Low-cost Semi-Active Laser Seekers for US Army Applications

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Abstract

The U.S. Army Research Laboratory (ARL) is exploring technologies to provide low-cost precision fires, applicable across both direct and indirect fire weapon systems. One of these applications involves a forward observer (FO) designating the target with a laser spot and a seeker on-board the munition detecting the reflected energy to allow terminal guidance. This approach, referred to as semi-active laser (SAL) guidance, has been utilized on numerous air-delivered munitions to include bombs, missiles and projectiles. However, the cost of these systems, driven by high quality optics, high sensitivity detectors and specialized electronics, has hampered their migration into gun-fired munitions such as mortars, artillery and grenades. To explore, develop and demonstrate minimal cost solutions, ARL invested in an Army Technical Objective (ATO) called Smaller, Lighter, Cheaper Munition Components (SLCMC). Specifically, SAL seeker hardware, predicated upon commercial components (COTS) and mass production techniques, is being prototyped for use with gun launched projectiles and laser target designators. The seeker system is comprised of several printed circuit board boards, a microprocessor, a quad-photo detector and, a molded optical lens unit. This seeker is designed to rapidly update the projectile boresight angle, interface with other strap-down sensors, and feed data into an on-board guidance, navigation & control (G,N&C) system to allow for projectile maneuvers. The seeker design and basic characteristics are discussed and presented through-out the paper and presentation.

Key Words

Seeker, Munitions, Precision fires, Artillery, Semi-active laser, Guidance systems, Strap-down sensors

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1. Introduction

Semi-Active Laser (SAL) guidance is utilized on the modern battlefield for multiple weapon systems ranging from rockets to missiles to guided bombs. The SAL guidance scheme relies on a laser designator to illuminate the target with energy. The reflected light and is then sensed by the seeker on the weapon system, usually containing a quadrant photo detector, for homing in on the energy reflected from the target [1]. Invented in 1960, the laser (light amplification by stimulated emission of radiation) has made a valuable contribution to many modern weapons. Early systems employing laser guidance were the Maverick, Copperhead, and Hellfire missiles which entered service in the late 1970's. These weapons systems employed semi-active laser homing seekers, operating at a wavelength of 1.06 micros, which are still being used and further developed today. These weapons are said to be semi-active because they do not emit the laser energy that passively they detect and track, in other words, the weapon system does not have a laser source installed but relies on an external laser designator. At present, the US Army has a very limited inventory of laser-guided, cannon-launched munitions, such as the 'Copperhead' laser-guided artillery shell. These precision weapons are typically quite costly and employed at medium to long ranges (i.e. > 3km). As a result, the U.S. Army has the need for low-cost, small, light-weight precision munitions, particularly a low-cost SAL seeker system for use at shorter ranges (i.e. 200m to < 3km).

This paper describes the conception and development of a low-cost SAL seeker for precision guidance of gun-launched munitions. Although a gun launched projectile was selected as the demonstration platform, the technology is adaptable to any artillery type projectile. To assure the lowest cost implementation, COTS electronic components were used exclusivly.
Figure 1 illustrates a short-range target engagement scenario where a concealed soldier selects an enemy building as the target for a laser-guided precision mortar by designating it with his compact, rifle-mounted, optical sight and laser designator. Note that digitally encoded target information can also be communicated from the soldier to the incoming precision mortar by means of suitable modulation of the designator laser pulses.

2. <u>SAL Seeker Basis</u>

The seeker technology is based on a nose-mounted, near-Infra-Red (near-IR), fixed 'strap-down' (i.e. not gyro mounted or gimbaled) SAL seeker using a direct semi-focused laser spot impinging on a four-quadrant photo-detector. A semi-focused spot on a four-quadrant detector is illustrated in Figure 2., which shows the target error vector (dx, dy) from the mortar bore-sight can be readily computed from the relative laser pulse illumination powers detected on the four quadrants.

The target error vectors (dx, dy) sampled and measured at the detection of each of the target reflected designated laser pulses, are input to a micro-controller, for digital signal processing in a flight control algorithm, to control the terminal flight phase of the projectile so as to guide it precisely onto its target by seeking to reduce the target error/offset angles from bore-sight to zero. The SAL seeker control system diagram is shown in Figure 3 and illustrates the laser target designation pulse function, seeker front-end laser pulse photo detection, followed by sampling, processor target/mortar model estimation, and flight control actuation. The flight control actuation modifies the projectile flight path, through interaction of aerodynamic forces, to reduce the target-mortar error angles towards zero and so hit the target precisely, in a sampled, closed-loop fashion.

3. Block Diagram / Implementation

Figure 4 illustrates the specific SAL seeker in block diagram form by showing the interconnectivity between the three, specially developed, seeker electronic sub-systems. The front-end analog board holds the four-quadrant photo-detector, optical semi-focusing lens, and optical filter on one side of the board to capture the incoming target-reflected laser designator pulses. The other side of the board holds the precision analog electronics necessary for accurate laser pulse detection over the full dynamic range of target engagement. The interface board provides precision sampling and analog-to-digital conversion of the detected laser pulses under control from the processor/logic section. It also provides a control/status interface to the processor/logic board, and a transceiver section for optional use as a telemetry/control link is included. The processor/logic section provides the main computing power to run the flight control algorithms, guidance/actuator control outputs, and other onboard guidance sensor inputs.

An overarching strategy for implementing this low-cost SAL seeker in a nominal tactical system is presented in Figure 5. The G,N&C system is broken into 5 major elements: SAL seeker, inertial measurement unit, navigation algorithms, guidance and control algorithms, and actuator/control mechanism. Regardless of whether a gimbaled or strap-down system has been implemented, though our approach is focused on low-cost strap-down hardware, a threshold in signal-to-noise ratio is prescribed to determine lock-on of the seeker. Atmospheric transmissivity (and therefore battlefield obscurants), scattering nature of the target (diffuse or specular reflectivity), laser energy, detector sensitivity, and path length (range from designator to target to detector) all factor into SAL seeker performance. The laser-range equation encompasses these parameters and is often used for rapid effectiveness analysis. The results of theoretical calculations of the maximum range for this seeker, based upon the standard laser range equation [2], and measured values of reflectivity for various objects including olive drab painted surfaces [3], are provided in Table 1. It is noted that under the most modest laser range conditions and assuming the smallest seeker optical aperture under consideration, in this case 10mm diameter, the maximum range (> 1 km) is still quite useful for indirect fire applications.

These calculations assume a laser designator having pulse durations of 8 ns and an inexpensive commercially available Silicon quad-photo detector.

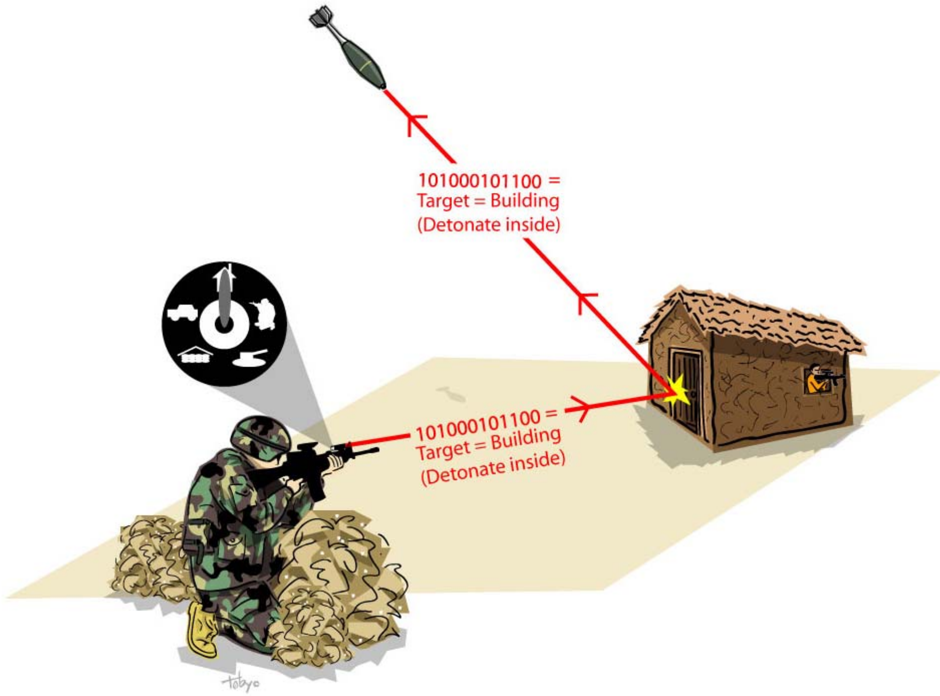

Figure 1. SAL seeker concept with solider illuminating target for projectile to impact.

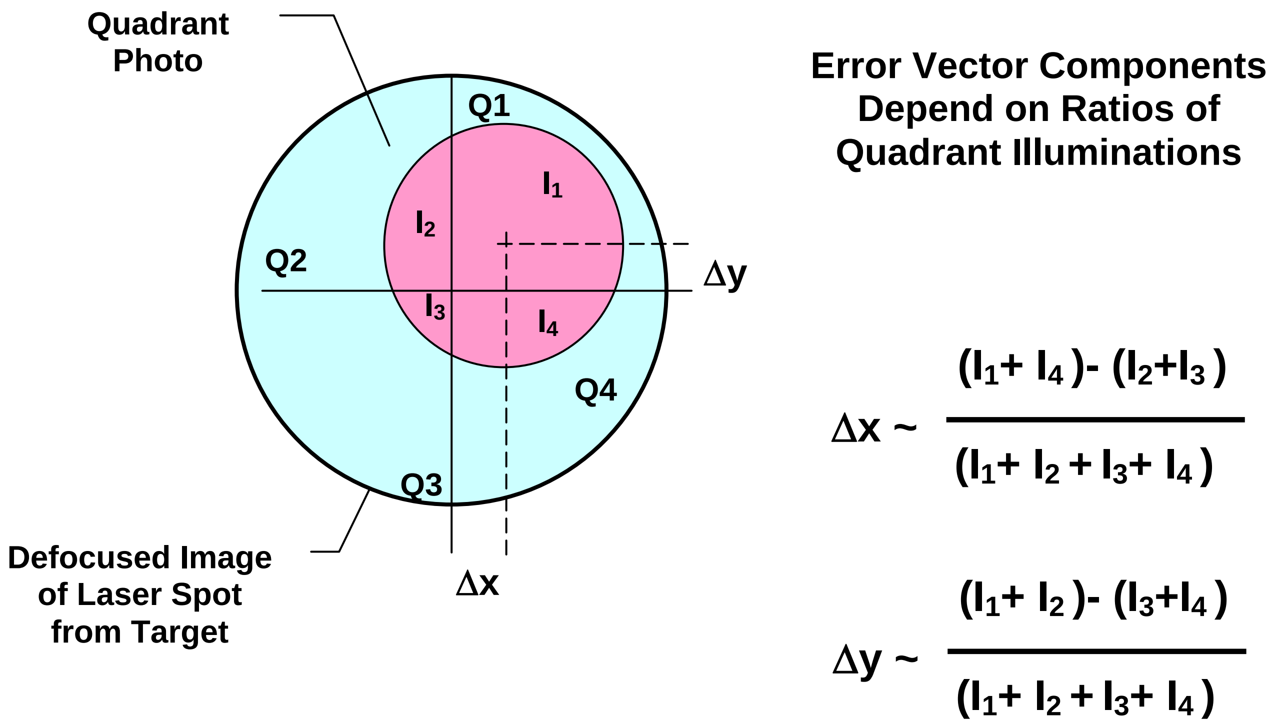

Figure 2. Schematic diagram of optical quad-detector with the standard relations for measured photo current and laser spot offset in x and y directions required for determining the position of the reflected laser energy from target designator.

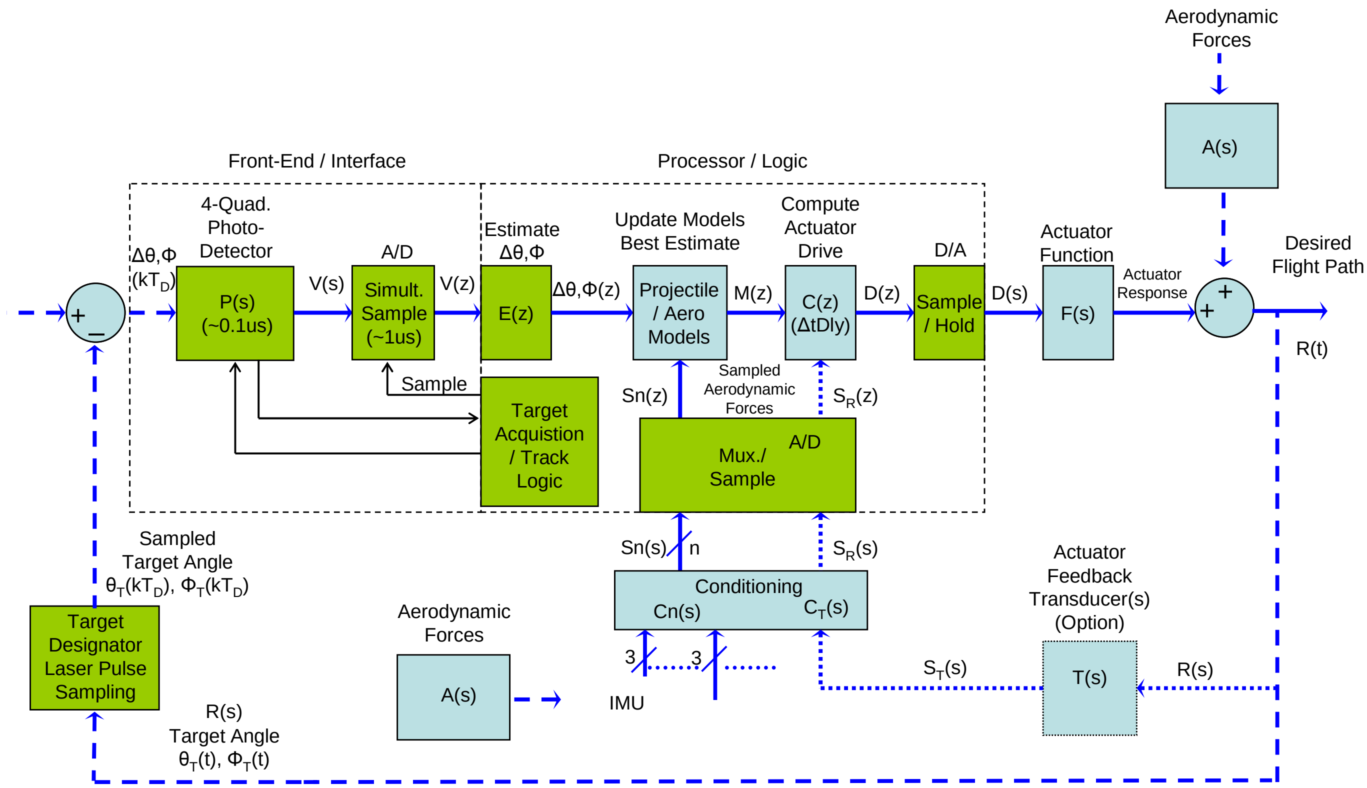

Figure 3. SAL seeker system control diagram.

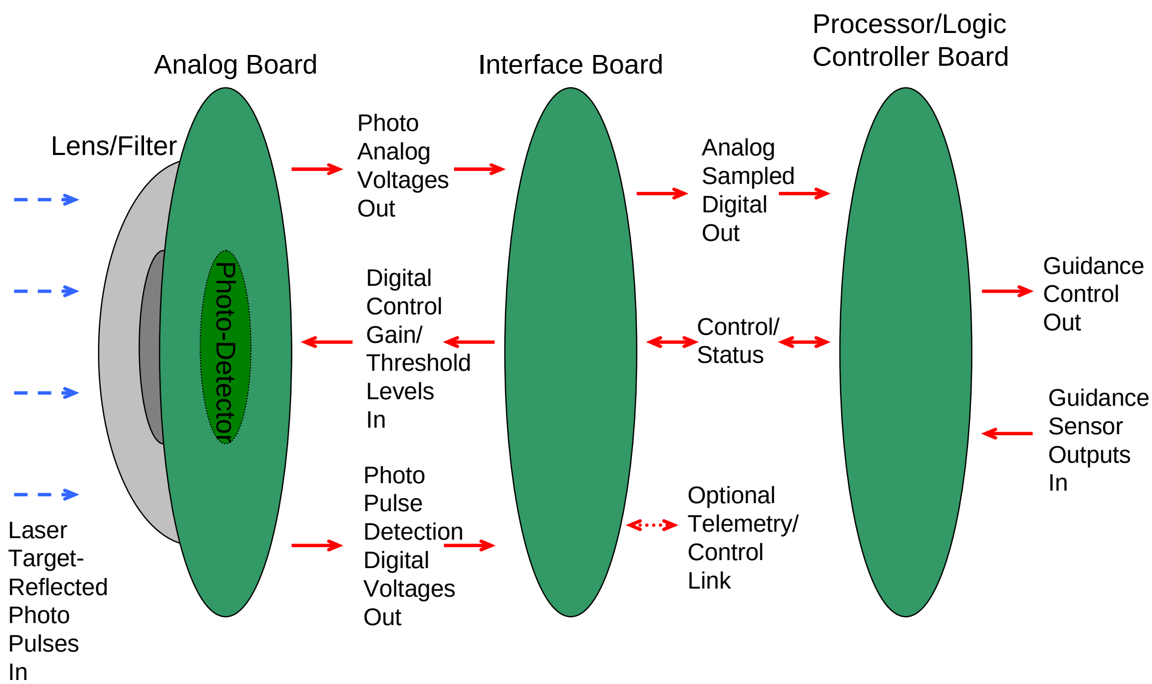

Figure 4. SAL seeker electronic board level block diagram.

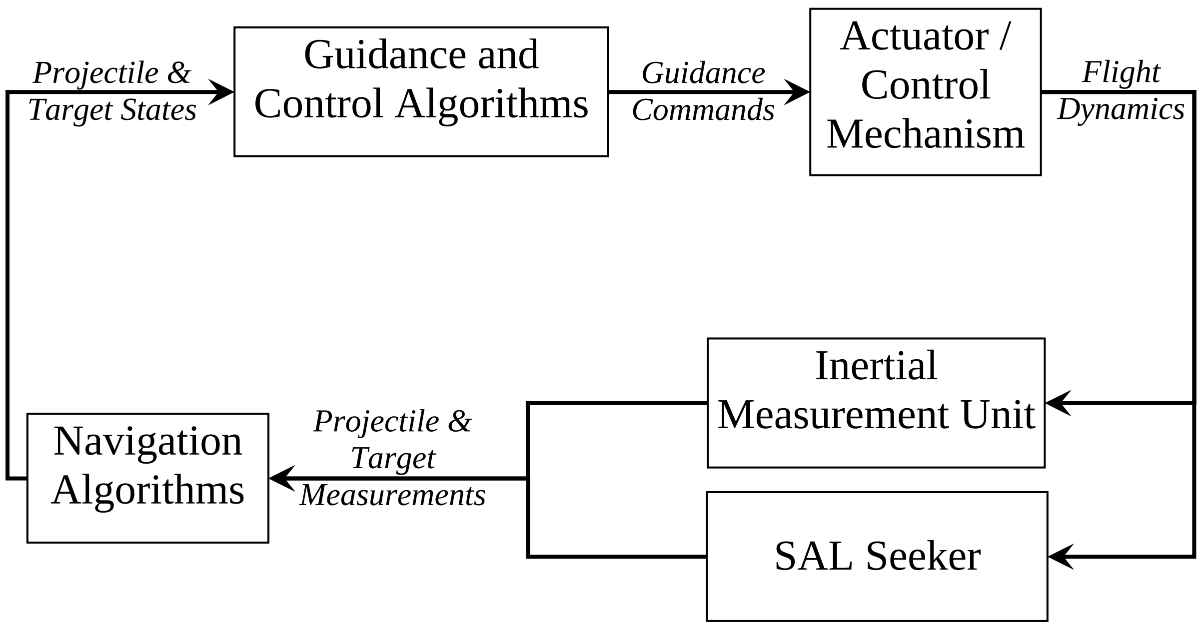

Figure 5. Block Diagram of SAL Seeker Implementation in GNC System

Table 1. Theoretical Seeker Range Values for Various Laser Designator Power Levels, Targets, Free Space Conditions, and Optical Apertures.

Max Range (m)	Laser designator pulse energy (mJ)	Target Reflectivity	Free Space Propagation loss	Seeker Aperture Diameter (mm)
20,575	80	0.9	0.7	100
14,549	80	0.9	0.7	50
8,313	80	0.9	0.4	50
3,695	80	0.4	0.4	50
2,612	40	0.4	0.4	50
1,168	40	0.4	0.4	10

Conclusions

The basic design and performance characteristics of a semi-active laser (SAL) seeker, appropriate for both direct and indirect fire applications, has been presented and discussed. This system represents a truly affordable, COTS based, SAL seeker guidance system for guided projectile applications with component costs totaling $300. The design and analysis indicates an effective solution for strap-down munitions applications is quite feasible, thus warranting continued studies with prototype hardware currently under development. Further studies will include confirmatory experiments under realistic conditions as well as coupling to a complete G,N&C system and hardware-in-the-loop simulation. This will provide for more exactly determining the system dynamic response and effective accuracy improvements.

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