Development of Semi-Active Seeker for Maneuverable Projectiles

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Abstract

A design for an optical seeker optimized for spin-stabilized projectiles is presented. Using the spin of the bullet to scan a linear photodetector array across the target field, a relatively wide field-of-regard seeker may be constructed with an adequate SNR for homing applications. The linear photodetector array is based on room-temperature quantum-well infrared photodetectors (QWIP) optimized for a wavelength of 10.6 microns. The entire seeker containing the 1 x 64-element linear photodetector array, amplifiers and signal processor/flight computer can be constructed on a single 1-cm square bonded chip-on-chip. A compact folded telescope has been designed to collect light from a CO_2 laser designator to guide the projectile to the target. Details of the seeker design as well as laboratory measurements of the concept using a visible light prototype seeker will be presented.

Introduction

The goal of our research program is the development of an all-weather long wavelength infrared (LWIR) seeker optimized for use on spin-stabilized projectiles with high quality imaging characteristics. Existing semi-active seekers typically utilize 4-quadrant detector arrays operating in the visible or near-infrared. Although currently intended as a laser guided seeker, our design has the potential to provide good imaging characteristics to enable automatic target recognition in the future. Another advantage of improved imaging properties will be the ability to use guided projectiles for missions such as active self protection that are currently addressed only by missiles. Long-wavelength infrared has much better penetration in clouds, fog and smoke that the shorter wavelength systems in use today.[1,2] Also,

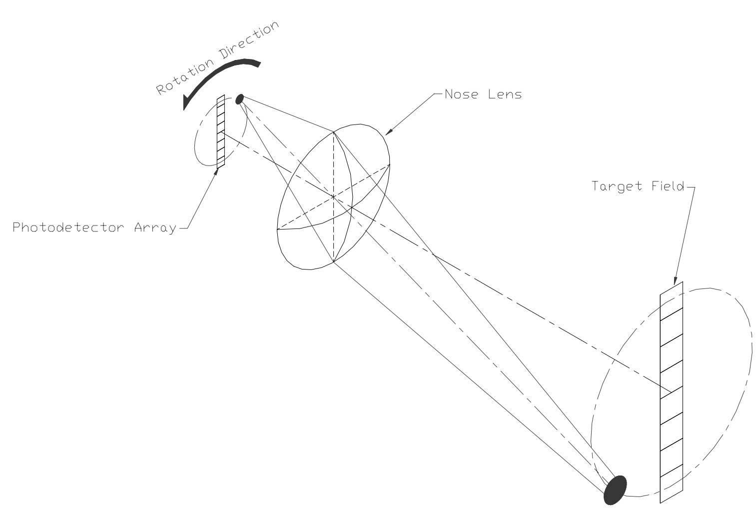

Figure 1 Schematic diagram of seeker concept

an LWIR based target designator will be compatible with existing thermal viewers employed by the military on many armored vehicles. A schematic diagram of the projectile seeker concept is shown in Figure 1. A linear array of photodetectors is located at the focus of a lens, which forms the nose of the bullet. The lens is shown a simple single element lens, however, the final design will probably result in a compact folded multiple-element lens configuration. One such design we are considering is shown in Figure 2. The first element on the left is a simple plano-convex lens. The second element is spherical element located near the focal plane array on the far right. A small aspheric lens is attached to the front lens and has a mirrored surface between the lenses. This combination combines good optical properties with the required short focal length.

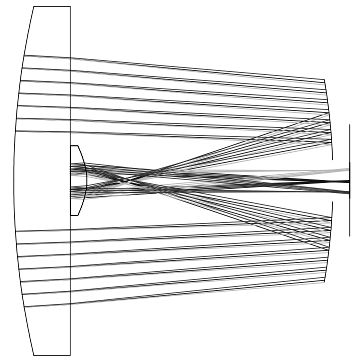

Figure 2 The compact folded lens uses one aspheric element with two commercially available lenses to produce an effective focal length of 30-mm with a diameter of 25-mm.

Spin-Scanned Semi-Active Optical Seeker

A linear photodetector array embedded in a spinning projectile can form a 2-D image of a target. This configuration allows a larger number of “2-D”pixels than an actual 2-D array with the same total number of pixels. Using the bullet spin and recording an image with a linear array containing N pixels, a “2-D” image can be captured with the same apparent image quality as if the seeker had a 2-D array with approximately N^2 pixels. For example a 1 x 400 pixel linear array can provide the same image quality as a 125,000 pixel square array. As the shell spins the projected image of the array on the target forms a circular field whose diameter is the magnification factor, M, of the optics system times the width of the array, N x a, where a = pixel size. The magnification ratio is the range, R, divided by the effective focal of the nose optic. The solid spot on the array corresponds to the laser spot on the target field. As the shell spins the spot will trace a circular pattern crossing the array twice per revolution. The two crossing points trace out the diameter of the circle, which is a measure of the angular correction needed for impact. Pitch and yaw (wobble) of the bullet will result in movement of the center of this circle. As the spot crosses the array, the direction to the target relative an axis defined relative to the bullet (the axis of the array) may also be determined. Using these two inputs the signal processor can correct the bullet flight to intercept the target. The imaging properties of the optics system and pixel size will determine the impact accuracy that may be achieved with the shell. The diffraction limit of the optics system is the determining factor in the pixel size at the target. At a wavelength of 10.6-μm the smallest spot size is on the order of 40-cm in diameter at a range of 1-km regardless of the aperture of the system. At longer ranges the target pixel will be larger, but a larger optic will not result in substantial improvement in target resolution. Assuming a wavelength of 10.6-μm and a range on the order of 1-Km, a minimum aperture of approximately 2.5-cm is required. It is interesting to note that a 25-mm to 40-mm shell is large enough to house the optics aperture necessary to satisfy the imaging properties of the optical seeker for the smallest targets currently envisioned for the smart bullet. Above, it was assumed that the transmitter optic is the same size as the receiver optic and the spot size on the target is diffraction limited. If the transmitter optic were made larger, the beam spot on the target could be smaller, but the resolving capability of the receiver would not improve. Also, the received signal strength would not improve with larger transmitting optics.

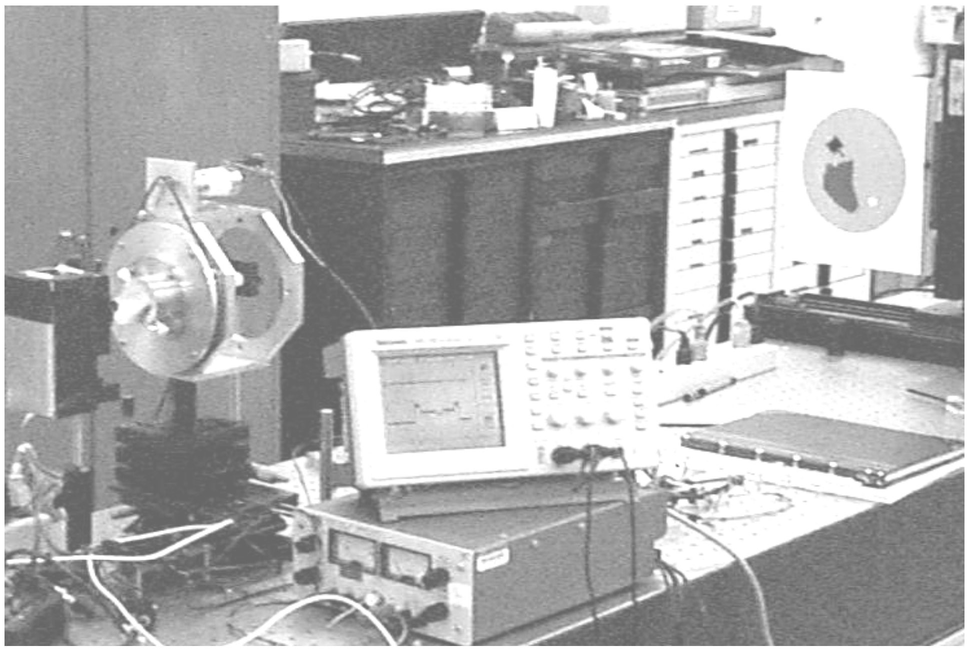

Figure 3 Visible light prototype seeker on a laboratory test stand.

Laboratory Testing

In order to test this concept, a linear array seeker has been developed using a commercially available visible light diode array. The Model TSL 1401, manufactured by TAOS, Inc., consists of an array of 1 x 128 pixels each with a size of 63.5 x 55.5 microns with a center-to-center spacing of 63.5 microns. A dove prism was used to simulate a rotating image of both a laser spot and/or an image for analysis. A photograph of the test set-up is shown in Figure 3. The array and lens in a black light tight housing is located on the far left of the photograph. The dove prism, located in a hexagonal aluminum frame is located immediately to the right of the detector assemble. A motor is mounted on the aluminum frame to rotate the prism to scan the target. A simulated target, printed on 8.5 x 11 inch paper, is located on the right of the photograph. Figure 4 shows the results on a single scan of the target. The discontinuity on the right on the scanned image is due to imperfections on the dove prism. The primary features of the target are all reproduced on the image.

Future Directions

The next phase of our program will involve the development of an infrared linear array and compatible signal processing electronics. We have been developing single element room-temperature quantum-well infrared photodetectors optimized for a wavelength of 10.6 microns for free space optical communications. The next step will be to evaluate the performance of a linear array of QWIPs and integrate the array onto a chip with the signal processor. In addition to the room-temperature QWIP detectors, we are developing compact CW RF-driven, air-cooled, sealed-off waveguide CO_2 lasers to serve as a target designator.

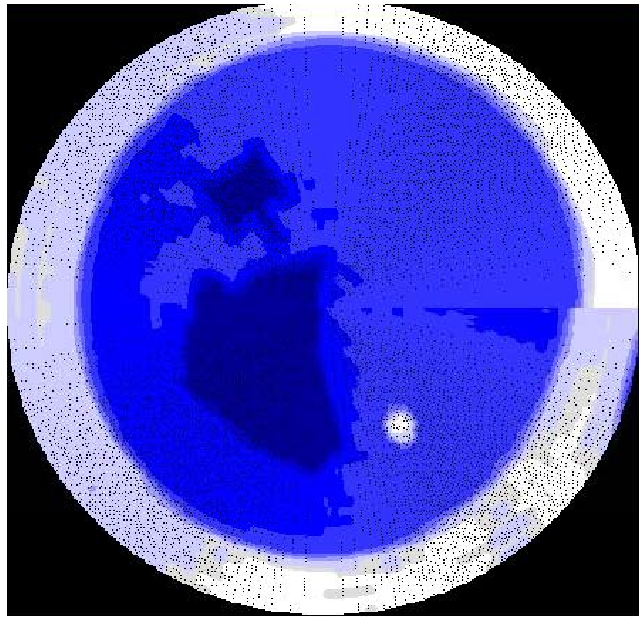

Figure 4 Captured image of the target using a single scan of the dove prism.

Summary

A concept for an optical seeker for a guided bullet has been presented. Using the spin of the bullet to scan the photodetector array, a relatively wide field-of-regard seeker may be constructed with excellent target resolution for homing applications. The seeker is sufficiently compact to fit the system on projectiles as small 30-mm or 25-mm .

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[1] D.B. Rensch and R.K. Long, “Comparative studies of extinction and backscattering by aerosols, fog, and rain at 10.6 μ and 0.63 μ,” Applied Optics, vol. 9, no. 7, 1970

[2] V. Chimelis, “Extinction of CO_2 laser radiation by fog and rain,” Applied Optics, vol. 21, no. 18, 1982