Generic Lidar Model Version 2.0

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LONG-TERM GOAL

The long term goals of the Generic Lidar Model (GLM) are to create a real-time software package which can predict and *visually* simulate the performance of any Lidar system and to allow a user to vary environmental/system specifics in an interactive mode. In addition to facilitating quick sensitivity analysis of important system and environmental parameters on system performance, the synergy of interactivity and fast execution speed will also allow the model to be used as an engineering tool to evaluate or suggest system enhancements in a quasi-video mode. This synergy will also allow the creation of an innovative, interactive training tool which will provide valuable experience for Navy personnel without the need for expensive deployment at sea of existing and emerging Lidar systems. By itself, the fast execution speed will allow the software package to be used as part of a guidance subsystem to help select a Lidar system platform's altitude and perhaps control some of the system's adjustable parameters (i.e., receiver aperture) as it searches a particular area of the ocean or coastal environment.

OBJECTIVES

Overall objectives proposed for FY98 were to extend the monostatic geometry of GLM 1.0 to a bistatic one so that a laser line scanning system could be modeled, to extend backscattering calculations to a bistatic system, to allow for a horizontally layered atmosphere as was done for the water column, to include the effects of the air/water interface on imaging systems, to divorce the receiver gate from the target, to incorporate the effects of target height on Lidar returns, to initiate the validation of the GLM modules and to create a user-friendly, interactive GUI which can run on a PC.

APPROACH

The extension to a bistatic geometry was accomplished only for continuous wave (CW) scanning systems along the lines of references 1 and 2. The approach found in these references includes a fast algorithm for calculating backscattering from a bistatic system, one of the objectives for FY98. The PI implemented these algorithms with assistance from the GUI primary software developer (Todd Shoemaker). Therefore, GLM 2.0 now has the capability, already documented in the literature, to

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simulate the three basic types of underwater CW scanning systems: the TV system, the flying spot scanner and the synchronous scanning system.

The GLM simulation of the Naval Surface Warfare Center's EOID sensor was accomplished with the help of the above CW scanning algorithms (synchronous system for laser light and TV system for ambient light). In an effort to initiate validation of the synchronous scanning system, highly variable data, both temporally and vertically through the water column, was input into the GLM. The data were collected at Oceanside, CA by an NRL-PSI team led by the co-PI under the Littoral Optical Environment (LOE) program. The GLM predictions were consistent with EOID performance and are presented in the RESULTS section.

For airborne Lidar systems, there exists a standard algorithm from reference 3 which calculates the effects of the air/water interface on imaging. In an effort to test the validity of this algorithm, the PI developed an underwater target-viewing algorithm which shoots a ray from each pixel in an airborne camera CCD array through a snapshot of a particular sea state simulated with the help of a user-given waveheight spectrum. Results from this validation effort are presented in the RESULTS section. Also for airborne Lidars, the treatment of the atmosphere was improved from GLM 1.0 and modeled as a series of horizontal layers of different optical properties in analogy with the water column characterization.

For pulsed, range-gated Lidar systems, the gate has been divorced from the target unlike GLM 1.0 where the gate height was centered on the target center depth. This has allowed the creation of an interactive GUI which allows the user to investigate changes in the pulse return as the values of system and environmental variables are changed. The target height is a variable which can also be changed to observe the change in shape of the pulse return corresponding to the depths around the target.

The approach to the interactive GUI was to use slider bars in order to help the user interact quickly and harmlessly with the software. The slider bars each have their own minimum and maximum values over which they can slide, thereby creating an automatic sanity check for the novice user. Because of the fast execution speed of GLM 2.0, there is almost instant response (2 seconds for a 256 x 256 pixel image on a 266 MHz Pentium PC) to any change in slider value. With the increase in clock speeds alone, the goal of instant response (less than half a second) will be met around FY00.

WORK COMPLETED

Due to the variety of Lidar system types modeled in the GLM, numerous interactive demos were developed in order to test the algorithms developed to simulate the environment and major Lidar system features. In addition, videos have been assembled in order to visually explore system performance as a function of a particular variable (i.e., system platform altitude above target).

GLM's treatment of the environment includes two major improvements over existing simulation models: the shower curtain effect for horizontally layered atmosphere and water column as well as a realistic simulation of the effects of the air/water interface on both laser illumination and target observation. Important preliminary conclusions presented in the RESULTS section have been drawn from the interactive GUIs created to simulate these effects.

At present, the GLM is able to simulate a pulsed range-gated system and a CW laser line scanner located on either an airborne or underwater platform. An interactive GUI simulating the time-resolved Lidar return from a pulsed range-gated system was created to enable the user to change important system and environmental parameters and visually assess the resulting changes in the (depth-dependent) shape of the Lidar return. Another interactive GUI has been created to simulate the influence of the environment on the imaging capabilities of a laser line scanner. Results from this simulation will be presented at Ocean Optics XIV in Hawaii in November 1998. Videos have been created which show the performance of the laser line scanning systems in the shallow waters of Oceanside, CA.

RESULTS

GLM 2.0 is the first Lidar model to incorporate the shower curtain effect, the depth-dependent image blurring effect of a thin scattering layer. As can be seen in Figure 1 below, the important parameter is the separation between the thin scattering layer (in green) and the target. As the separation increases the blurring effect becomes more pronounced. This effect has been neglected in previous modeling efforts in open oceans where the optical properties can be considered homogeneous. However, this “blue water” assumption cannot support system operation in littoral waters where experimental data has shown a high degree of vertical variability in optical properties.

An important consequence of the need to include the shower curtain effect in coastal regions is that Lidar system performance characterization needs to be refined for the littoral scenario. Up till now, system performance has been characterized in terms of the number of attenuation lengths at which a particular level of detail on a target can be discerned. However, vertical variability in the attenuation coefficient c, typical of littoral regions, allows for an infinite number of profiles which can add up to a given number of attenuation lengths between source/receiver and target. In Figure 2 below, three linear profiles of c have been selected such that they each have the same number of attenuation lengths (each thin (blue) scattering layer has the same thickness Δz). It can be seen that the performance of the simulated Lidar system is different in each case. Clearly, additional information such as the rate of variation in the attenuation coefficient c with depth is needed in order to more accurately describe Lidar system performance in littoral waters (see last paragraph in this section).

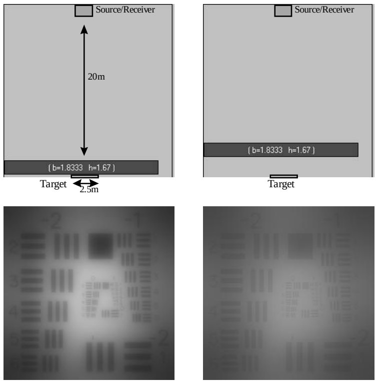


Figure 1. Shower Curtain Effect

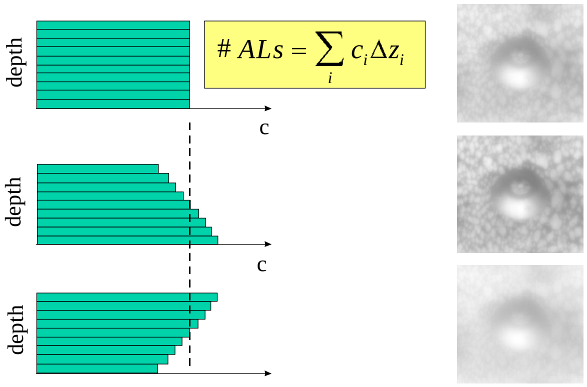


Figure 2. Lidar performance vs. c variability

Another important result concerns the investigation of the correctness of the air/water interface analytical formulation taken from reference 3. The algorithm averages the air/water interface effects on the airborne imaging of an underwater target over many realizations or “snapshots” of the sea surface. Therefore, Lidar system performance can only be characterized in terms of “average” effects. Implementation of this algorithm shows that the underwater target is blurred increasingly as the windspeed increases without any motion of the target centroid. In order to test the above analytical formulation, the PI generated a typical sea surface realization such as the one shown in Figure 3 from a given waveheight spectrum.

Results from the raytracing algorithm, mentioned in the APPROACH section, show that the analytical formulation is valid only for small enough windspeeds such that the target centroid does not undergo any appreciable motion as seen from an airborne camera. Figure 4 shows both the airborne source illumination at the target depth and the target as seen by the airborne camera as a function of sea state (windspeed). The source is collocated with the camera, about 25 meters above the sea surface.

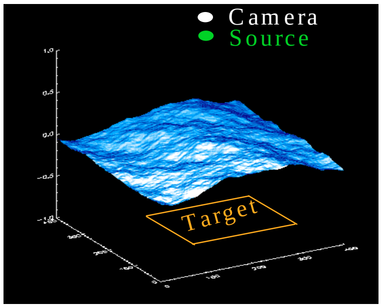
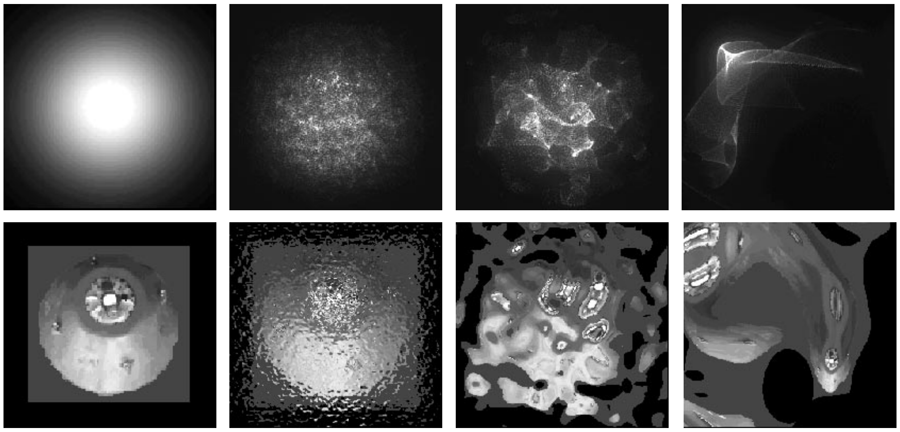


Figure 3. Snapshot of sea surface

Although Figure 4 presents results from only one sea surface realization, it can be seen that averaging over hundreds of realizations will result in motion-free target centroids for only the lower windspeeds where the small capillary waves only blur the finer details of the target. For larger windspeeds, the target centroid undergoes larger and larger excursions and it can be seen that multiple small target images appear in the bottom right picture in Figure 4. When averaged over many realizations, no information about target detail will remain. The raytracing algorithm therefore reveals that the analytical formulation from reference 3 is valid only for the rather limited and rare case of a sea surface topology made up only of capillary waves.



Increasing windspeed →

Figure 4. Source illumination (top) and target observation (bottom) as a function of sea state (windspeed)

Simulation of the laser line scanner has revealed a couple of important results. The first is that increased imaging resolution can be achieved by reducing the receiver field of view. However, this increased resolution comes at the expense of received power. The second is that the alignment of source and receiver boresights in the target plane is not as critical in turbid waters as it is in very clear waters. The reason for this is that the scattering characteristics of turbid waters contribute to what we call their "forgiving aspect" for laser line scanning systems. In turbid waters, the source illumination pattern at the target plane is broadened compared to its size in clear waters and the receiver aperture will accept photons scattered from the target which would otherwise have not entered the receiver in clearer, less scattering waters.

Preliminary observations from a multitude of simulations reveal that the most important optical parameter which affects Lidar system performance over a given system-to-target separation is the median scattering angle up to .01 radians. This quantity can be derived from the shape of the volume scattering function in the near-forward scattering angles and is defined by Wells as the average scattering angle over the range of forward scattering angles from 0 to 10 degrees. For median scattering angles greater than .01 radians, the most important optical parameter is the total scattering coefficient b. These results will be presented at Ocean Optics XIV.

In view of the above results, it is suggested that Lidar system performance in littoral waters be expressed in terms of "the spatial frequency ν which is still discernible in waters with a median scattering angle θ_0 over n attenuation lengths with an attenuation profile characterized by a slope equal to m", where the value of m is referenced to the source/receiver depth (+ for increasing, - for decreasing slope).

IMPACT/APPLICATIONS

GLM is being developed to model both the environment and a variety of Lidar systems in a realistic manner and in response to user inputs. As such, the model has a number of applications as a mine warfare tool (supporting a system such as CSS's Laser Line Scanner), as an ASW tool (supporting airborne detection of submerged objects), and in support of submarine security. In association with applicable databases, GLM can be a powerful tool to the mission planner/on-scene tactician. Designed for modularity, GLM is adaptable and can ingest new capabilities as they mature.

TRANSITIONS

At present, this research project remains in 6.2.

RELATED PROJECTS

1. Monte Carlo validation of GLM modules is planned for FY99. Initial efforts began in FY98 to coordinate with George Kattawar (Texas A&M) to validate the shower curtain effect. Additional modules will be validated similarly in FY99.
2. Data from NRL's Littoral Optical Environment (LOE) Program was used in FY98 to serve as a preliminary check for GLM results under dynamic environmental conditions (internal wave passage). In

FY99, we plan to work with the LOE PI (Alan Weidemann) to further this research.

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