A Test Bed for Short Pulse OA Detection of Optical Directors in Amphibious Operations

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ABSTRACT

This paper describes the design and deployment of a transportable test bed for a short pulse optical augmentation (OA) system to detect optical directors of potential threats in amphibious operations. The use of a short pulse duration allows discrimination of retroreflections from natural sources such as rock formations and vegetation. The test bed has been fielded in experiments on ground ranges and aboard ships in the Chesapeake Bay and Cardigan Bay. The data collected in these trials show that an optical cross section of 300 m^2/sr can easily be detected at a range of 9 kilometers, proving the feasibility of using such a system aboard vessels in amphibious operations.

The test bed was built in a 15' long trailer that incorporated an optical bench with the probe laser, steering gimbals, detector assembly, visible tracking camera and data acquisition subsystem. Data collection and storage as well as beam control and tracking were performed by a computer system located in the front of the trailer. With a water chiller for the laser attached to the tongue, the trailer became a self contained unit which could then be towed for ground testing, shipped inside a standard ISO container, and lifted onto the decks of ships for testing. In this way the test bed was loaded onto an LCM-8 landing craft and was also deployed aboard the R/V Colonel Templer in the UK to participate in sea trials off the coast of Wales.

The probe beam used was a 532 nm Nd:Yag with pulse energy of up to 500 mJ and a repetition rate of 10 pulses per second. The detector was a photomultiplier tube which was connected to a data acquisition system sampling at 1 gigasamples per second. A range gate was set up to collect 1500 samples around a selectable range of interest. A global positioning system (GPS) receiver was used to calculate ranges to known targets.

The system incorporated visible image-based beam steering and stabilization. A visible CCD camera coaligned with the probe beam and detector axis was used to calculate ship motion and compensate by moving the gimbals. Motion compensation algorithms were incorporated into the control program which also calculated the range; controlled the data acquisition system; collected, displayed, and archived the data; and provided user interface.

Form SF298 Citation Data

Report Date *("DD MON YYYY")* 00001999	**Report Type** N/A	**Dates Covered (from... to)** *("DD MON YYYY")*

Title and Subtitle A Test Bed for Short Pulse OA Detection of Optical Directors in Amphibious Operations	**Contract or Grant Number**
	Program Element Number
Authors	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Maryland Advanced Development Laboratory Greenbelt, MD 20770	**Performing Organization Number(s)**
Sponsoring/Monitoring Agency Name(s) and Address(es)	**Monitoring Agency Acronym**
	Monitoring Agency Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes	
Abstract	
Subject Terms	
Document Classification unclassified	**Classification of SF298** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** unlimited
Number of Pages 8	

The development of this transportable test bed allows OA measurements to be taken for a variety of targets and backgrounds from a self contained unit that can be easily deployed on ships and ashore. It has already demonstrated that an OA system will be highly effective against a number of hostile targets in littoral warfare.

1.0 INTRODUCTION

In amphibious operations it is desirable to detect potential threats that are deployed ashore at ranges greater than the effective range of the threat. One method that may be employed is to use optical augmentation to discern the guidance optics of a threat. High quality optics have high optical cross sections, resulting in strong retroreflections. The approach is to scan a target area with a laser and to record the intensity of the reflection from each location in the scan area. Thus, the presence of optics aimed at the scanner can be determined.

Several issues present difficulties with this approach. The first is that it is necessary to distinguish between light that is reflected by objects in the scan area and ambient light. By using optical filters tuned to the wavelength of the scanning beam most of the ambient light can be filtered out. A sensitive detector (in this case a photomultiplier tube at the focal point of a telescope) is used to generate a voltage waveform. Retroreflective targets can be detected by processing this waveform.

However, high quality optics are not the only sources of retroreflection found in the environment of an amphibious operation. Other objects - both natural (such as rocks, vegetation) and artificial (highway signs, automobile reflectors) - also retroreflect. It is therefore desired to discriminate between retroreflections due to these clutter sources and due to actual targets.

The retroreflection from an optical target can be considered as emanating from a point source. Thus, there is no range variance to the source of the reflection, i.e. the reflected pulse waveform (its intensity vs. time) has exactly the same shape as the intensity waveform of the scanning waveform. Many clutter sources, on the other hand, are composed of reflections from many points spread out across space at the target area. Retroreflections that are spread across the field of view results in a return that is not spatially concentrated. Similarly, the spread of retroreflecting points along the range axis causes a temporal smear of the scan waveform. By spatially and temporally filtering the retroreflected signal, it then becomes possible to eliminate these false alarms.

The advantage of using a short pulse scan waveform is that it becomes much easier to detect the temporal smearing caused by retroreflectors spread out in range. For example, if a 30 ns wide pulse is used, this gives a range resolution of about 150 feet. Thus, it becomes difficult to distinguish whether a reflection is from an optic (a point source) or from a tree (reflectors spread out over tens of feet). However, if a 3 ns wide pulse with the same energy is used, the return from the optic is concentrated within a 3 ns time window, while the background return is spread out in time. Therefore, using a short scan pulse and spatio-temporally filtering the detector output, it is theoretically possible to reject many sources of spatially distributed reflections.

It was decided to test this theory by building a short pulse OA system and collecting actual data on its performance. This was done by building a test bed that could be used at ground ranges at taken to sea for trials.

2.0 SYSTEM ARCHITECTURE

The most important element of the test bed is the scanning laser. A Continuum Powerlite 8100 Nd: Yag laser which can produce pulse energies at up to 500 mJ at a pulse repetition rate of 10 Hz was available. This laser is capable of producing pulses that are about 5 ns wide. The relatively high output energy and short duration of each pulse presented unique problems in the design of the optical path and in safety considerations.

The 532 nm output of the laser was routed by high reflectivity mirrors through a refractive divergence control stage. The divergence of the beam could be precisely varied from collimated light to about 4 degrees using this stage. The beam was directed by a 12" gimballed mirror onto the target area.

Facing the same mirror, a 4" Maksutov telescope was used to collect the reflected light. A 10 nm wide filter was placed in the optical path and a Hamamatsu 1894 photomultiplier tube was placed at the focal point to detect reflections. The detector output was fed to the data acquisition system.

The data acquisition system consisted of a Tektronix 520C oscilloscope capable of digitizing and storing 1 gigasamples per second, and which was equipped with a GPIB interface. During the trials waveforms of 150000 points at 1 ns resolution were gathered. This corresponded to a range limit of about 21 kilometers for the system. The GPS derived position and the known position of the target area were used as a range gate to collect 1500 points (corresponding to a 210 meter window) of the detector output.

A personal computer (PC) was used to control beam steering through the gimbal, for the collection, range gating, and archiving of the return data, and for motion compensation. This PC was the central controller of the test bed and included a GPIB board for communicating with the data acquisition system, a motion control board for interfacing to the gimbals, a video frame grabber for motion control, and a serial interface for communicating with the GPS receiver. The test bed control software resided on this PC.

Motion compensation was done by using a visible light camera with zoom lens which was coaligned with the scan beam and detector telescopes to stare at the target area through the gimbal mirror. Tracking the location of objects in the target area as they appeared on the visible light video made it possible to move the gimbal to stabilize the image. By stabilizing this video image the coaligned laser scan beam and detector field of view were also stabilized. The motion compensation algorithms operated at the full video rate of 30 frames per second.

3.0 TEST BED LAYOUT

One of the primary considerations in the design of the test bed was that it had to be deployable on ground and aboard ship, and had to be easily transportable. Given the size and weight of the scan laser (approximately 24" x 36" x 12", 100 lbs.) and the attached water chiller it was decided to build a mobile laboratory inside a trailer. The trailer was chosen so that it would fit inside a standard ISO container for overseas shipment.

The optics, including the laser, divergence control, telescope with detector assembly, gimbals, visible light camera with zoom lens and detector power supply were installed on a 3' x 5' optical bench. The data acquisition system was installed under the bench. This bench was positioned at the back of the trailer, to have the scan beam radiate out the back doors. An aluminum light shield was constructed for safety, in order to isolate the front of the trailer. The water chiller for the laser was mounted on a platform built on the tongue of the trailer.

The front part of the trailer was the operator's cabin with its own side door. The control computer with its display console was located here. Additionally, the laser power supply and controller, gimbal drive electronics, video recording equipment, GPS receiver, and communications equipment were all placed in this cabin.

The interfaces between the controlling PC and the optical bench consisted of a video link from the visible light camera used for beam stabilization and steering, the GPIB interface to the scope, and the laser connections (consisting of electrical cables and water chiller hoses).

4.0 DEPLOYMENT

The test bed was first deployed for ground testing at the Fort Meade, Maryland rifle range. This is (for OA purposes) a relatively short range with the farthest target at about 550 meters. But this range provided a convenient location for a trial and boresighting of the system at a location where the beam could safely be terminated at a grassy berm. At this range beam divergence was verified and the detector optics and visible light video camera were boresighted to the scan beam. Circular retroreflectors commonly found in hardware stores were used to verify the operation of the data acquisition system and to set focus the detector telescope. The control software, especially the operator interface and motion control algorithms, were finalized based on the experiences gathered at the ground test site.

The first sea deployment of the test bed was at the Naval Research Laboratory (NRL) Chesapeake Bay Detachment (CBD). The NRL LCM-8 landing craft was used for testing off the CBD facilities at Chesapeake Beach. The trailer was fitted with two removable steel beams with lift points, and these were used for placing it on deck using a 25 to crane. The total weight of the test bed was 4800 pounds.

At the Chesapeake trials tactically significant targets were detected against vegetation backgrounds at ranges of up to 5 kilometers. It was not possible to perform tests at longer ranges because of problems with boat traffic and the safety criteria that were observed.

The test bed was then loaded into an ISO standard container, and shipped to the United Kingdom. Upon arrival the boresight and alignment of the laser, detector and video camera as well as divergence control were verified. The trailer was then installed on the deck of the Research Vessel Colonel Templer.

Testing was held in Cardigan Bay, off a Defence Research Agency facility at Aberporth, Wales. This facility has 400' high rocky cliffs immediately rising from the sea. The target was placed at a site on the face of the cliff.

5.0 CONCLUSIONS

The data collected showed that tactically significant targets can be detected by using OA detection using a short pulse laser probe. The R/V Colonel Templer positioned itself at a stationary location 2000 meters from the cliffs at Aberporth. These cliffs rise 400 feet above sea level and are covered with deciduous vegetation two thirds of the way down to the sea. The bottom third are sheer rock faces with angular facets with dimensions ranging up to 50 feet. On the cliff face was a small brick building, beside which a Calibrated Optical Target Set (COTSET) was placed. The smallest optical cross section tested was COTSET #7 at 14.3 m^2/sr which gave an OA detection of approximately Signal to Noise Ratio of 267 at 2000 meters range. Noise is defined as emanating from the deciduous vegetation in the immediate background. This is an excellent indication of fast pulse superiority with the benefits of the concentration of signal in time.

To understand the limits of performance that this projects to, the "IRRAD" one-on-one OA performance model was used to predict the maximum range of performance that this result corresponds to when compared against meaningful military targets. The model was first calibrated with the actual result that was achieved with COTSET 7 at 2000 meter range. Then the maximum range that was achievable with the same optical cross section was computed. This showed that certain discernment of COTSET 7 signal would have resulted as far out as 5500 meters.

The model was then exercised for the tactically meaningful target cross section of 300 m^2/sr. The laser was reduced to 100 mJ at 3 ns to be reflective of a smaller output but wavelength agile and faster laser that would be fielded, rather than the laboratory Powerlight used in the test bed. S/N was raised to 8 to provide for ease in target discrimination by autonomous algorithms. The practical range for discrimination clearly fit the requirement for OA detection for amphibious assault columns transitioning over the horizon.

During testing several possible enhancements were noted for improving the system. The most important of these was the need for faster gimbals. On some days, when the Chesapeake had a light chop, it was noticed that the motion control algorithms could track and attempt to stabilize the motion of the LCM-8, but that the gimbals could not move fast enough. This was not a problem on the R/V Colonel Templer, which is a much larger and more stable platform, but on the landing craft it limited the amount of data that could be collected.

Another improvement that is being considered is the installation of a second detector slightly displaced from the primary detector and scan beam. This would allow bistatic measurements to be made simultaneously with the monostatic detector. Experience based on the data gathered shows that the difference between the monostatic return and bistatic returns could be used to discriminate actual targets from other retroreflectors, such as highway signs.

6.0 ACKNOWLEDGEMENTS

We would like to thank the staff at NRL CBD, Mike Kosky, Bob Cantin and the crew of the LCM-8: Bill Drury and John Meister; and the officers and crew of the R/V Colonel Templer. This work was funded by the Naval Research Laboratory under contract number N00014-91-C-2302.

7.0 FIGURES

Figure 1. OA test bed deployed at Fort Meade, MD Rifle Range

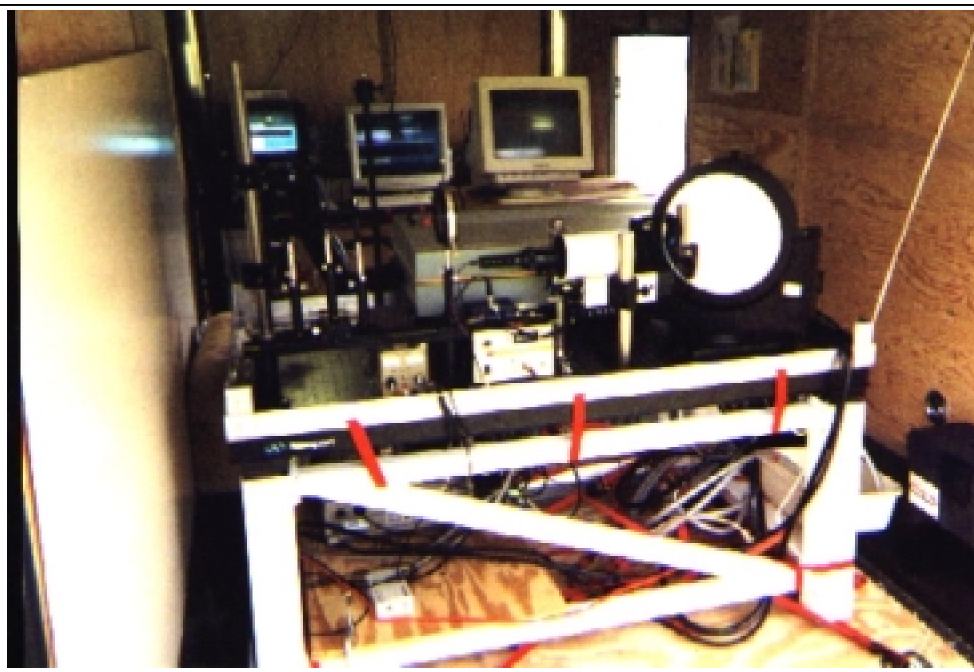

Figure 2. Internal layout. (Note that the safety shield has not been installed yet)

Figure 3. Loading on LCM-8 for Chesapeake tests.

Figure 4. Deployed on Chesapeake Bay

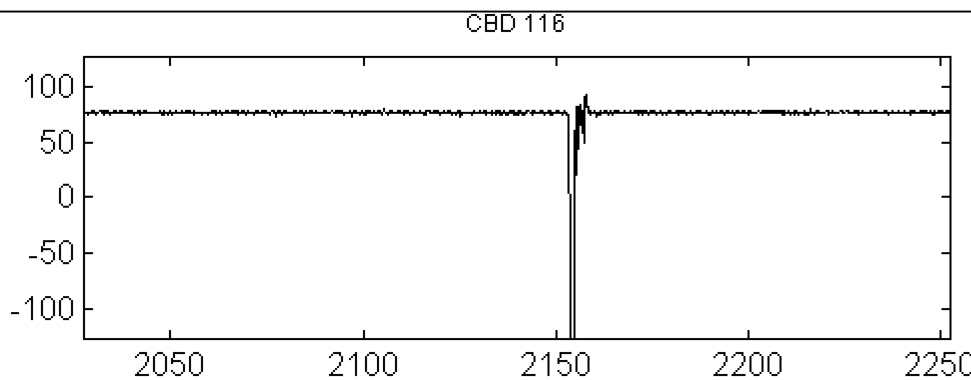

Figure 5. A detection on the Chesapeake Bay with trees in background

Figure 6. Test bed deployed on R/V Colonel Templer for Cardigan Bay trials.

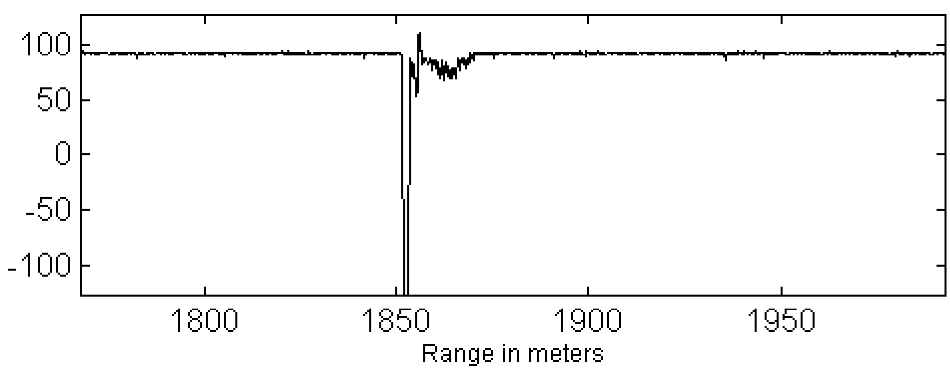

Figure 7. COTSET 7 detection off Aberporth with rocky and deciduous background.