FULL SCALE HYBRID LIDAR-RADAR SYSTEM

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ABSTRACT

This paper concerns a novel hybrid lidar-radar system for underwater surveillance. Simulations and laboratory measurements based on the hybrid detection scheme revealed a 17 dB suppression of the water backscatter signal (clutter) and corresponding target contrast enhancement. These results led to the design, implementation and testing of a full scale lidar-radar system. Details of this system and results obtained in the ocean experiment are presented.

INTRODUCTION

Lidar (light detection and ranging) is used for underwater surveillance. A pulse of blue-green optical radiation is transmitted from an airborne platform, and target information is extracted from the detected echo. Although lidar has the potential for replacing existing techniques for underwater navigation, attenuation, dispersion, backscatter clutter and lack of coherent signal processing limits the performance of lidar in the detection of underwater objects.

In response to this problem, a novel detection scheme with superior capabilities has been conceived by combining the sophisticated detection schemes of microwave radar and the underwater transmission capability of lidar. In the hybrid configuration, the radar signal is impressed on the optical carrier by modulating the carrier at microwave frequencies. The reflected optical signal, with the superimposed microwave envelope, is detected by a high-speed photodetector. The radar subcarrier is then recovered by a microwave receiver and processed independently from the lidar return. In this technique, both the optical carrier (lidar) and the microwave envelope (radar) are examined simultaneously from a single measurement.

Past publications have reported various laboratory experiments performed to evaluate the feasibility of the hybrid detection scheme for underwater target detection. An optical fiber-based ocean mass simulator (OMS) [1] was utilized to evaluate the coherency of a microwave signal as it traverses the water medium [2]. Computer simulations and laboratory experiments were then conducted to evaluate the performance of hybrid lidar-radar over the conventional lidar system [3]. This theoretical and experimental study indicated that the backscatter clutter is suppressed by 17 dB, and the target contrast is improved.

These laboratory experiments established the significant advantages of the new approach. However, complex mechanisms governing the transport of light through water cannot be totally represented in the laboratory environment. This consideration led to the design and realization of a full-scale system to be utilized in an ocean experiment, which is described in the next section.

EXPERIMENTAL SETUP

The full-scale hybrid lidar-radar system, shown in Fig. 1, is comprised of four principal elements: the optical transmitter, the transceiver (optical beam control and detector), the lidar and radar receivers, and the signal processing apparatus. These subsystems are described in the following sections.

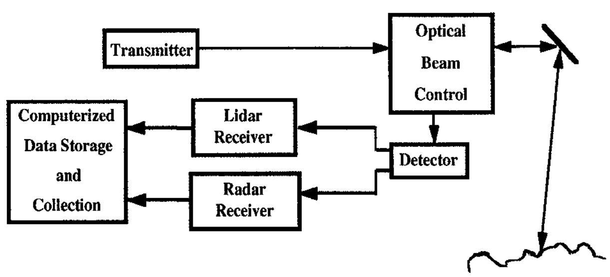

Fig. 1. Block diagram of the hybrid lidar-radar system.

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Modulated Transmitter. The main challenge in designing a transmitter to be utilized in an ocean experiment is the loss incurred in the backscatter measurement (> 60 dB). Thus, various techniques were evaluated for producing a high-power, blue-green, microwave-modulated, stable optical pulse [4]. The most effective technique for achieving these specifications is shown in Fig. 2. This optical transmitter consists of a laser oscillator, an optical amplifier and a frequency doubler. The key component is the oscillator, an optical cavity containing a flashlamp-pumped Nd:YAG rod, a 3 GHz phase modulator and a passive Q-switch.

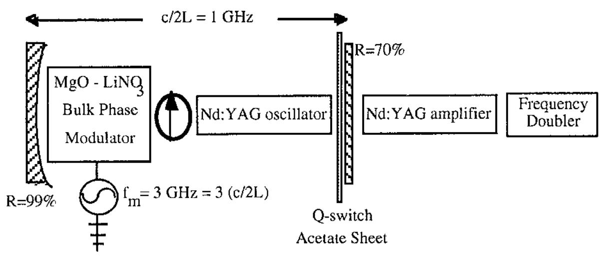

Fig. 2. Block diagram of the 3 GHz modulated transmitter.

Six random samples of the modulated transmitter output as detected by a high-speed streak camera are shown in Fig. 3. All the pulses exhibit one hundred percent modulation depth at 3 GHz, with good relative amplitude stability. The corresponding frequency spectrums of these pulses are shown in Fig. 4. Although the pulses contain some energy at harmonics of the fundamental modulation frequency, the majority of the signal energy is contained at 3 GHz.

Other essential features of the modulated transmitter include a peak output power of 10 kW, and a pulsewidth variable from six to twenty nanoseconds by appropriate choice of passive Q-switch. The output beam quality is good due to the oscillator transverse mode control produced by the 1 mm modulator aperture. In addition, the use of a passive Q-switch eliminated the noise problems associated with the active counterpart.

Transceiver. The transceiver components include optics for transmitted beam divergence control, received optical signal focusing and filtering, and receiver field of view regulation. Also included in the transceiver is the optical detector, which is an intensified photodiode (IPD) [5]. The IPD is a combination of an 8 mm GaAsP photocathode and a 1 mm GaAs PIN photodiode, with a 10^3 low noise gain. The 3 dB bandwidth of the device is 1 GHz with an appreciable output at 3 GHz.

Radar and lidar receivers and signal processing. The output of the IPD is split into its high frequency (radar) and low frequency (lidar) components, which are processed independently. The radar receiver contains two low noise microwave amplifiers, a bandpass filter centered at 3 GHz, and a microwave detector, while the lidar receiver contains a low frequency (100 MHz) voltage amplifier. The radar and lidar signals are displayed and digitized simultaneously on two separate channels of a digitizing oscilloscope. The data collection and storage is controlled by an external computer.

System integration. The entire hybrid lidar-radar system was assembled and evaluated prior to the ocean test. The measured dynamic range is better than 90 dB. The transmitter beam divergence ranges from 1 to 40 milliradians (half-angle), while the receiver field of view (FOV) is variable from 10 to 50 milliradians (half-angle).

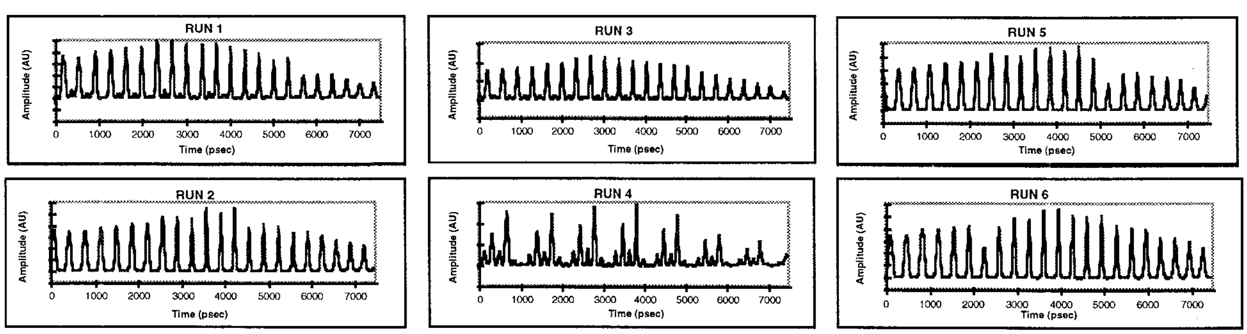

Fig. 3. Six random samples of the modulated pulse output as detected by a sreak camera.

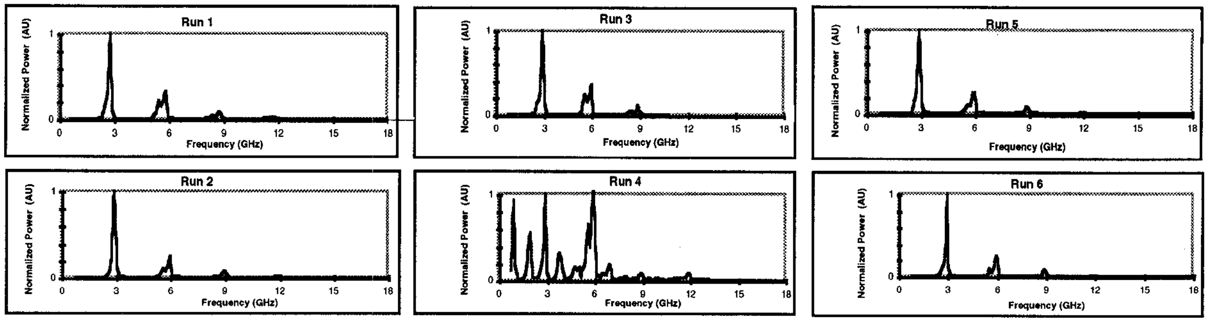

Fig. 4. Frequency spectrum of modulated pulses shown in Fig. 3.

RESULTS

The ocean experiment was performed at the Atlantic Undersea Test and Evaluation Center (AUTEC) on Andros Island, Bahamas. The ultimate goal of the experiment was to study the relative sensitivity of the hybrid detection scheme as a function of various system and environmental variables. On the basis of the difficulty in building such a system and the novelty of the approach, the first two priorities were to insure that the apparatus operated effectively and that the microwave signal did not suffer significant distortion as it traveled through the water. The attainment of these goals led to experimentation involving a systematic variation of the target size and depth, the receiver field of view, and the beam divergence in order to study their effect on the sea surface, sea bottom, and target return signal strengths and the backscatter and system noise levels.

The experiments were carried out from a tower located approximately 1 mile from shore. The advantages of this site include moderate cost, direct access to 30 ft of clear ocean water, and resemblance of a realistic lidar environment. In addition, the 35 ft elevation of the tower above the ocean surface facilitated deployment of underwater targets and alignment of the system to detect the targets.

One of the primary goals of the experiment was to study the ability of the hybrid detection scheme to reduce the water backscatter signal which limits the contrast of small, shallow underwater targets (as was shown in laboratory experiments). To evaluate the lidar and radar backscatter signal levels, the optical signal was transmitted at a slight angle to the water surface to eliminate sea surface reflection. The result of this test is shown in Fig. 5. Since the surface return is absent, the signal consists of a steady rise of the backscatter signal as the transmitted pulse enters the water. The peak occurs when the pulse eventually enters the water. The signal then decays exponentially due to absorption and scattering of the optical beam by the water column. The main difference between the lidar and radar backscatter returns in Fig. 5 is that the radar backscatter signal is suppressed by approximately 9 dB. Since a narrow beam divergence was used in this measurement (<.1 m spot size), further backscatter reductions are expected as the beam footprint approximates the situation in a typical aerial lidar system (approximately 10 m).

Experiments with various target size, FOV, and beam divergence combinations were then performed to evaluate the target contrast enhancement produced by the hybrid system backscatter clutter reduction. On the basis of our theoretical analysis, the benefits of hybrid lidar-radar are optimized when the lidar system is

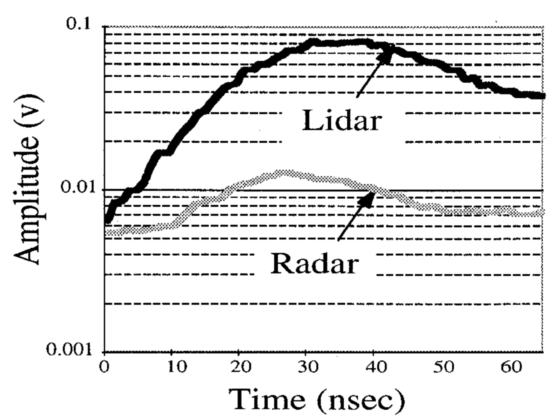

Fig. 5. Lidar and radar backscatter signals indicating the bakcscatter reduction capabiltiy of hybrid lidar-radar.

contrast limited. This scenario occurs when the target is small compared to the lidar footprint and is located at a shallow depth. Furthermore, microwave interference effects which reduce the microwave signal return are minimized when the receiver FOV is narrow. Typical lidar and radar returns obtained with this set of parameters (1 ft target at a 15 ft depth, narrow FOV, wide beam divergence) are shown in Fig. 6. This figure clearly demonstrates that the contrast of the radar target return is improved as compared to the corresponding lidar return. This result is a direct consequence of the backscatter clutter reduction produced by the hybrid lidar-radar detection scheme.

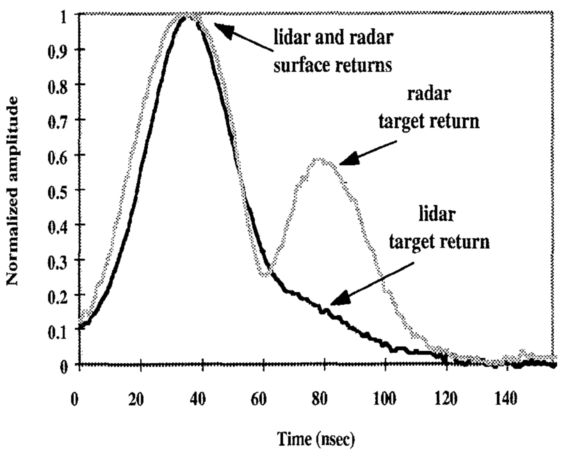

Fig. 6. Lidar and radar target return signals obtained with the following set of parameters: wide FOV, narrow beam divergence, 1 ft target at a 15 ft depth. This figure demonstrates the ability of the hybrid detection scheme to improve the contrast of a small, shallow underwater target.

CONCLUSIONS AND FUTURE WORK

A hybrid lidar-radar system has been developed and has been utilized in an ocean experiment. The system performed well in the ocean environment and provided return signals with good signal-to-noise and stability. Various experiments were performed to evaluate the relative sensitivity of hybrid lidar-radar to lidar as a function of various system and environmental variables. A preliminary analysis of the results obtained in the ocean experiment confirms the ability of the hybrid system to reduce incoherent backscatter clutter and enhance the contrast of small, shallow underwater targets. Future work includes analyzing the remaining experimental data and performing additional experiments to better understand the capabilities and limitations of the new technique. Some of these studies include testing the existing system in different water types and depths, and developing a more sophisticated system to study the effects of different modulation frequencies on the performance of the hybrid detection scheme.

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