laser transmission and signal return paths that are completely separate, obviating problems associated with scatter generated in the scanner optics. The beam from a cw argon-ion laser capable of delivering 7 watts of power all lines (457-514 nm) is injected into the scanner to intercept a horizontal scan mirror. It is then reflected down to a vertical scan mirror and out of the scanner to a periscope mirror assembly where it is directed to the target (figure 1). The return signal is detected and scanned with an image dissector tube (IDT) The IDT is a scanning photomultiplier tube in which a signal generated at any small region of the photocathode can be selectively detected at the anode. In the UWLIS system, the IFOV of the IDT is raster scanned when the appropriate drive signals (electric fields) are applied to the IDT deflection plates to scan the photocathode interrogation region. The drive signals are amplifications of the output from sensors monitoring the position of the scan mirrors. The present raster-scanning system utilizes an existing mechanical system to accomplish beam scanning and generation of the RS-170 video signal.

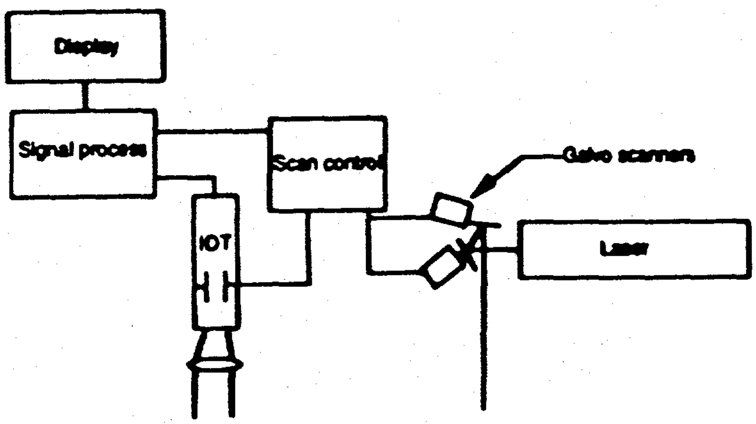

Figure 1

To generate the raster scan the horizontal mirror galvo is driven at a rate of 3933 Hz by a sinusoidal drive signal. The horizontal mirror galvo is a resonant device that runs freely. System timing is derived from the horizontal galvo motion. The vertical mirror galvo is a ordinary stepping type scanner that is driven by a 60 Hz sawtooth wave to produce the vertical dimension of the raster scan (figure 2) The IDT imager generates fields every 1/60th second in which alternating lines are scanned and full frames every 1/30th second. Processing electronics complete the scan conversion to RS-170 video format.

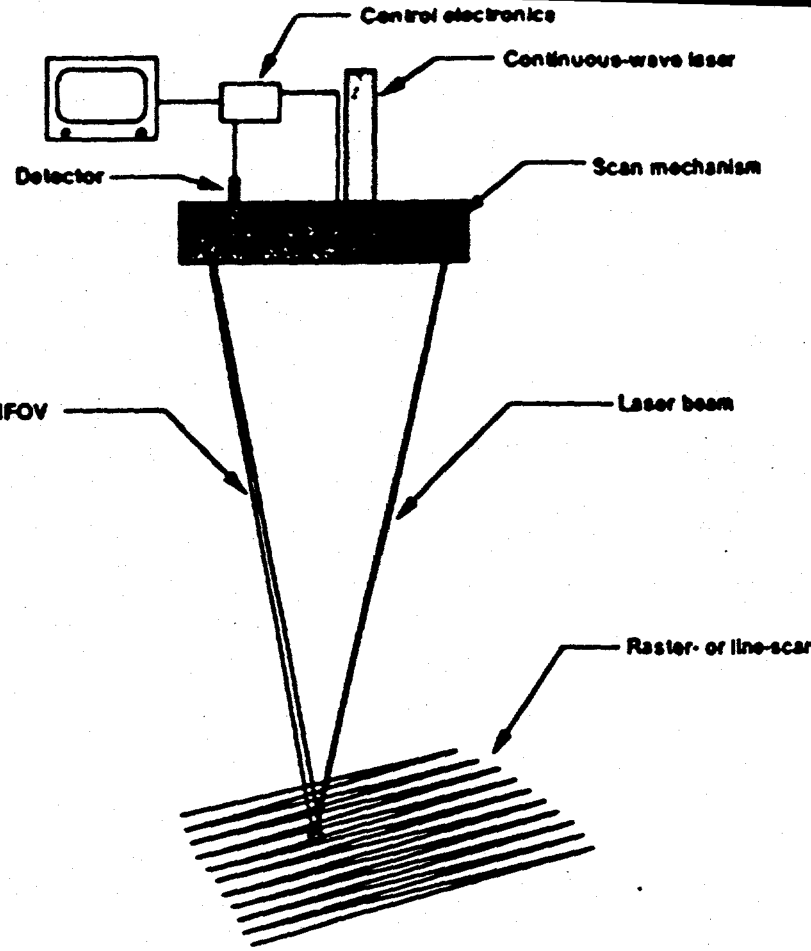

Figure 2

The system FOV is currently limited by the particular resonant horizontal scanner being used. The maximum view angles for the raster scan are 18 degrees by 14 degrees, for the horizontal and vertical dimensions respectively. As previously mentioned, the horizontal and vertical galvo position sensor signals are amplified and used to drive the horizontal and vertical deflection plates of the IDT. Photoelectrons from the photocathode region are focused by a set of electrodes and deflected by the deflection plates through a small aperture. The position of the interrogation region on the photocathode is determined by the voltages on the deflection plates, while its size is determined by the size of the aperture. The present IDT has a custom aperture size of 265 um and an electronic lens magnification of 0.5. The resulting diameter of the photocathode collection area is 530 um. The target region is imaged onto the IDT with a f/1.2, 50 mm focal length camera lens. The collection optics produce a circular IFOV with a divergence of 10.6 mrad, which is approximately ten times greater than the 1 mrad divergence of the argon-ion laser beam. The oversized IFOV is necessary to accommodate synchronization at all positions of the raster because of distortions in the IDT, allowing fully synchronized imagery over the full system FOV.

At ranges of less the 4AL the imager was capable of producing acceptable video images at the full imaging bandwidth (real time, no averaging). At longer range it was necessary to reduce the frame rate (signal average) to improve the image signal-to-noise ratio. At ranges between 4 and 5 AL, an eight-frame average was used. Between 5.0 and 5.7 AL a 32-frame average was used, although an four-frame average still produced usable images up to 5.5 AL. To reach 6.3 AL, a 128-frame average was used. The results of the test demonstrate that the UWLIS was limited by the magnitude of the return signal and the residual electronic noise and not common volume back scatter. The ultimate range achievable for this type of system is determined by laser power, optical collection geometry, and the degree of frame averaging that is used (figure 3).

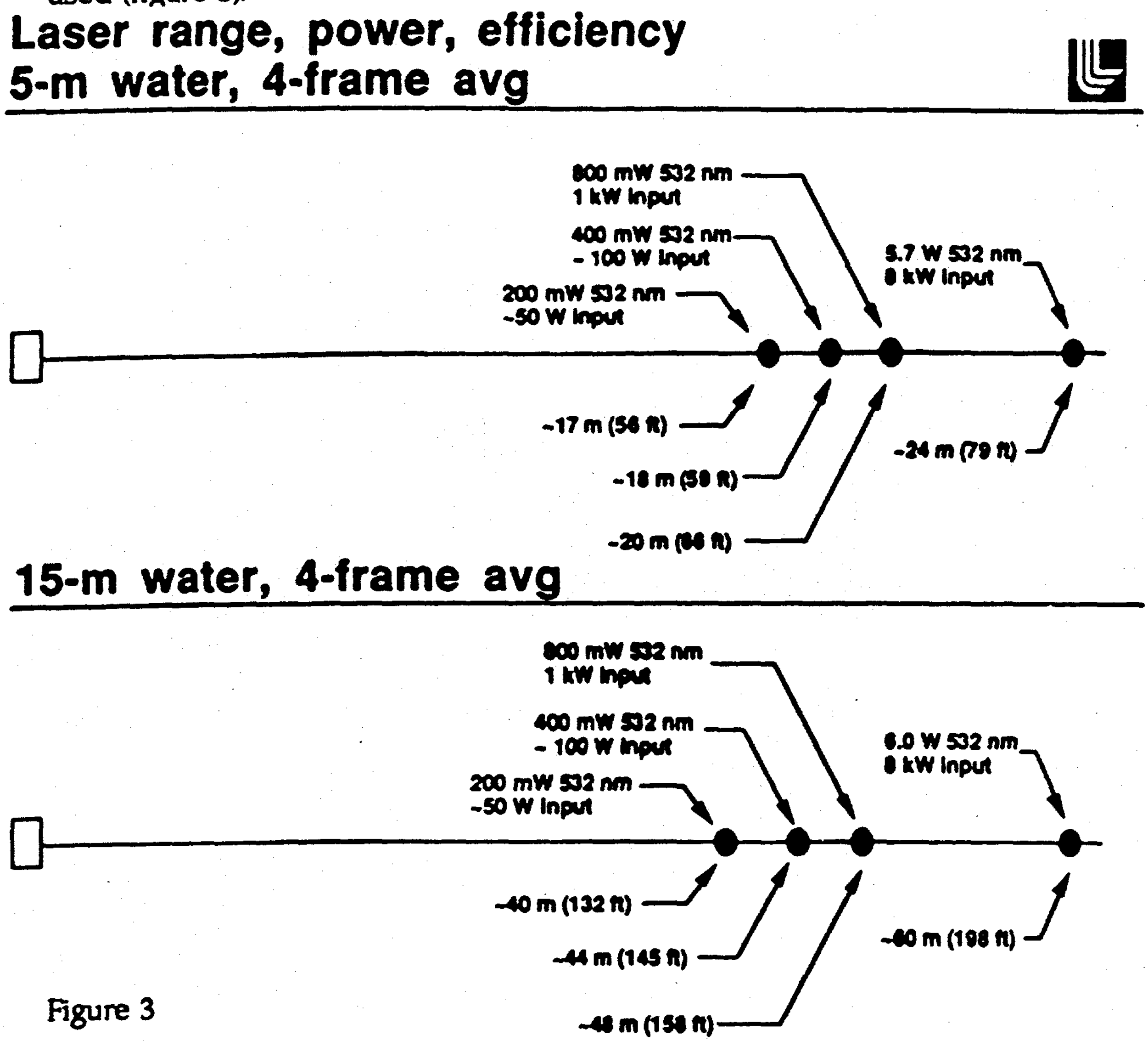

Figure 3

PROJECTED IMPROVEMENT AREAS

Several areas of improvement exist to facilitate the implementation of an enhanced UWLIS commensurate with ROV platform applications. The improvements noted here are development oriented and would bring the system up to a point where packaging and not specifications would begin to be the main development concern for a field ruggedized system. They include the laser source, scanner, collection optics, and receiver.

Presently, an electrically inefficient and mechanically cumbersome argon-ion laser is being utilized as a source for UWLIS. Recent developments in the area of frequency doubled, diode pumped Nd:YAG lasers have resulted in 532 nm sources operating at power levels of 800 mW to 1.2 W with input power requirements of 60 to 150 W. Compared to the 10 kW necessary to run a 7 W argon-ion laser, it becomes possible to allocate the power required to operate a laser on a moderately sized platform. Not only will the power budget limitations be relaxed, but the solid state blue-green light sources are more reliable and far more compact (less than one tenth the physical size) than the present argon-ion source, resulting in a laser source more easily adapted to operations in rugged environments.

The two-dimensional scanning UWLIS is suitable for operations in which the platform is either to remain stationary or move in a random fashion. While this is acceptable for certain operations, it is not compatible with wide swath search operations in which large areas of ocean floor must be covered. For such applications an enhanced FOV system would be more appropriate, the redesigned, modified FOV system would allow imaging at a variable FOV of between 8 and 60 degrees. This can be accomplished using the same mirror configuration with modified galvanometers in a new double reflecting geometry that will allow a doubling of the horizontal FOV with the same mechanical displacement. The vertical FOV will be doubled by increasing the vertical mirror displacement. The system can be further modified to allow either line or raster scanned operations. The new system would then have a combined capability of wide swath search imaging and narrow FOV inspection. In a typical application, the imager would be flown in a line-scanned or wide FOV raster scanned mode until a target is spotted, at which point a narrow raster scanned FOV would be used to view the target at higher resolution for visual identification (Figures 7&8).

Combined system

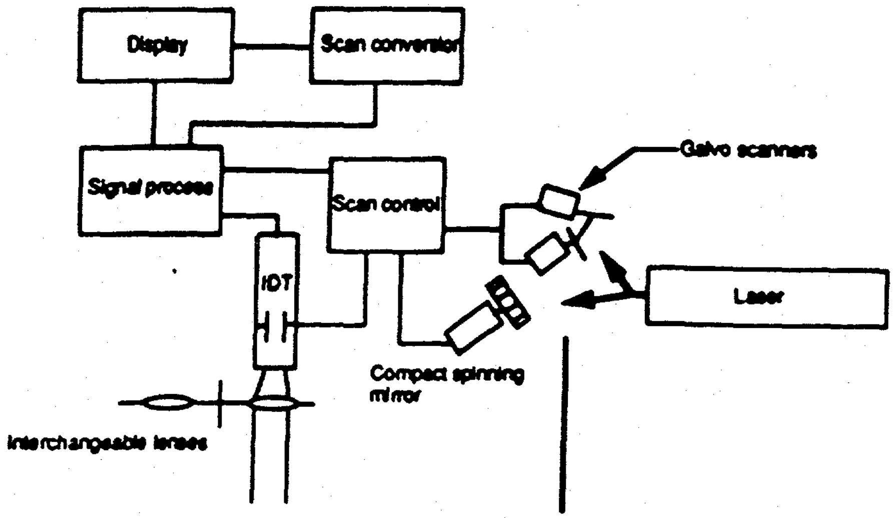

Figure 7

Packaging concept - dual system

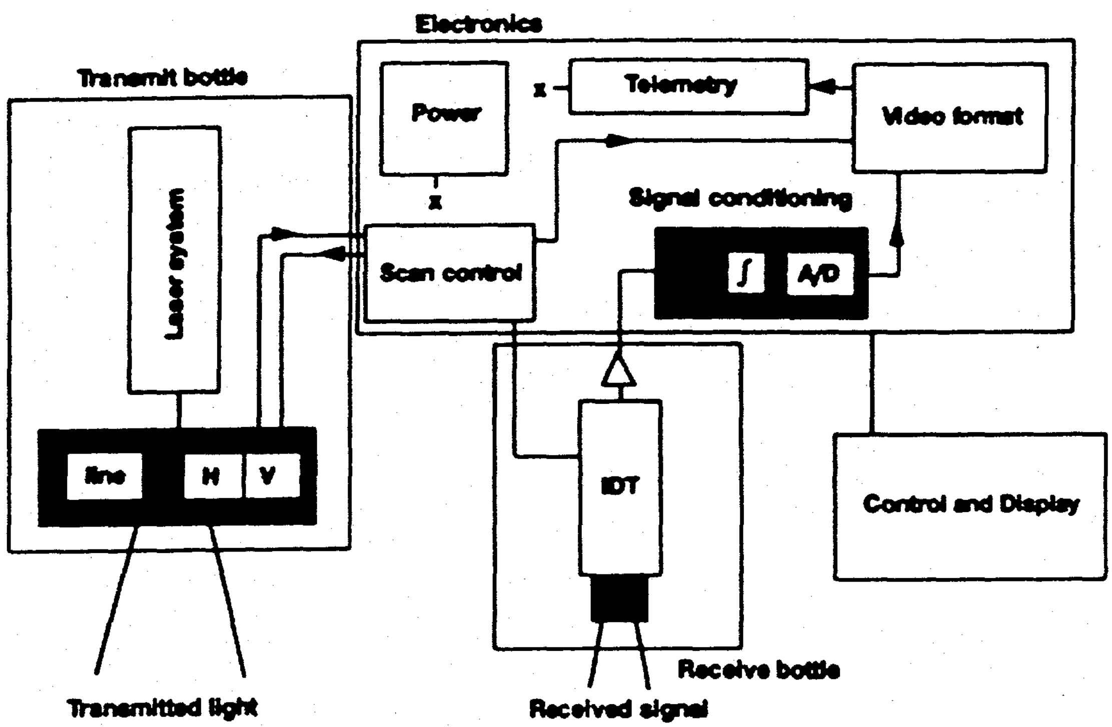

Figure 8

Further system improvements can be realized in the IDT. As previously stated, the IDT currently being employed has a fixed aperture of 250 um and an electron lens magnification of 0.5. In conjunction with the f/1.2, 50 mm focal length imaging lens, the IFOV acceptance angle is approximately ten times the divergence of the laser beam. A properly designed IDT with adjustable aperture could decrease this mismatch, and further enhance common volume backscatter discrimination (figure 9). By reducing the f-number of the receiver lens, the collection efficiency of the system can be increased. Installing a motor controlled lens would allow remote adjustment of the system f-number via autofocusing, resulting in a maximized return signal at any range within the system limits.

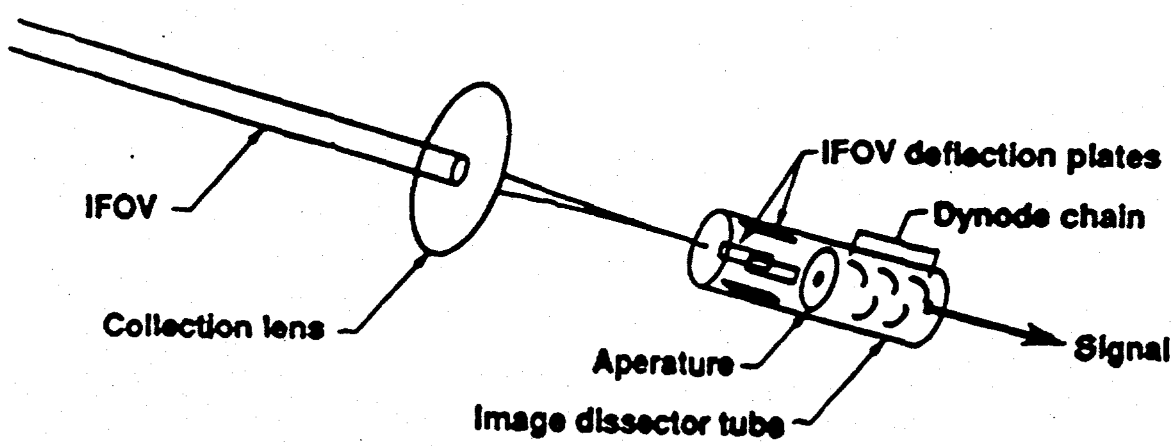

Figure 9

REFERENCES

T.J. Kulp, D. Garvis, R. Kennedy, T. Salmon, and K. Cooper, "Results of the Final Tank Test of the LLNL/NAVSEA Synchronous-Scanning Underwater Laser Imaging System (UWLIS)", Proceedings of SPIE, Ocean Optics XI, (Society of Photo-Optical Instrumental Engineers, Bellingham, WA,1992),, San Diego, CA, pp. 453-464

T.J. Kulp, D. Garvis, R. Kennedy, T. Salmon, and K. Cooper, "The Development and Testing of a Synchronous Scan ning Underwater Imaging System Capable of Rapid Two-Dimentional Frame Imaging", accepted for publication in *Appl. Opt*, January, 1993

T.J. Kulp, "Underwater Laser Imaging System (UWLIS) Ocean Test Report", NAVSEA/OOC Office of Salvage and Diving, U.S. Navy, May, 1993