New sensor determines threat angle-of-arrival and impact point, aiding countermeasures

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A new laser radar (ladar) technology, which exploits several spectral bands to discriminate the position, angle-of-arrival, and velocity of ballistic threats, provides increased protection of military vehicles. This polyspectral ladar uses multiple sheets of light, each at a unique wavelength, fanning out from the vehicle, and representing planes that the threat must cross to impact. Determining the time and angle at which the threat crosses these planes enables calculation of both threat velocity and arrival angle. BAE Systems has demonstrated the feasibility of an optical polyspectral ladar sensor, including system design, modeling and analysis, requirements, and experimental results. This sensor was successfully demonstrated in the laboratory using surrogate threats.

The problem of vehicle self-protection
Ballistic threats pose significant problems for military vehicles worldwide. Threats such as rocket-propelled grenades (RPG) are especially difficult due to their relatively simple operation, ballistic nature, and high speed. Figure 1 shows an RPG being ejected from its launcher. Protection of military vehicles from these threats is being investigated from various perspectives using several technologies. While countermeasure queuing approaches (prioritizing actions to defeat ranked threats) have been investigated, there still exists the need for a sensor that provides a high probability of detection for a wide threat range while providing a low rate of false alarms. The sensor developed here determines velocity, direction, angle-of-arrival, and threat impact point, and can be used to queue a reactive countermeasure.

The success of passive approaches—such as bar armor, metal grilles attached to a vehicle and used to detonate incoming missiles before they reach its body—is dependent upon the matched geometry of bar openings and the threat diameter, which determines if the impact will crush or capture the threat to prevent detonation. The motivation behind the sensor described here is an alternate approach: a reactive countermeasure providing a high probability of intercept for a wide range of threats and a low false alarm rate, all at a reasonable cost.

The polyspectral ladar solution
The polyspectral ladar sensor consists of a transmitter, receiver, acquisition and processing electronics, and a controller. The

Figure 1. RPG being launched.
Figure 2. Orientation of light planes relative to vehicle

transmitter provides four spatially- and spectrally- separate light sheets that fan-out from the vehicle. Coarse wavelength division multiplexing isolates and associates incoming radiation from a unique source. Each light sheet is considered a plane and is anamorphic: the vertical beamwidth is a function of coverage area and beam placement. Normals must be unique in \( x, y, \) and \( z \) for a unique solution. Likewise, the receiver consists of four spatially- and spectrally-separate detectors matched to a transmitter. Energy received from a detected threat is time-tagged using a fixed-amplitude threshold calibrated above the noise, critical to producing accurate and repeatable temporal tagging. Once all detections are received and tagged, relative times are sent to the velocity-processing algorithm. This determines the relative crossings between planes, provides a location along the vehicle, and furnishes a timing trigger. It also provides the threat impact point and velocity. The algorithm determines a unique solution during the time a threat travels from the last plane to the vehicle. Figure 2 shows light-plane orientation on a vehicle.

A laboratory demonstration validated sensor operation. To ensure a reasonable file size, the threat launch space and vehicle impact location were reduced. Since this area could be moved to any place within the desired coverage area, validation was not compromised. MATLAB was used to model the ladar and geometrical aspects of the sensor. It also provided a means to trade design parameters, including laser power, receiver field of view, and aperture size.

Plane orientation depends on the minimum distance from the vehicle to the closest plane: all are dependent upon countermeasure reaction and processing time and determined using an estimate for the minimum time needed between intercepts. Sufficient differences in their normal vectors provides an unambiguous solution. The premise of the velocity algorithm is that the projectile path, assumed to be a straight line, is characterized by five unknowns: launch location; \( y \) and \( z \) in the distance plane; end location; \( y \) and \( z \) in the vehicle plane; and velocity magnitude. In the demonstration, the four crossing times and velocity were determined and the hit point on the vehicle displayed.

An indoor laboratory environment limited the threats that could be used for demonstration: velocities up to \( 31 \text{ms}^{-1} \) were achieved and the lookup table constrained to reduce processing time. The search program output a list of possible launch and hit locations based on a programmable tolerance uncertainty for the five parameters. The best timing uncertainty is that yielding the smallest ambiguity while still producing viable matches. Lookup table resolution was sufficient and, based on the list produced by the search and samples and the accuracy of the demonstration system, was adequate for countermeasure queuing.

Conclusion
A novel optical sensor that combines ladar and geometrical detection of projectiles has been modeled, developed, and demonstrated. Full-scale vehicle coverage has been demonstrated in a segmented fashion and acceptable hit location accuracy has been found on a prototype system. The extension of this concept to include more planes and a real-time velocity algorithm is expected to provide a very small unambiguous accuracy with the capability to queue a reactive countermeasure.

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