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CREOL LASER RADAR ACTIVITIES AT BMDO's ISTEF

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INTRODUCTION

The Laser Radar Laboratory at CREOL is currently developing advanced coherent laser radar array receivers for the Ballistic Missile Defense Organization (BMDO) to be tested and evaluated at BMDO's Innovative Science and Technology Experimentation Facility (ISTEF) at the Kennedy Space Center. This technology provides a solution to the fundamental scientific problem of the adverse effects of target-induced speckle and atmospheric-induced turbulence on coherent lidar receivers. The development of this coherent laser radar array technology is organized by projects as: Laser Radar Simulation, Speckle Characterization and Receiver Development.

LASER RADAR SIMULATION

The goal of the lidar computer simulation is to develop a computer model that will simulate the various aspects of a coherent laser radar array transceiver including physical targets which produce both fully and partially developed speckle. The simulation is separated into two categories: 1) the transceiver model, and 2) the propagation/target interaction model.

The lidar simulation models both the spatial and temporal characteristics of the field, facilitating analysis of both spatial and temporal variations in the heterodyne signal. The simulation focuses on various target geometries with surfaces varying from smooth to very rough including both moving and fixed targets.

The propagation and target interaction simulation is performed via the Huygen-Fresnel Integral, which is evaluated on an nCube super-computer. The high computing performance of the nCube facilitates the generation of real-time receiver plane speckle frames. Data from these speckle frames is extracted by the receiver model to generate the temporal heterodyne signal. In addition the speckle frames can be viewed as a receiver plane speckle movie to facilitate the study of receiver plane speckle dynamics or as 3-D images or "speckle volumes" for the study of speckle propagation. Simulated speckle volumes are generated by stacking speckle image slices taken at increasing distance intervals from the illuminated object. These volumes are useful in visualizing speckle behavior in 3-space for purposes of feature analysis, tracking and system evaluation.

Figure 1 compares the PDF of an experimental speckle pattern with a simulated "ideal" fully developed speckle pattern for a linearly polarized source. The departure of the experimental from the ideal PDF, which is quantified by the normalized variance (1.0 ideal, 1.25 experimental), could be due to a number of sources including: depolarization, laser noise, pixel resolution, laser linewidth, background light contamination, target/camera motion, etc. The source of the discrepancy is currently under investigation and once identified will be incorporated in the simulation model.

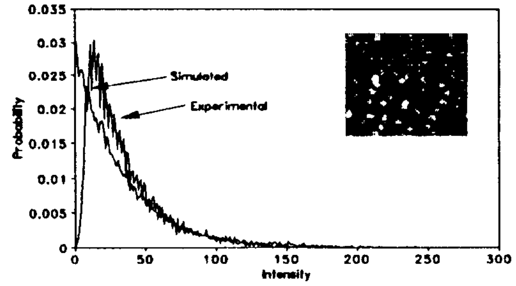

Figure 1. Comparison of simulated and laboratory speckle PDFs

SPECKLE CHARACTERIZATION

Speckle phenomena results whenever coherent radiation is reflected from a rough surface or propagated through a random media such as atmospheric turbulence. The spatial and temporal characteristics of the speckle pattern will depend upon the size, shape, material, texture, and motion of the target as well as the wavelength, spectral bandwidth, and state of polarization of the illuminating laser beam. This speckle phenomena is a major concern since it can cause fading and reduce the signal-to-noise ratio in coherent laser radar applications. In general, the return signature is accompanied by "glints" which further complicate the analysis of speckle effects upon laser radar performance.

We have experimentally characterized the speckle effects from a variety of target shapes and surface textures and compared the results to the predictions of the coherent lidar array receiver simulation code discussed above.

Of particular interest is a detailed description of the average speckle size as a function of intensity threshold level. The results of extensive experimental measurements have been compared to a previously developed theoretical model of this quantity.[1] Figure 2 illustrates the excellent agreement obtained for intensity threshold levels greater than approximately twice the mean intensity level. The target was a rough rectangle with 2 to 1 aspect ratio yielding asymmetrical speckles as indicated. The departures between theory and experiment lie in the assumptions inherent to the theoretical model.[1]

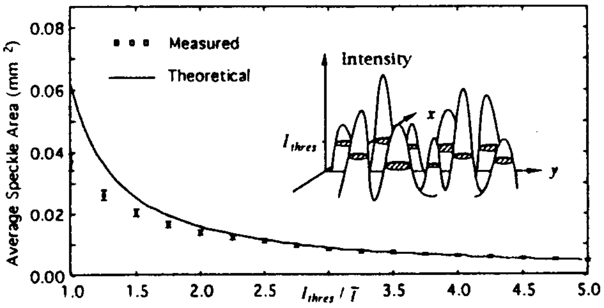

Figure 2. Exp. validation of theory: average speckle size vs. intensity threshold level.

RECEIVER DEVELOPMENT

Traditional coherent laser radar transceivers are limited in useful aperture diameter by the transverse coherence length (speckle size) of the receiver aperture plane field. This in turn limits the range capability of the laser radar. Another consequence of this phenomena is a Rayleigh fading amplitude causing severe fading in the heterodyne signal. We are studying how to mitigate these adverse effects though the use of multiple receiving apertures. By matching the size of the apertures with the return signal field transverse coherence length, and by sensing and then adjusting the phases of the intermediate frequency (IF) signals from each coherent aperture (usually by adjusting the phase of the local oscillator at each aperture), it is possible to add the individual IF's in phase so as to achieve an overall higher CNR and reduced fading. We have shown, for an array of "M" independent apertures, the CNR increases by a factor of M while the strength of the fading decreases by a factor of 1/M.

A digital algorithm has been developed for co-phasing the individual IF's. This algorithm minimizes the phase difference between a pair of IF's by minimizing their cross correlation. A computer simulation of an eight element coherent array was designed to verify the theoretical predictions and demonstrate the robustness of the co-phasing signal processing algorithm. Simulation experiments were conducted such that at least 500 independent regions (samples) of the Rayleigh amplitudes were collected. Statistics from the calculated CNR of the synthetic data were found to be in excellent agreement with the theoretical predictions.

Laboratory experiments have been conducted using a two element array and off-line processing. The positive results of these verification experiments prompted us to develop of a real-time two element prototype coherent array which can be extended to an arbitrarily large array (cf., Figure 3). Preliminary laboratory experiments using this two element real-time prototype array against a diffuse target and a thermal phase screen have been successful. In April 1994 we will demonstrate this system's ability to compensate for atmospheric turbulence on the 1 km range at ISTEF. A real-time 8 (possibly 32) element array is currently under development for demonstration at ISTEF.

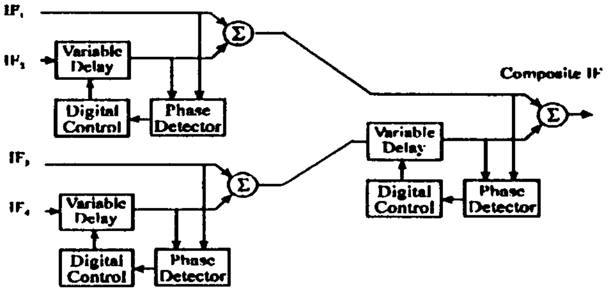

Figure 3. Coherent Array Signal Processing Block Diagram

REFERENCES

1.T. L. Alexander, J. E. Harvey , and A. R. Weeks, "Average Speckle Size as a Function of Threshold Level: Comparison of Experimental Measurements with Theory", submitted to Applied Optics

2. Gatt, P., Perez, W. P., Heimmermann, D. A, and Stickley, C. M., "Coherent Laser Radar Array Receivers: Theory and Experiment", OSA 7th Conference on Coherent Laser Radar, Paris, France, July 1993.