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Range Gated Imaging Experiments Using Gated Intensifiers

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ABSTRACT

A variety of range gated imaging experiments using high-speed gated/shuttered proximity focused micro-channel plate image intensifiers (MCPII) are reported. Range gated imaging experiments were conducted in water for detection of submerged mines in controlled turbidity tank test and in sea water for the Naval Coastal Sea Command/ U.S. Marine Corps. Field experiments have been conducted consisting of kilometer range imaging of resolution targets and military vehicles in atmosphere at Eglin Air Force Base for the U. S. Air force, and similar imaging experiments, but in smoke environment, at Redstone Arsenal for the U.S. Army Aviation and Missile Command (AMCOM). Wavelength of the illuminating laser was 532nm with pulse widths ranging from 6 to 12ns and comparable gate widths. These testes have shown depth resolution in the tens of centimeters range from time phasing reflected LADAR images with MCPII shutter opening.

Keywords: Range gated imaging, LADAR, Scattering Media Imaging

1. BACKGROUND

Range gating is a well known imaging technique that can be used to determine distances from the detector to a object and conceptually can also be used to image through scattering media such as smoke, fog, and turbid water.[1,2] In an active range gating system a pulsed laser illuminates the scene and the return photon signal is detected by a gated imager. The range resolution is determined by the laser pulse width and detector gate width. A one-nanosecond pulse combined with a one-nanosecond imager gate width provides a range resolution of between 30 and 60 cm (1 to 2 ft.). If the gate and laser pulse widths are short so that only photons in the near vicinity of the target plane are detected, the signal to noise ratio of the return signal is significantly increased. It then becomes possible to obtain images through scattering media provided the media is not opaque to the pulsed laser photons.[3] The concept is illustrated in Fig. 1.

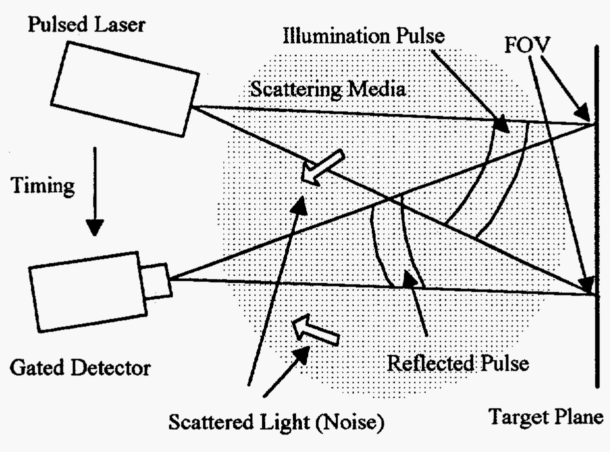

Fig. 1. Illustration of range gated imaging. The laser source illuminates the target with a short pulse and provides a timing signal to the gated detector. The gated detector is set to accept light from the vicinity of the target plane and reject most of the light scattered by the intervening medium.

We have carried out several range gated imaging demonstrations in conjunction with our high-speed imaging development projects.[4] The following describes three of these applications.

2. AIRBORNE MINE DETECTION AND SURVEILLANCE (AMDAS)

The purpose of AMDAS and follow on programs such as Mine Detection Laser Technology (MDLT) and Magic Lantern Adaptation (MLA) is to use pulsed lasers and fast optical shutters in a range-gated LADAR configuration to search for and detect and identify hidden minefields in beach areas where military troops are expected to be deployed.[5] The successful identification of minefield locations can prevent troop casualties by either destroying the mines prior to troop landing or by selecting alternative mine-free locations confirmed by the LADAR. The system could also be employed in the broad ocean area to detect submerged mines. Measurement of the pulse delay between the interrogating (incident) and reflected (return) laser pulses would be used to determine mine depth.

The system concept for AMDAS is shown in Fig. 2. An airborne laser rasters the region of beach intended for troop landing. The illuminated beach region is imaged by reflected laser light onto an accompanying intensified/shuttered CCD camera. The intensifier is gated to record images from strategic depths corresponding to suspect minefield deployment. The images are telemetered to a shipboard base station where image processing is carried out to assess the presence of minefields. Because of the size of mines and extent of the minefield, the large area coverage, and optical scene clutter in the laser beam's flight path, the image data rate is too high for real-time manual operator detection and classification. Thus, computer data storage and automated image processing are required. However, it is envisioned that trained analyst would complete final assessment.

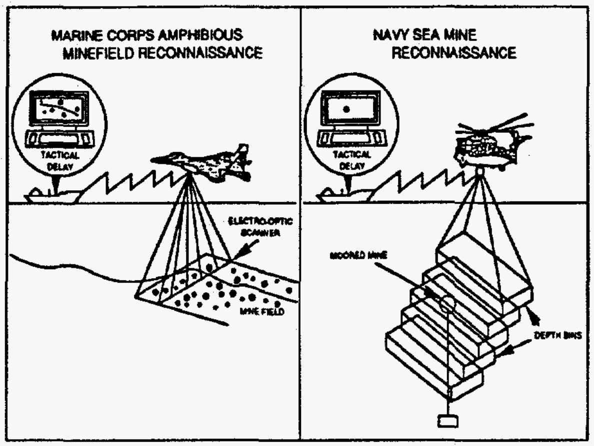

Fig. 2. Conceptual illustration of the AMDAS system.

No commercial camera could meet the frame rate of 1000 - 4000 frames/s with high resolution that was required by the application. It was therefore necessary to develop such a camera. The high-speed, high-resolution camera developed for the project was designated the GY-5 and an improved follow-on model the GY-6.[6] The GY-5/6 camera was designed around the Fairchild model 222 inter-line transfer CCD, which has an array of 244 x 380 pixels and a single output port. The CCD was fiber optically coupled to an ITT model F4111 Generation II microchannel plate (MCP) image intensifier (MCPII) for shuttering.[7] The MCPII was modified according to Los Alamos design specifications, which include (1) electrically conductive but optically transmissive nickel undercoating of the S-20 photocathode to permit gating/shuttering in the few nanosecond regime, and (2) high strip current MCP and short persistence P-48 phosphor to allow high repetition rate operation for compatibility with the fastest CCD readout rate.

Development of an AMDAS airborne system was not completed due to funding limitations; however, preliminary field range gating experiments were carried out in a tank, constructed at EG&G Santa Barbara, CA, in which sea water conditions could be controlled. Targets were submerged at known depths and water turbidity factors varied. A schematic diagram of the experiment is shown in Fig. 3.

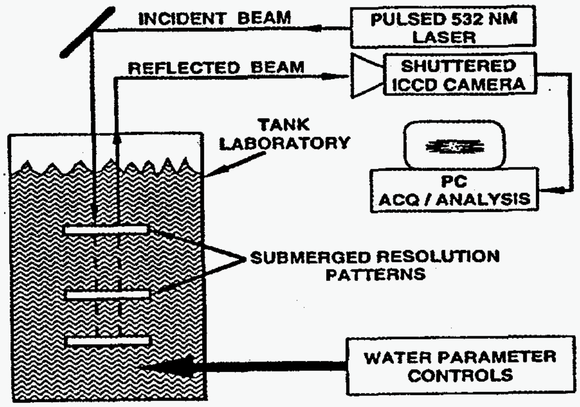

Fig. 3. Simplified schematic diagram of experiment for depth profile imaging for mine detection studies.

A probe laser provided pulses of 532nm light in a few nanosecond FWHM pulse width and the GY-5/6 MCPII shutters were synchronized to open properly time-phased and only long enough to record reflectance images from specific target location depths in the tank. In this manner, the GY-5/6 sensitivity and resolution were calibrated in environments similar to those expected in experiments carried out in the ocean where mine field decoys and related targets were to be imaged. Both series of tests were conducted using only one GY-5/6 camera. Sample imaging data is shown in Fig. 4.

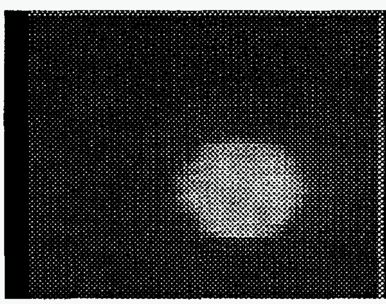

Fig. 4A.

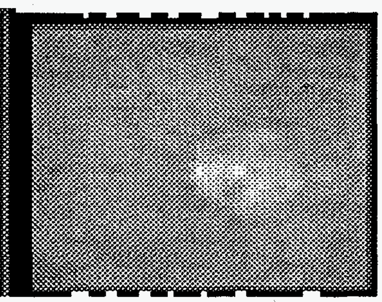

Fig. 4B.

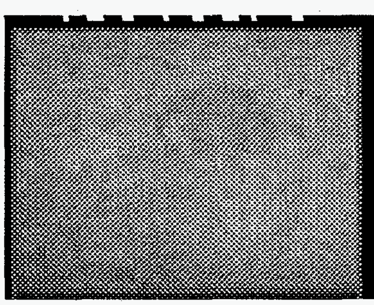

Fig. 4C.

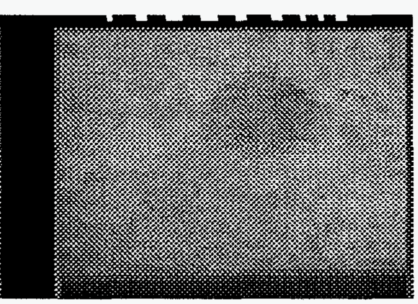

Fig. 4D.

Fig. 4. Images obtained using the GY-6 gated image intensified camera system to image reflected laser images from mock mine. Mine imaged in air, Fig. 4A, and at depths of 1.4m, Fig. 4B, 5.6m, Fig. 4C, and 7.0m, Fig. 4D. Tank water at constant water turbidity (not quantified here).

3. EGLIN AFB EXPERIMENTS

The purpose of the experiments at Eglin Air Force Base, Ft. Walton Beach, FL, was to evaluate range gating in atmospheric conditions. The experiments, which were conducted at a base laser range, consisted of range gated imaging of two billboard size resolution patterns located approximately 500m down range and military vehicles at approximately the same range. Several of the experiments were conducted in light rain, which had no noticeable effect on the imaging acquired.

The imaging system used a CCD camera, which was jointly designed by Los Alamos and the Atomic Weapons Establishment, UK, and manufactured by English Electric Valve, UK, operating in an RS170 frame format and having a reset and triggered output capability. A Philips microchannel plate fast gating intensifier, model XX1412MH, which incorporates a Los Alamos high-speed gating design, was fiber optically coupled to the camera. The Philips microchannel plate can be gated as short as 200ps; however, in these tests we used a 6ns gate, which better matched the laser pulse width. The laser used in the experiments was a Big Sky frequency doubled Nd:YAG operating at a wavelength of 532nm, with a pulse width of approximately 12ns, and an energy of approximately 100mJ per pulse. Pulse repetition rate of the laser was approximately 10Hz. The overall range resolution of the imaging system was limited by the 12-ns laser pulse width. This pulse width corresponded to a range resolution of approximately 3.5 meters.

The Eglin laser range is approximately 1 km in length and several hundred meters wide. The range ends at the edge of a wooded area. Several targets are in place in the clear area between the experiment building and the wooded area. At a distance of approximately 500m, two large billboard size resolution targets have been set in place. These resolution targets are approximately 4m high and are fabricated from aluminum panels, which have a dimpled diffuse reflecting surface. Resolution patterns of various sizes are cut out of the panels. An image of portions of the two resolution targets taken with the ungated camera in daylight illumination is shown in Fig. 5A.

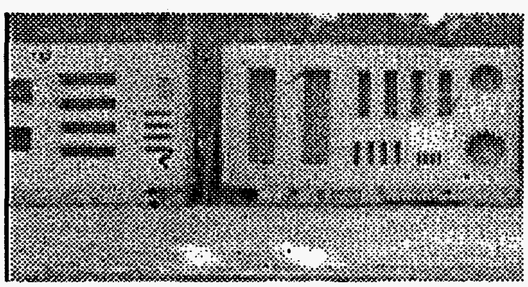

Fig. 5A. Ungated Scene

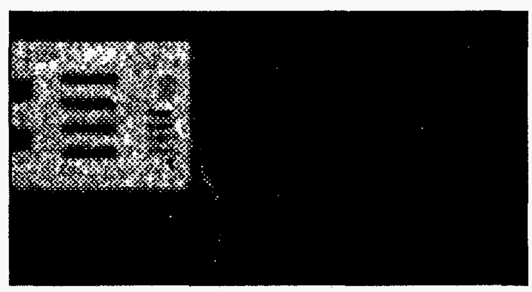

Fig. 5B. ΔT = 3210ns Range 481m

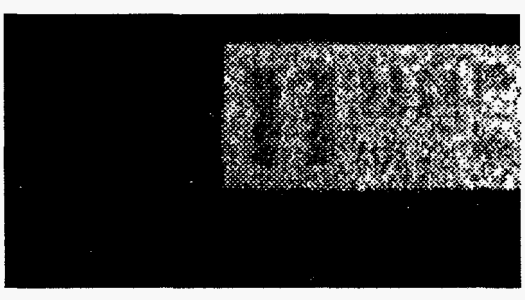

Fig. 5C. ΔT = 3240ns Range 486m

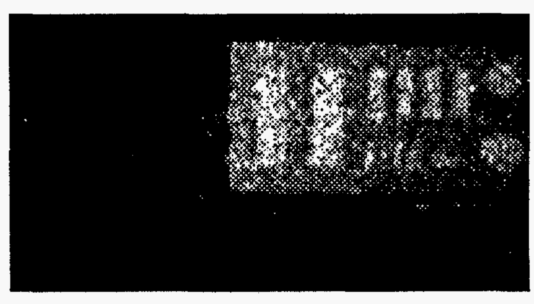

Fig. 5D. ΔT = 3260ns Range 489m

Fig. 5. Range-gated imaging of two resolution pattern panels; the panel on the left in Fig. 5A is located 481m down range and the panel on the right is located 486m down range.

The panel on the left side of the image in Fig. 5A is approximately 6 meters closer to the observation point than the panel on the right side. Also, there is nothing behind the cutouts of the target on the left in Fig. 5A while a solid panel has been placed behind the cutouts of the target on the right side. The distance between the back panel and the front panel of the right hand target is variable. This distance had been set at approximately 60cm during this test.

A series of images were taken over a range of gating delay times. With the appropriate delays we expected to be able to view first the near target, then the farther target, and finally just the back panel of the farther target. The imaging from this experiment is shown in Fig. 5. Fig. 5B shows a gated image with the time delay set such that only the left panel is visible. The gate delay was set at a round trip distance of the laser pulse at 3210ns, which corresponds to a distance of approximately 481m with an error of plus or minus 2m due to the widths of the laser pulse and gate. The gate picks up only the laser light in a region approximately 4m in the neighborhood of the target. When the gate is delayed to 3220ns, which corresponds to a nominal range of 483m, the image records no return signal because the gate range is between the two target panels. At a gate delay of 3240ns, which is shown in Fig. 5C, the front of the laser pulse has just reached the front panel of the right target but has not reached the back panel, which is 60 cm further away. When the gate is delayed to 3250ns light is reflected equally from both panels and the resolution cutouts are not distinguishable in the image. Finally, Fig. 5D shows the image with a gate delay of 3260ns in which just the end of the laser pulse illuminates the back panel of the target. The cutouts show light against a dark front panel. Since the technique allows the imaging of objects, or portions of objects, at specific distances a series of images taken at various distances contains three-dimensional information and can be used to construct a three-dimensional image of that portion of the scene viewed by the imager. The resolution of the three-dimensional image will depend upon the laser pulse and gate widths.

4. REDSTONE ARSENAL EXPERIMENT

Range gating experiments were conducted at Redstone Arsenal to examine range gated imaging in a smoke environment. The laser range at Redstone is several hundred meters in width and approximately 5km in length. Our primary target was an Armored Personnel Carrier (APC) located approximately 500m down range from a 100ft tower where the range gated imager was located.[8]

The illuminating laser, which was manufactured by Big Sky, operated at a wavelength of 532nm, with a pulse length of 8ns and energy of approximately 30mJ/pulse. Timing was provided by a Stanford DG535 pulse generator. The camera used in the experiments was the same as used in the Eglin tests. A frame grabber card installed in a Compaq computer was used to capture images from the camera and associated display and analyzing software was used to record and display the images. As a backup, image data were recorded on a VCR and on a LeCroy storage 9314L oscilloscope.

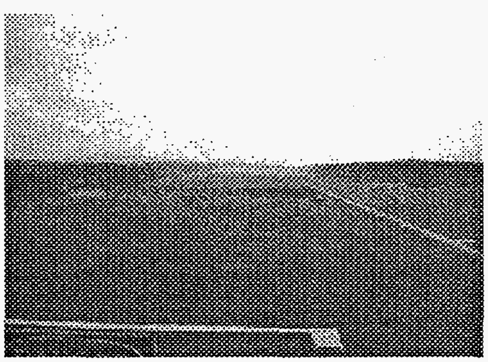

Fig. 6A. View of Redstone laser range from observation tower.

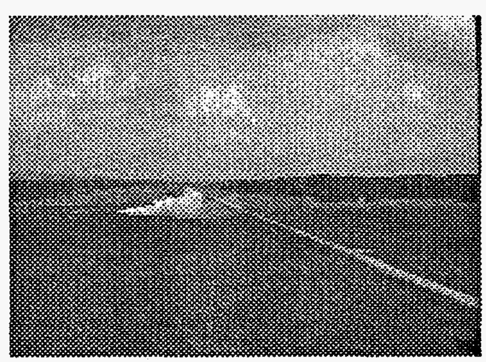

Fig. 6B. View of Redstone laser range with smoke generator in place.

A view of the range from the observation tower is shown in Fig. 6A and the same scene with the smoke generator in operation is shown in Fig. 6B. The smoke was produced by burning fog oil and then using a jet engine starter to blow it across the field. We qualitatively classified the smoke in the experiment into three levels of density, Light, Medium, and Heavy. Light smoke has a density such that an observer can just see the target APC by eye. Medium smoke is at a level such that the target can easily be lost to the observer. Heavy smoke is at a level that the target is fully obscured.

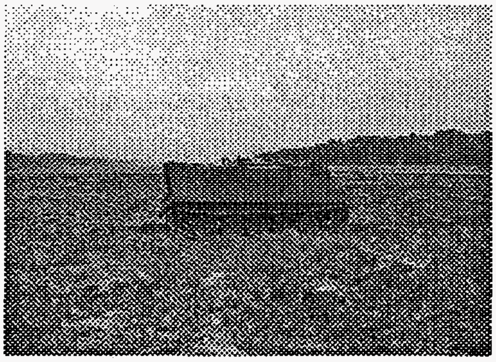

Fig. 7A.

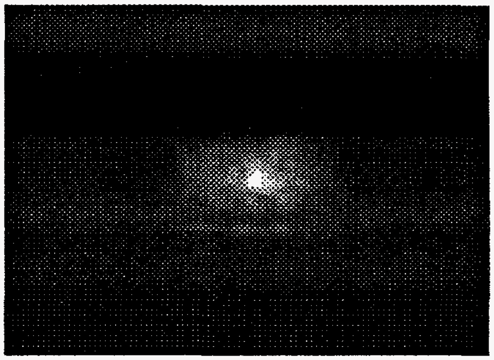

Fig. 7B.

Fig. 7. Close-up image of target APC is shown in Fig. 7A. Range gated image of APC showing laser beam hot spot, which was used to obtain maximum penetration of obscurant, is shown in Fig. 7B.

Fig. 7A is a close-up view of the target APC taken in daylight and Fig. 7B shows an unobstructed range gated image viewed through the 300mm telephoto lens used to obtain the image data. As seen in Fig. 7B, the beam was concentrated in a relatively small area in order to obtain as high a flux density as possible to penetrate the smoke with the relatively low-energy laser that was used in the experiment. One can observe in the range-gated image the shape of the APC and portions of the wheels and tread

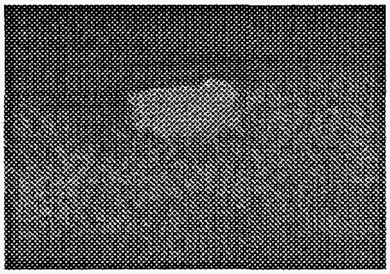

Fig. 8A.

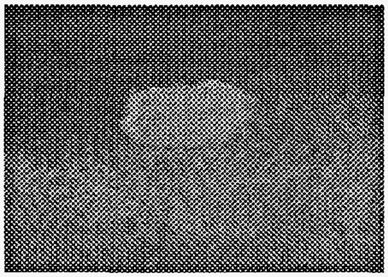

Fig. 8B.

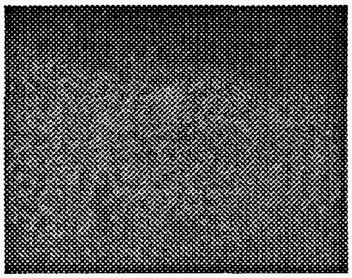

Fig. 8C.

Fig. 8. Range gated imaging of APC taken through Light, Fig. 8A, Medium, Fig. 8B, and Heavy, Fig. 8C, smoke.

Fig. 8 shows a series of range gated images taken through Light, Medium, and Heavy smoke. Details of the target APC were not obtained in the imaging because the gain of the MCPII was adjusted near maximum in order to ensure detection of the return signal. A high return signal was recorded for the Light smoke, Fig. 8A, and Medium smoke, Fig. 8B, cases; however, only the area of highest intensity was recorded for the heavy smoke case, Fig. 8C. A higher energy laser pulse would have been required in order to obtain better penetration and, thus, a higher return signal from the APC in the heavy smoke. Nonetheless, a system having the capability of imaging through scattering media appears to be a distinct possibility.

5. CONCLUSIONS

Range gated imaging has been demonstrated in a number of situations to obtain range information and imaging through scattering media. Range gated imaging has been used to obtain range information to various portions of a target with a range resolution of a few tens of inches and to obtain imaging of targets through both turbid water and smoke scattering media. It should be possible to develop three-dimensional images from the range data by taking a series of images at various ranges. Resolution of the three-dimensional images is dependent upon the pulse widths of the illuminating laser and gate width of the MCPII shutter. Resolutions of approximately 30 cm (1 ft.) will require a laser pulse width and MCPII gate width of between 0.5 and 1ns. Relatively high laser energy will be required to penetrate dense scattering media, such as a heavy layer of smoke or fog. However, when penetration of the media is possible, targets can be imaged that would otherwise be obscured from an observer.

6. ACKNOWLEDGEMENTS

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