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Jed Khoury, *Bahareh Haji-Saeed, Charles L. Woods, *John Kierstead

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14. ABSTRACT
We propose using the smart antenna principle as the basis of a new design for smart optical receivers in LADAR systems. This paper demonstrates the feasibility of designing a LADAR system with a receiver consisting of an array of photodetectors, which leads to field-of-view enhancement and beamforming by fusing streams of video information received from the detectors. As a proof of concept, we demonstrate this design by fusing several video information streams from different fields of view using our Mathworks Simulink® model. The fusion algorithm uses the fuzzy logic maximum operation on the data output from the cameras.

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Smart Optical Receiver for Beamforming and Enhancement of Field of View in LADAR Systems

Jed Khoury[1], Bahareh Haji-saeed[2], Charles L. Woods[1], and John Kierstead[2]
[1]Air Force Research Laboratory, Sensors Directorate, Hanscom Air Force Base, MA 01731
[2] Solid State Scientific Corporation, Hollis, NH 03049

ABSTRACT

We propose using the smart antenna principle as the basis of a new design for smart optical receivers in LADAR systems. This paper demonstrates the feasibility of designing a LADAR system with a receiver consisting of an array of photodetectors, which leads to field-of-view enhancement and beamforming by fusing streams of video information received from the detectors. As a proof of concept, we demonstrate this design by fusing several video information streams from different fields of view using our Mathworks Simulink® model. The fusion algorithm uses the fuzzy logic maximum operation on the data output from the cameras.

Keywords: LADAR, beamforming, data fusion

1. INTRODUCTION

Smart receivers in RF wireless and free-space telecommunication use arrays of receivers combined with smart signal processing algorithms to enhance signal quality and calculate beamforming. Beamforming is a signal processing technique that increases the receiver's ability to enhance the desired signal relative to interference and background noise. For example, free-space optical telecommunication smart receivers have been used recently for many applications such as indoor high-speed wireless communication[1-5]. In such systems, infrared (IR) signals offers several advantages over radio signals: (a) IR transmitters and receivers are capable of achieving higher bit rates at lower cost, (b) the IR spectral region has virtually unlimited bandwidth, and (c) IR transmission cannot be intercepted outside the room from which it originated, since IR radiation is blocked by walls and other opaque barriers. In IR telecommunication systems, three types of free-space optical receivers can be considered: (a) a single-element receiver consisting of an optical concentrator coupled to a single photodetector, (b) an angle-diversity receiver consisting of multiple receiving elements with different angles of detection[6-8], and (c) an imaging angle-diversity receiver, which uses a single imaging lens coupled to an array of photodetectors[6]. Like optical telecommunication systems, laser radar (LADAR) systems use laser sources. LADAR systems scan and process the signal reflected from a target in order to create an image of the desired area.

In digital free-space telecommunication, the laser is modulated on and off. The received bit is susceptible to dispersion, scattering, and aberration, from propagating through the atmosphere. At very high bit rates, dispersion limits the resolution between two successive bits. Additionally, scattering and aberration limit the amount of light that can be collected by a photodetector. With high scattering and aberration, the intensity of the received signal is reduced, leading to poor signal-to-noise ratio and very high bit error rate.

In LADAR systems, atmospheric dispersion can affect the pulse width (the laser radar time of flight), as well as the phase of the reflected beam, which leads to ambiguity in the range information. Noise and atmospheric turbulence reduce the fraction of the reflected light that is collected by the detector. This affects both the sampling rate (spatial resolution) and the A/D resolution (range resolution). Reflected or scattered light from the target cannot be collected by one detector, which leads to collection of only a portion of the field of view (FOV). In order to cover the entire scanned area, the use of multiple detectors is necessary. The data collected from each detector is processed by a circuit to extract the range information. The range information from all the circuits is fused together according to a fusion algorithm in order to enhance both spatial and range resolution.

We propose, for the first time, to use an array of photodetectors to detect the reflected signal. Specifically, we propose a LADAR system in which the collected information from different views of the target is focused separately onto a photodetector array, leading to a large overall FOV of the target compared to single-detector information collection.

In the single-element receiver mentioned above, the desired signal, combined with unwanted signals such as noise, interference, and delayed components, is received by a single detector. The drawbacks of this receiver can be overcome if an angle-diversity receiver is used. This receiver uses multiple receiving elements pointed in different directions, so the signals received by the various elements are amplified separately. The advantages of using this receiver are: (a) high optical gain with a wide FOV, and (b) low noise, low interference, and low multipath distortion detection, since these unwanted signals are in many cases received from different directions than the desired signal. The angle diversity elements require a separate optical concentrator for each receiving element, which makes the device expensive and

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bulky; therefore, Yun and Kavehrad proposed the fly-eye receiver[6]. This receiver consists of a lens focusing the received light onto an array of photodetectors, thereby separating signals that arrive from different directions. This design has two advantages: (a) all photodetectors share one concentrator, leading to reduced size and cost, and (b) all the photodetectors can be in a single array, which makes having a large number of receiving elements feasible.

As a proof of concept, this design was modeled using the Mathworks Simulink® software to show the feasibility of the proposed idea. The fusion algorithm used in this design uses the fuzzy logic maximum operation on the data output from the camera channels.

2. EXPERIMENT

Figure 1 shows an experimental setup for a conventional LADAR system. A laser source is amplitude modulated, then sent to an X-Y scanner to scan a target. The return signal from the target is captured by a photodetector, whereby the modulated signal is recovered, then electrically amplified. The amplified signal is then homodyne detected by mixing it with a reference signal from the laser modulator. The output signal from the mixer is captured by a line-scan frame grabber, which is triggered and synchronized by the X-Y triggers from the scanner driver. It is the output of the frame grabber that is displayed. In this setup, having one detector collecting the reflected light from the target was not sufficient to capture the entire FOV. Therefore, in order to enhance the field of view, we propose using several photodetectors.

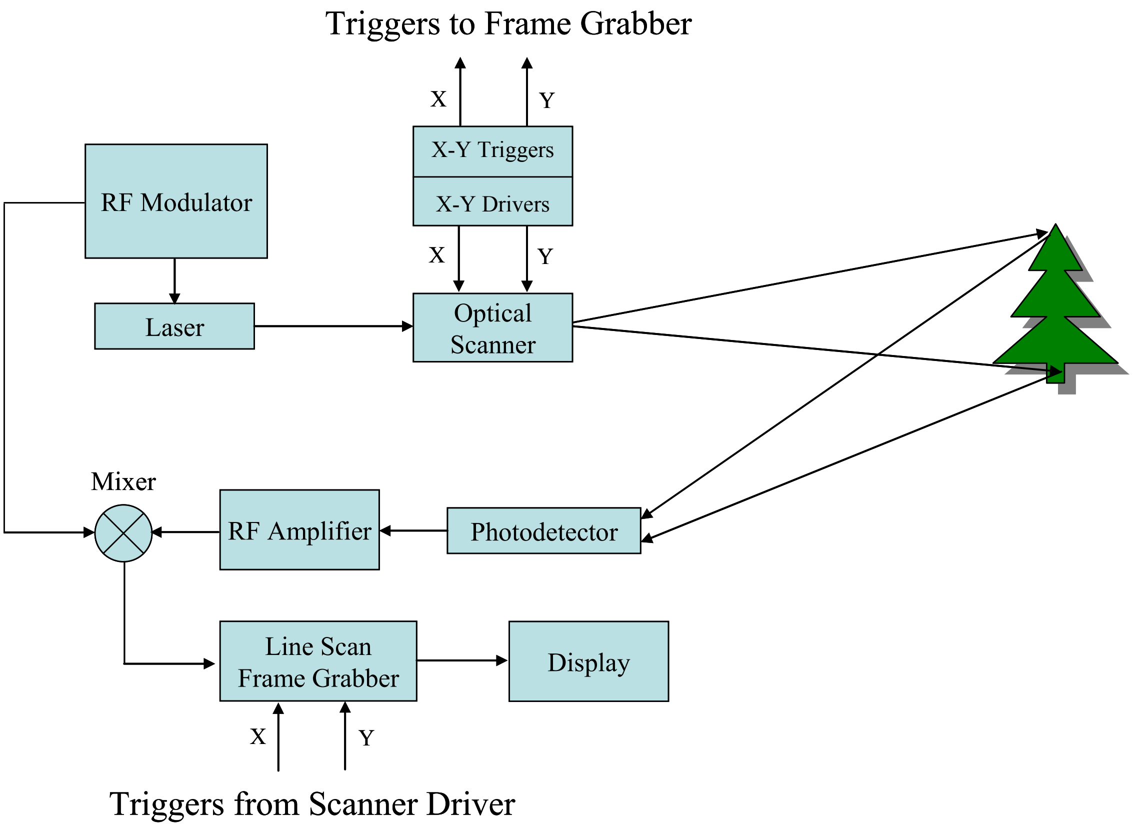

Figure 1. The experimental setup for a conventional LADAR system.

We initially tested this design by moving the photodetector from left to right and capturing the data from each view. An evenly spaced array of smooth circular metal pins (a pet comb), as shown in Figure 2, was used as a target for our LADAR system. The fuzzy logic maximum algorithm was used to fuse these data.

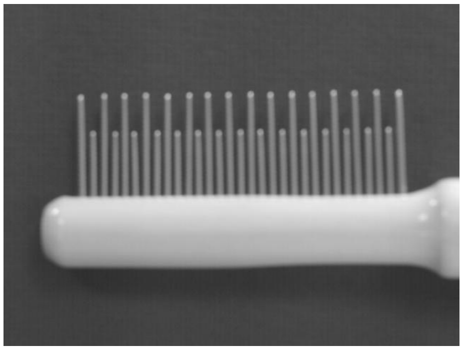

Figure 2. A pet comb used as a target.

Figure 3 shows the data collected from: (A) the left side of the target, (B) the center of the target, (C) the right side of the target, and (D) the fused image of all three. The image frame includes the data acquired by the scanner for both the forward and the reverse scan directions. The collected images do not show equally spaced pins due to the sinusoidal motion of the scanner, which can be compensated for optically or electronically [9-11]. The fusion was achieved using the MATLAB® fuzzy logic MAX operation (maximum value) on all the collected input frames. It is evident from these results that the fused image shows all the pins in the target, indicating the fidelity of our approach in field-of-view enhancement. This experiment was performed using the setup described in Figure 1.

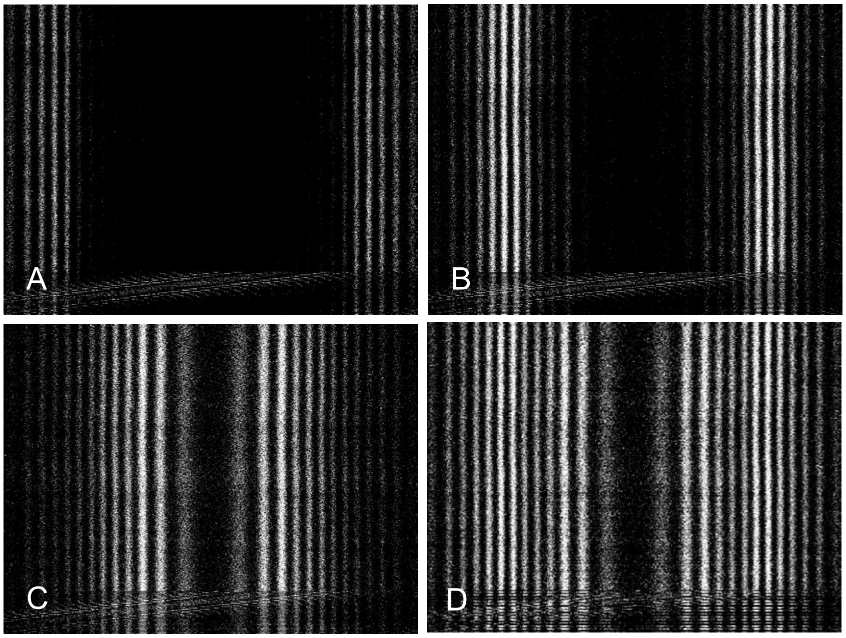

Figure 3. Collected scanned data from a comb: (A) the left side of the target, (B) the center of the target, (C) the right side of the target, and (D) the fused image of all three.

For clarification, the intensity plots of one row of these images are shown in Figure 4.

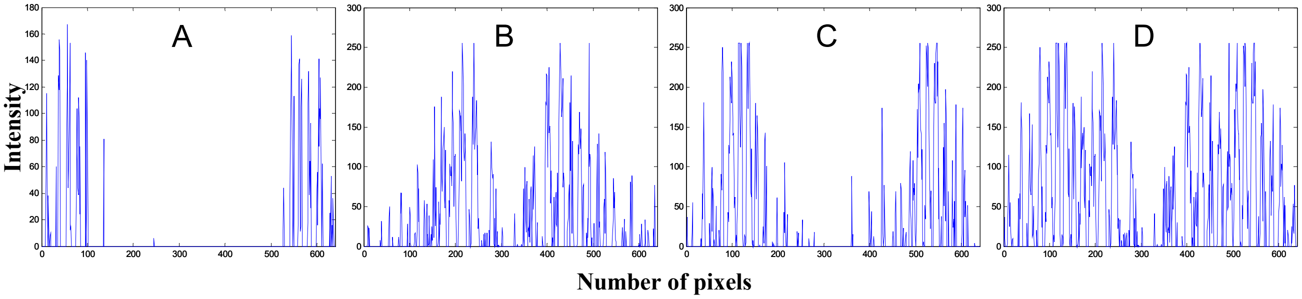

Figure 4. The plots of one row of Figure 3 images.

The alternative proposed experimental setup with several photodetectors is shown in Figure 5. In this setup, instead of one detector, an array of photodetectors is used (for simplicity, this figure shows just two photodetectors). The outputs from the detectors are amplified and homodyne detected. The output signals are then synchronized and amplified via the video amplifiers. Ultimately, these signals are digitized and collected by computer software to be fused and displayed.

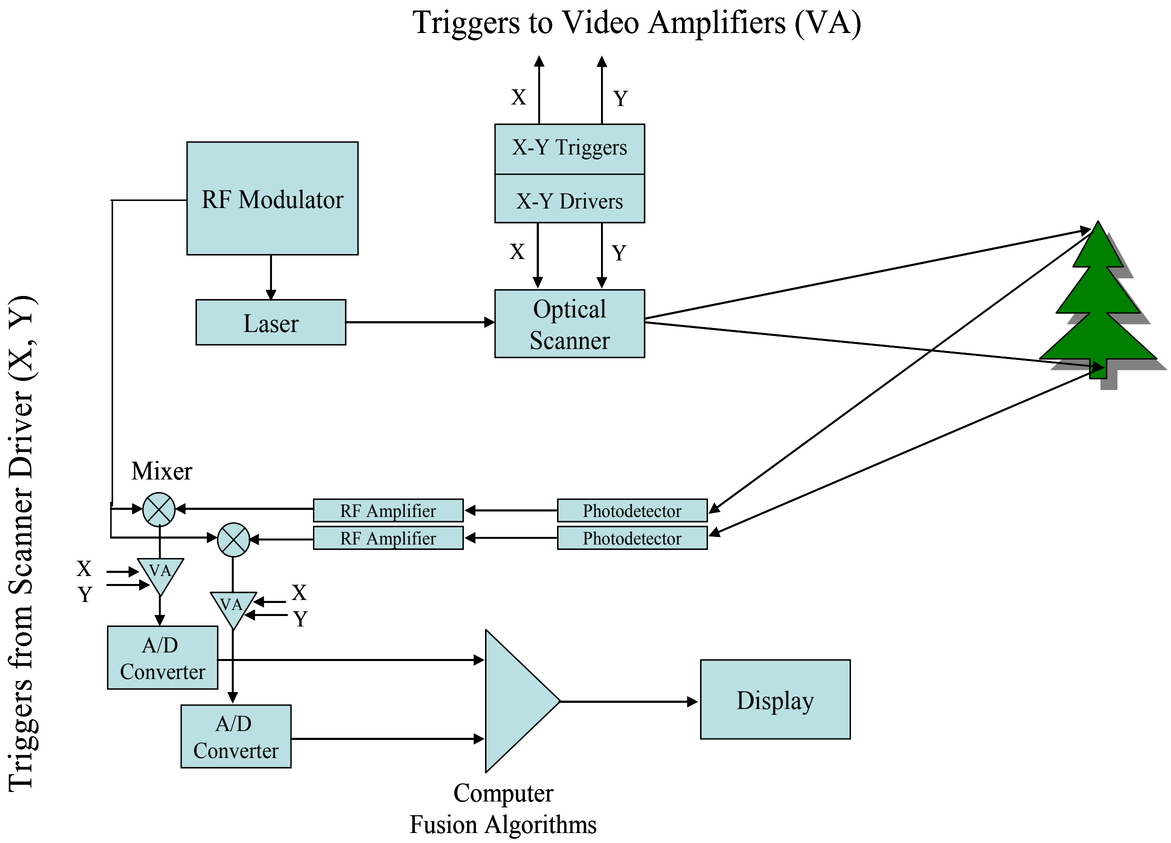

Figure 5. The alternative proposed experimental setup with two photodetectors.

3. SIMULATION

For proof of concept and demonstration of real-time performance of our algorithm, we simulated the experimental setup using our Mathworks Simulink$^{®}$ model. This model is shown in Figure 6.

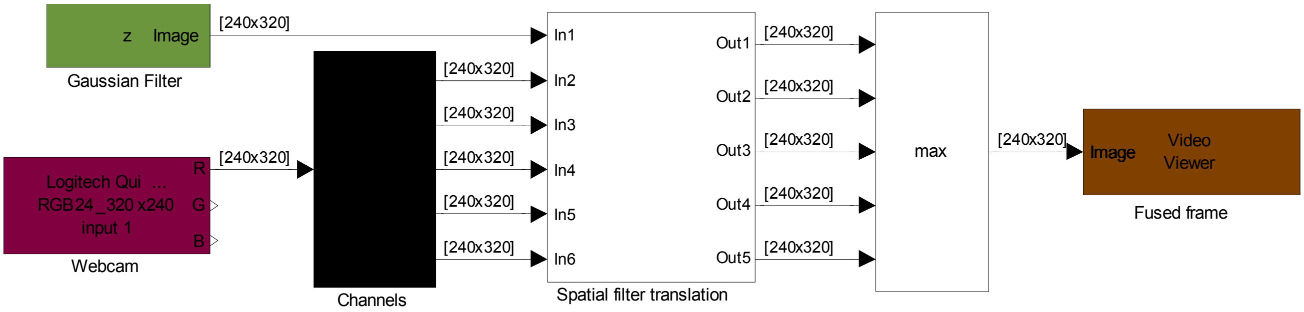

Figure 6. Simulink model of real-time performance of the fusion algorithm.

We simulated scanning and data collection via several photodetectors by collecting video data from a webcam in which each frame is 240 × 320 pixels. Since we cannot use multiple webcams (because each webcam is a separate system with its own scanner), the video information was distributed equally to five channels. Each channel's data was digitally filtered by a spatially translated Gaussian filter in order to simulate the situation of having several detectors, each of which collects a portion of the scanned FOV. The respective Gaussian translations in these channels were 0, 50, 100, -50, and -100 pixels. The Gaussian translation can be explained as follows: (a) the 0 position corresponds to the center detector, (b) the 50 and 100 positions correspond to detectors on the right and the extreme right, respectively, and (c) the -50 and -100 positions correspond to detectors on the left and the extreme left, respectively. The corresponding video frames for these images are shown in Figure 7 (A, B, C, D and E). Figure 7(A) represents the case in which the optics FOV is around the center of the scene. Figure 7 (B and C) shows the cases in which the optics FOVs are the right and the extreme right part of the scene, respectively. Figure 7 (D and E) shows the left and extreme left FOVs of the scene, respectively, and Figure 7 (F) shows the fused video frame using the fuzzy logic MAX operation.

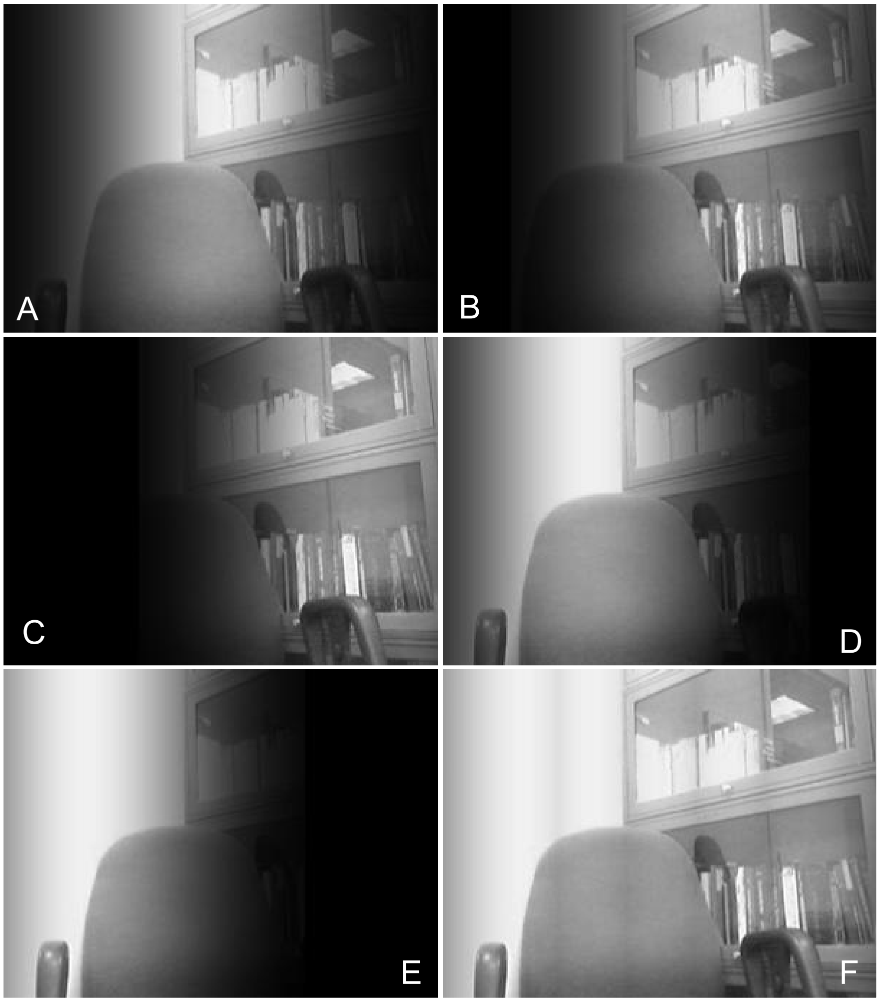

Figure 7. Simulation results, different FOVs: (A) center, (B) right, (C) extreme right, (D) left, (E) extreme left, and (F) the fused video frame using the MAX operation.

4. CONCLUSION

We proposed a LADAR system in which the collected information from different views of the target is focused separately onto an array of photodetectors, leading to a large FOV of the target compared to single-detector information collection. We demonstrated this LADAR design by collecting the images from a webcam and sending them to a Mathworks Simulink® model to be fused. The fusion algorithm used in this design chooses the maximum value from camera output data.

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