Extended Range Optical Imaging System for AUV Use

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LONG-TERM GOALS

The long-range goal of this program is to develop a new imaging system for underwater use that can be deployed on an AUV. This includes a consideration of the physics of the underwater environment with respect to light propagation, the use of contemporary illumination systems, optical components, and the development of digital signal and image processing algorithms.

OBJECTIVES

To design and test an underwater optical imaging system specifically tailored towards deployment on an AUV.

APPROACH

Our approach is to follow standard engineering practices. This involves the investigation and review of various designs and permutations that can be adapted to fit on the autonomous platform and also provide the performance necessary for high-resolution imaging in turbid environments. At the same time, the balance between current technology and design strategy must be continually resolved so that high performance can be achieved even with the small space, power constraints and rugged environment posed by AUV operations. The design must also promote high reliability, minimize or eliminate any setup time or pre-cruise adjustments so that its high performance capability can be maintained in the ocean environment.

WORK COMPLETED

A number of different permutations of the original Laser Line Scan (LLS) concept, particularly with regard to the backscatter reduction capability of the receiver, have been considered and reviewed in terms of performance benefit and the small size and power issues relating to the AUV environment. Strategies for accomplishing certain system performance requirements have been investigated and the technology specified to begin laboratory prototyping and testing. The development path has also been orchestrated to provide parallel development of other underwater imaging technologies, such as high frequency modulation and passive mode applications, so that with appropriate reconfiguration for AUV operation, these technologies might be modularly installed into the system core for field-testing and evaluation. Much of the groundwork in establishing the laser line scanner design and components

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14. ABSTRACT

The long-range goal of this program is to develop a new imaging system for underwater use that can be deployed on an AUV. This includes a consideration of the physics of the underwater environment with respect to light propagation, the use of contemporary illumination systems, optical components, and the development of digital signal and image processing algorithms.

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has been completed, as well as the acquisition system, DSP hardware and a route outlined for data compression and storage. The opportunity for trying out high frequency modulation techniques has also been investigated with a simpler and less complex design being proposed for AUV installation

RESULTS

Scanning and receiver optics

The laser line scanner design uses a narrow highly collimated laser beam to scan back and forth athwarthships to the direction of motion. In order to circumvent the source-receiver separation limit defined by the nominal 21” diameter of the housing, the source-receiver separation is orientated along the long axis of the housing. The receiver comprises 16 PMT channels that divide the receiver’s field of view up into 16 rectangular sections with the long dimension unaffected so that it covers the scan swath of the laser beam, i.e., ~ 70°. (For 20” source-receiver separation, the vertical angular field of view required to cover a range of 2 to 50 m is roughly 18°). See Fig. 1.

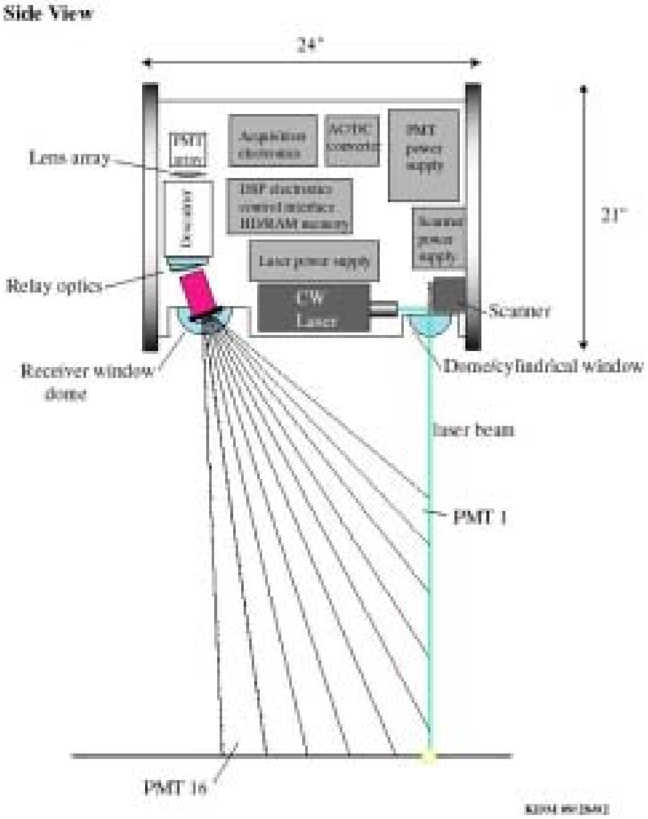

Fig. 1.

The shorter dimension of each channel roughly subtends 1° and is effective in blocking the collection of laser backscatter. Depending on the target range, the light from image of the laser beam incident on the target will be collected by only one of the channels so that the backscatter is reduced in proportion to its field of view. This ability to select only one PMT signal (i.e., the one that images the beam incident on the target) from an array with different look angles eliminates the need to preset the receiver field-of-view (one PMT) for a particular target range.

Since the image of the laser beam moves across the field of view of the receiver during a scan, and is viewed from an oblique angle, the task of masking all but the laser beam becomes a difficult task. One solution was to incorporate a specialized solid-state optical component with customized surfaces to normalize the image plane (i.e., eliminate the parallax involved in oblique viewing) and a rotating polygon scanner to cancel any scanning movement of the beam in the image plane. That is, the custom optical component compensates remaps the receiver field of view so that its horizontal dimension covers the same lateral distance regardless of its range (or vertical view angle). See Fig. 2. At the same time the polygon scanner is synchronized to the laser scanner but rotated in the opposite direction to cancel the movement of the scanning laser, so that the resulting image of the laser beam remains stationary despite motion in the object plane. The image of the laser beam can then be spatially filter by interception with the linear detector array or with the addition of a slit mechanism. The second solution was to utilize a set of galvanometric mirrors to deflect the laser beam image in such a way as to cancel out its movement *and parallax* at the same time so that similar results are obtained. This latter option for descanning the receiver was preferred since it provides the flexibility to recalibrate for changes in view angles and, despite the requirement of two additional moving components, i.e., the scanners, this ability to recalibrate quickly in the field by internal compensation may be more advantageous than a solid-state configuration that cannot be easily monitored for possible drift over its life time. These options are also of interest because of the small form factor that they can provide.

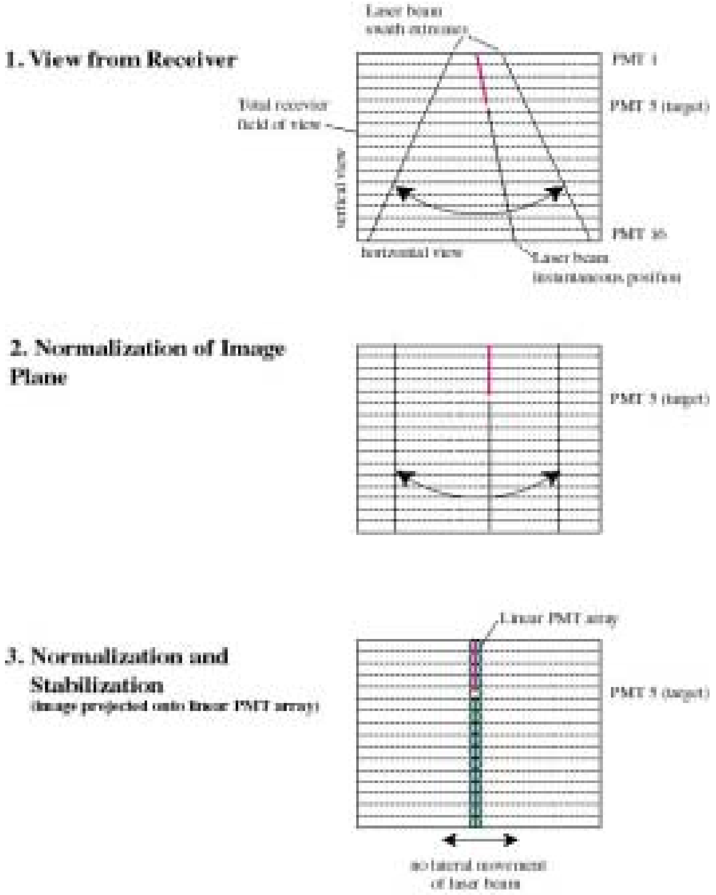

Fig. 2.

We have chosen a solid-state CW laser at 532 nm (Melles Griot) as the illumination source due to its small size and low power consumption. Initially, we do not intend to apply any focusing or beam modification techniques to the laser output, although the design allows for that as a future upgrade. The source and receiver window must be dome or cylindrically shaped in order to accommodate the large scan and view angles (i.e., 70°+). The use of cylindrical window ports is preferred since alignment in the third dimension can be ignored although mounting these windows may be more difficult and cumbersome. We have located of PMT array with 16 channels as candidate for the detector. This PMT package is particularly attractive due to its small size (less than 1.5" cubic inches) and may be easily inserted into the focal plane of the receiver optics. Other options include an array of individual PMTs connected to the focal plane by a fiber optic relay. We are also interested in using the more rugged and very fast (but less sensitive) intensified photodiodes (IPDs).

High-frequency modulation

We have also begun looking into the possibility of including modulated beam techniques which have shown promise under laboratory conditions (Dr. Linda Mullen, NRL). We have been in consultation with Dr. Mullen in order to better understand the technique so that it can be included or somehow added on to the system in order to verify its performance in the field. In order not to interfere with the progress in the development of the core system, we believe that a reduced and simplified version of the lab prototype can be developed separately for AUV operation and then can be later added or fused with the rest of the system in a modular sense for testing. Incorporation of the technique into the laser line scanner provides a means of testing the method in a scanning mode, which has not yet been done, and hopefully demonstrate its capability in the field. The hardware used in Dr. Mullen's laboratory happens to be of high performance but particularly bulky and cumbersome, e.g., the network analyzer. Since it is unfeasible to include this type of equipment on a system intended for AUV use, we have explored a more rudimentary design that can be adopted to fit into/with the remainder of the system. The amount, size and complexity of the hardware requirements can be reduced by opting for a single modulation frequency of 70 MHz. A single frequency electro-optic modulator (EOM) eliminates the need for the bulky network analyzer and simplifies the design and control aspects. A number of off-the-shelf electronic components can be used to control and amplify the reference frequency such as a reference oscillator, attenuators and high power RF amplifiers. At the receiver, a number of choices can be considered to provide the high sensitivity and response time. A gated PMT could be used in synch with the modulated source, or with the very fast intensified photodiodes (IPD). Once the light signal is detected and converted into an electrical signal, it must be conditioned by bandpass filtering and demodulated in order to measure its in-phase and quadrature signals (using an I/Q circuit). However, these additional measurements place an increased burden on the acquisition system.

Acquisition system

Specification of the acquisition system depends on the sampling resolution and speed over ground, number of samples per scan (one swath athwartships), the number of receiver channels and the digitization resolution. Our goals for the system are to be able to acquire up to 2048 samples per scan, 16 PMT channels digitized at a minimum of 12 bits and a nominal operational ground resolution of 1 cm (athwartships and along track) for an AUV speed of 4 knots (~2m/s). This implies the instrument will acquire a ~ 2 m scan length 200 times a second. This amounts to a sampling rate of roughly 400 kHz per channel, so that the total acquisition rate for 12 bit resolution is ~ 10 MB/s (~ 13 MB/s at 16 bits).

We have identified a PCI based acquisition card that can simultaneously acquire up to 32 analog input channels and digitize at 16-bit resolution. It includes a 33 MHz PCI interface with DMA capability and a 160 MB/s FPDP interface for data transfer. The card can be operated by oversampling each channel at 20 MHz and outputting digital information at 2.5 MS/s (5 MB/s per channel). We intend to use the oversampling capability to optimally integrate the photonic signal during the sampling interval, which may be advantageous when acquiring at slower rates in order to increase the SNR. Since the data rate approaches the maximum write speed of the hard disk storage media (20 – 30 MB/s) and that faster data rates may be required for different AUV speeds and resolutions as well as for use with high frequency modulation techniques, it is intended to compress the data before sending it across the PCI backplane. This can be done by sending the digitized data via the FPDP interface to a digital signal processing PMC card. Data compression is expected to be quite efficient given the redundant information collected by most PMT channels collecting backscattered laser light. Development of compression algorithms based on LZ77 and ZLIB have been initiated with preliminary compression ratios of roughly 50 and 90% respectively being achieved although the algorithms have yet to be tried on real AUV scanning data. The host computer system is a 933 MHz Pentium III with dual Ethernet adapters and an Ultra 160 SCSI interface.

IMPACT/APPLICATIONS

It is our goal that this underwater laser line scanning system that can provide high-resolution target images even in turbid waters and to be able to achieve this high performance with technology and smart design so that a rugged and small enough form factor can be realized with low power requirements for AUV use. The system should also be self-calibrating (self-monitoring) so that any pre-flight preparations can be substantially reduced or eliminated altogether.

TRANSITIONS

This was the first year of funding for this new project. We currently have no transitions to report.

RELATED PROJECTS

The Marine Physical Lab currently has an AUV program that is funded by ONR. In that program, our Lab is working on refining technology for AUV deployment and control.

PUBLICATIONS

None.