DEVELOPMENT AND CHARACTERIZATION OF LOW COST SEEKER TECHNOLOGY FOR US ARMY APPLICATIONS

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ABSTRACT

The US Army Research Laboratory (ARL) is pursuing advanced seeker technologies for use with guided precision munitions under an Army Technology Objective (ATO) called Smaller, Lighter, Cheaper Munition Components (SLCMC). Specifically, semi-active laser (SAL) seeker hardware, predicated upon highly affordable commercial (COTS) components, is being developed and experimentally characterized for use with both standard and notional laser target designators. Emphasis is on utilization of low cost component technology and techniques, where possible, without making significant sacrifices in system capability. The concept under development at ARL, is comprised of numerous custom analog and digital electronic circuits, a central microprocessor, a COTS quad-photo detector and a custom low cost optical lens unit. The resulting prototype layout is being packaged in a modular fashion on three circular printed circuit boards 60mm in diameter. Its output is designed to be integrated with other on-board high-g sensors to a guidance processor for the computation of dynamic vehicle state in real-time. The resulting guidance solution is then used to drive an embedded actuator control system, producing the required trajectory corrections. The system design and dynamic characteristics, including relevant control system analysis, are discussed through-out the paper and presentation. Although this effort was focused on the characteristics appropriate for gun-fire projectiles (high-g survival, range, response time, etc.) the technologies under development are applicable to a wide range of terminally guided munitions.

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, either ground-based or airborne, to illuminate the target with laser energy. The reflected light is then sensed by the seeker on the weapon system, typically containing a quadrant photo detector. This information is then processed, within the guidance algorithm, to determine miss angles and compute the required corrections. In this sense SAL seekers provide a terminal homing capability, based upon laser energy being reflected of the target in such a geometry that the in-coming munitions is able to detect it. [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 weapon systems employed semi-active laser homing seekers, operating at a wavelength of 1.06 micros, which is 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 narrow inventory of laser-guided, cannon-launched munitions, limited to the 'Copperhead' laser-guided artillery shell, a munition that was fielded decades ago and is very difficult to employ. This type of precision weapon are quite costly and can be used over a narrow band of operating conditions. As a result, the U.S. Army has the need for low-cost, easily deployed, light-weight precision munitions, enabled by a low-cost SAL seeker system for use at shorter ranges (i.e. 100m to < 3km).

Key Words

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

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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 easily scalable to other munition platforms. To assure the lowest implementation costs, COTS electronic components were utilized exclusively. Figure 1 illustrates a short to mid range target engagement scenario where a soldier in contact calls for the neutralization of an enemy occupied building. Due to numerous considerations such as lethality, collateral damage, ease of employment and time to engage, a laser-guided indirect fire projectile is determined to be the most appropriate weapon selection. Following coordination with the firing platform, the soldier designates the target 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 projectile by means of suitable modulation of the designator laser pulses, adding a degree of functionality that currently does not exist.

2. SEEKER BACKGROUND

The seeker technology is based on a nose-mounted, near-Infra-Red (near-IR), 'strap-down' (i.e. not gyro mounted or gimbaled) SAL seeker using a semi-focused laser spot impinging on a four-quadrant photo-detector. This approach is illustrated in Figure 2, which shows the target error vector (dx, dy) from the munition 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 guidance algorithm. These outputs control the terminal trajectory, or end game, 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/munition model estimation, and flight control actuation. The flight control actuation modifies the projectile flight path, through the generation of asymmetric aerodynamic forces, to reduce the target-munition error angles towards zero, in a sampled, closed-loop fashion. Such an approach does not guarantee a target intersect, but will at least drive the nose to be pointed at the target during the end game, given ample control authority.

3. SYSTEM DESCRIPTION AND IMPLIMENTATION

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 notional laser designator having pulse durations of 8 ns and an inexpensive commercially available Silicon quad-photo detector.

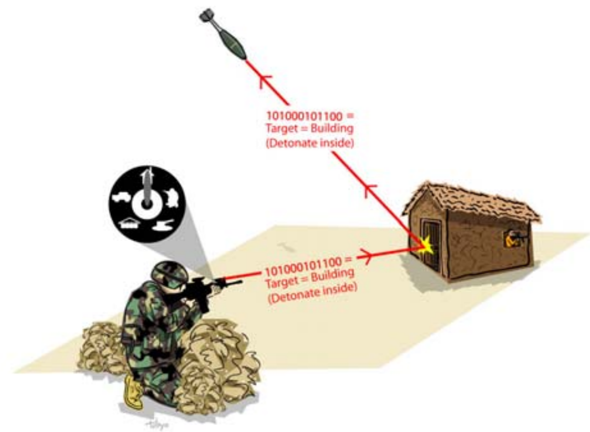

Figure 1. SAL seeker concept with solider illuminating target for projectile to impact.

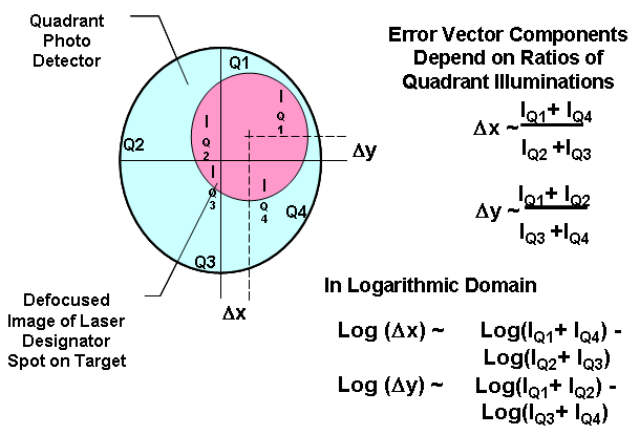

Figure 2. Schematic diagram of optical quad-detector with the standard relations for measured photo current and laser spot offset in x and y directions required for determining the position of the reflected laser energy from target designator.

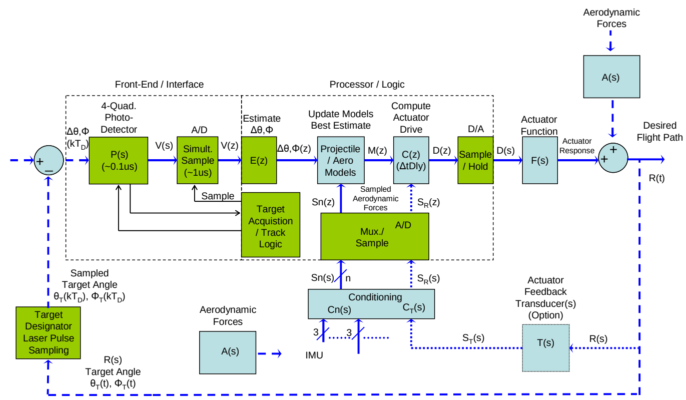

Figure 3. SAL seeker system control diagram.

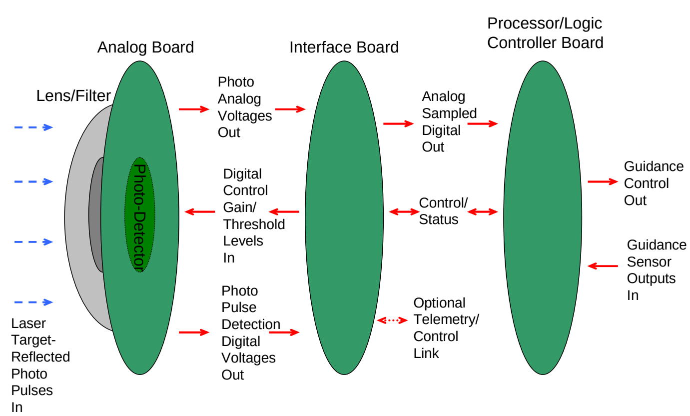

Figure 4. SAL seeker electronic board level block diagram.

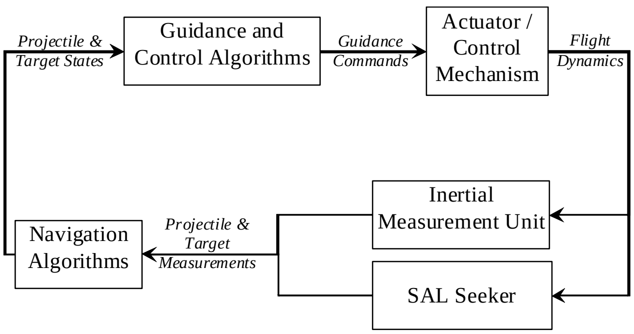

Figure 5. Block Diagram of SAL Seeker Implementation in GNC System

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

4. 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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