A FOCAL PLANE ARRAY LADAR SYSTEM USING CHIRPED AMPLITUDE MODULATION

Barry Stann, Keith Aliberti, John Dammann, Mark Giza, Brian Redman, William Lawler, Debbie Simon, and William Ruff
U.S. Army Research Laboratory
AMSRD-ARL-SE-EM, Adelphi, MD 20783

Daniel Carothers
BAE Systems
Photonics Group/Advanced Systems and Technology, Nashua NH 03060

ABSTRACT

The Army Research Laboratory is researching system architectures and components required to build a focal plane array ladar system. In this paper we report on the development of the ladar and its imaging performance.

1. INTRODUCTION

The Army Research Laboratory's (ARL) research on focal-plane-array ladar will lead to a compact, low-cost sensor yielding three-dimensional imagery of scenes at video rates. This capability supports a variety of Future Combat System (FCS) applications including smart munitions, reconnaissance, face recognition, robotic navigation, target identification and range determination. Here we briefly discuss the ladar architecture, breadboard design, imaging results, and future work.

2. LADAR ARCHITECTURE

Figure 1 is a block diagram of the ladar architecture. A clock circuit controls the generation of a "chirp" signal which is a microwave signal that begins at a low start frequency, increases linearly in frequency (the period of a chirp signal is typically commensurate with video frame-rates), and then quickly returns to the original start frequency. The chirp signal is amplified and summed with a constant current to drive a diode laser. This yields an intensity-modulated light signal that floodlights the target scene of interest. A small portion of the transmitted beam is reflected from the target toward the ladar and collected by the receiver optics. An array of opto-electronic metal-semiconductor-metal (MSM) detectors is located at the focal plane of the receiver optics (Stann, 1996, 2000; Ruff, 2000; Shen, 2000). When the chirp signal is applied across the MSM detectors, a photocurrent response is recovered at each detector that is the product or mixing of the chirp signal and the intensity-modulated light waveform. An analysis shows that a frequency difference proportional to range to the target exists between the chirp signal applied across the MSM detectors and the chirp signal intensity-modulated on the reflected light. The mixing process in the MSM detectors produces a sinusoidal photocurrent at that difference frequency. To recover the photocurrents from the individual pixels, we employ a unique focal plane read-out concept based on code division multiple access (CDMA) techniques commonly used in cell phone transmission (Stann, 2003). To implement this technique, we multiply the chirp signal for each column of the array by a unique binary code. The net effect is to orthogonalize the photocurrents for all pixels in a row, allowing all currents to be combined into a single wire that connects to a transimpedance amplifier (TIA) to the side of the detector array. The TIA converts photocurrents into voltage that is sampled at the code clock rate by an analog-to-digital (A/D) converter. The CDMA read-out technique allows us to sample the photocurrents at rates that would normally be difficult using the standard read-out technologies for focal plane arrays. For our research program, the CDMA read-out technique was also advantageous because it could be built with discrete electronic components thereby eliminating the need to build a custom read-out integrated circuit which requires substantial development time and is usually expensive. Demuxing of the data is done digitally in software on a PC. Here the data from each row's A/D is successively multiplied by the codes associated with each pixel to recover the respective photocurrents. Because the frequency of the pixel photocurrents is proportional to range, we perform the fast Fourier transform (FFT) on each of the de-multiplexed photocurrents to map the data space into a three dimensional image space.

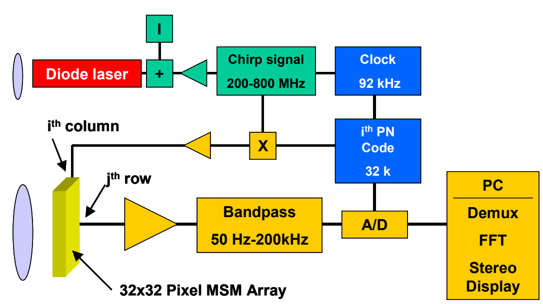

Figure 1: Laboratory ladar breadboard block diagram.

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3. 32x32 PIXEL BREADBOARD

Figure 2 shows the front view of our laboratory breadboard. We have the ability to illuminate the scene with either a single 100-mW GaAs diode laser (single-spot illumination) or with a multi-stripe 3.2-W GaAs diode laser (flood illumination). Backscattered light is received with a 5-cm diameter lens and focused onto the 32x32-pixel FPA. The range resolution of the system is 0.25 m and the frame-rate for data collection is about 3 Hz. The PC processes the data and displays it in stereo at around a 1-Hz update rate. Currently, the laboratory breadboard ladar system is built with discrete components; fielded designs would employ integrated circuits that would radically reduce the ladar size. Field-programmable gate arrays can be used to perform the signal processing thereby achieving video frame rates.

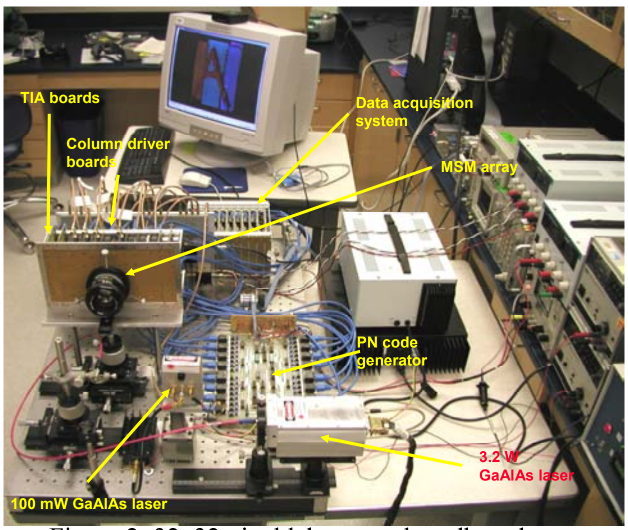

Figure 2: 32x32 pixel laboratory breadboard.

4. BREADBOARD TESTS

For the imaging test, we set up a scene about 10 m from the breadboard in the back of our lab bay as shown in Figure 3. Here a cardboard "A" is supported on a pedestal followed by a poster board to the left side of the "A" and 0.25 m further in range. A brown cardboard box is positioned roughly behind the poster board about 0.75 m further in range. A white cardboard box is alongside the brown cardboard box and 0.25 m further in range. Figure 3 also shows a rotated ladar image of the laboratory scene. Note that the "A" is very well-formed and shows a clear staircase function along the legs as one would expect for an image with pixel-limited resolution. In addition, the poster board and cardboard boxes are range resolved as expected.

Figure 3: Laboratory scene and ladar image.

5. CONCLUSIONS AND FUTURE WORK

Currently our system is amplifier noise limited with noise performance a factor of roughly 10 worse (in a voltage sense) than the level theoretically achievable. In the future we will evaluate a variety of techniques to improve the signal-to-noise of the receiver. One technique is to replace the resistive TIAs with capacitive ones. Another promising approach is to couple the MSM output into an avalanche-gain CCD shift register. The CCD gain register operates by application of a small amount of avalanche gain, in the 1.01-1.015 range, at each element of the analog shift register. With hundreds of elements, aggregate gain of several hundred is practical at MHz shift rates, with input-referred noise less than 1 e^{-}_{rms}. We may also evaluate the use of InGaAs avalanche detector arrays bump-bonded to an array of TIA/mixers. Following this we plan to build such technologies into an integrated ladar design that will miniaturize the system and make it practical for some of the proposed applications. We are also looking forward to further development of InGaAs MSM detector arrays that will allow the breadboard to operate at eye-safe wavelengths.

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