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OPTOELEKTRONICZNE SYSTEMY WYKRYWANIA STRZELCA WYBOROWEGO

Streszczenie: W artykule przedstawiono współczesne systemy detekcyjne przeznaczone do wykrywania snajpera. Wśród systemów tego typu, wprowadzanych na uzbrojenie wielu armii istotną rolę pełnia pasywne i aktywne systemy optoelektroniczne. Ich zaletą jest możliwość wczesnej detekcji zagrożenia, zwłaszcza przed oddaniem strzału przez snajpera. Przedstawione systemy pasywne wykorzystują kamery termowizyjne i zaawansowane metody analizy obrazu w celu wykrycia sygnatur snajpera i strzału z broni palnej. Systemy aktywne wykorzystują z kolei promieniowanie laserowe w celu wykrycia optycznych przyrządów celowniczych i obserwacyjnych. W artykule przedstawiono charakterystyki techniczne i taktyczne szeregu urządzeń optoelektronicznych przeznaczonych do wykrywania snajpera, pracujących jako samodzielne urządzenia bądź jako elementy składowe wieloczujnikowych systemów detekcyjnych.

OPTOELECTRONICS SYSTEMS FOR SNIPER DETECTION

Abstract: The paper presents modern sensor systems for sniper detection. Among such systems there are active and passive opto-electronic devices. Its primary advantage is the possibility to early recognize the threat, before the sniper is able to take the shot. Presented passive systems employ thermal cameras and advanced image processing algorithms to distinguish the sniper and muzzle blast signatures. Active systems, in turn, rely on the detection of laser radiation, retro reflected from pointed optics (optical sights and observation scopes). The paper presents basic technical and tactical characteristics of sniper detection devices, both standalone and included in multi-sensor detection systems.

1. Introduction

Sniper detectors are still a work in progress. The acoustic detectors have had the most success, and over 500 of them have been shipped to Iraq and Afghanistan. Sniper detection systems provide directional information about where the snipers are. Several generations of these systems have showed up over the last three years. The usefulness of these anti-sniper systems has increased as the manufacturers have decreased the number of false alarms and improved the user interface. There other reasons for all this progress, including major advances in computing power, sensor quality and software development. The latest improvement is providing nearly instant and easy to comprehend location info on the sniper.

The primary phenomena used in sniper detection are acoustic signal from the shockwave generated by a supersonic bullet and the muzzle blast, optical signal from the muzzle flash and retro-reflection from the optical sight. The bullet can also be detected optically in flight. Here, the muzzle flash will be discussed. This type of sensor can also provide both cueing of other sensors and substantially reducing the false alarm rate. The flash image can also be shown to an operator for inspection.

The most important aspect of counter-sniper actions is the ability to detect the sniper before he could take a shot. Such task can be accomplished by passive and active optoelectronic sensors. The former are usually thermal systems with search and track capabilities, whereas the latter are laser systems which detect reflections from optical sights. The advanced methods of analysis of reflected laser radiation can distinguish objects of interest from the reflecting elements of scenery, like windows and car headlamps.

The table below presents the summary of sniper detection systems used by armed forces of the world, showing the physical phenomena those systems use for sniper detection. The data presented in this table were gathered from all commonly available sources of information.

Name	Manufacturer	Muzzle Blast	Bullet Shock Wave	Muzzle Flash	Bullet in Flight (IR)	Optics Laser Reflection
Prototype	Sanders	X	X			
Bullet Detection Indicator	G D Associates		X			
Bullet Ears	BBN	X	X			
PD Cue	AAI Corporation		X			
Pilar	Metravib	X	X			
VIPER	Maryland Advanced Development Lab			X		
Prototype	Hughes Aircraft	X			X	
Integrated Sniper Location System	Sanders, LMIIS, and Sentech	X	X		X	
Sight Laser Detector (SLD)	Cilas					X
Target Observation and Locating System	Sanders					X
Sniper Acoustic Detection Sensor	Rafael	X				
SECURES	Alliant Techsystems	X				
Sentinel Sniper Location System	SAIC	X	X			
Fast IR Sniper Tracker	Thermo Trex			X		
Lifeguard	LLNL				X	

2. The passive electro-optics systems for detection of sniper

The phenomena detected in IR spectra are muzzle flash and thermal signature of the bullet in flight. Muzzle flash is IR signature associated with the ejection of the bullet from the sniper's rifle. The muzzle flash can be detected with IR sensors out to a kilometer or more, but the sensors must have line of sight to the weapon, and the flash can be suppressed. The thermal signature of the bullet in flight can be theoretically detected with IR sensors out to several kilometers in range. Since the bullet is much hotter than “room temperature,” it is detected most effectively in the medium-wave infrared (MWIR) band, with wavelength between 3 and 5 μm. Sample shot signatures in that spectral band are presented in Fig.1. However, long-wave infrared (LWIR)-based systems operating in the wavelength band between 8 and 10 μm can also detect such signatures. The object of detecting signatures of the bullet in flight is to estimate the bullet’s trajectory and backtrack it to find the location of the sniper.

Fig. 1. Muzzle flash recorded in the 3-5 μm infrared range.

Most commonly used acoustic sensors can measure angles to the acoustic source, but not the range. To establish a track of the bullet it is required that an array of acoustic sensors is deployed. One alternative approach is to obtain an approximate direction to the sniper from the acoustic information, then to cue an IR sensor to backtrack the bullet more precisely. A second alternative is to detect the muzzle flash with a wide-field-of-view IR sensor, which then initiates an IR track of the bullet, resulting in a backtrack to the sniper.

The backtracking process in the city is complicated by buildings, which may obstruct the view of the sniper’s location. If much of the bullet track is visible, it is feasible to use the computer simulation to complete the backtrack in the virtual world of the computer. This procedure could provide GPS coordinates for a weapon delivered from a UAV.

The development of optical system designed for sniper detection concentrates on several aspects. They are: design of optics, new types of sensors and signal processing methods. As far as infrared detection of explosive event (i.e. muzzle flash) is concerned, the optimal wavelength range, covering sniper fire, mortar fire and rocket propelled grenades (RPGs) lies between two spectral bands, one centered at 2.8 μm and one at 4.5 μm. Therefore, the mid-IR range is commonly chosen, which means that a sniper detection system operating in the 3 to 5 μm region must deal with the potential problem of false alarms from solar clutter. The detection of muzzle flash requires fast reaction times and scanning rates, significantly exceeding typical values of 30 or 60 Hz of standard cameras. It is not fast enough for detection of signals such as sniper fire, which is believed to have duration of about 2 milliseconds. Additionally, the wide field of view is necessary to scan the surrounding area yet retaining the possibility to pinpoint the location of the muzzle flash event (sniper location). Some examples of real IR systems for sniper detection are described below.

WeaponWatch, developed by Radiance Technologies, provides very capable, reliable and flexible weapon detection and response system. It provides a complete solution that detects, locates, classifies and responds to fired weapons from fixed and rotary wing aircraft, UAVs, ground vehicles, towers and tripods.

Employing a powerful infrared camera and high-speed 5th generation data processing technology, WeaponWatch recognizes and analyzes in real time the heat signatures of fired weapons. WeaponWatch’s speed and accuracy make it possible to detect and respond to enemy weapon fire-by alerting soldiers, by communicating the type and location of the weapon, even by returning fire-before the sound of the enemy weapon reaches the sensor.

WeaponWatch detects weapon fire in real-time day or night across a wide 120° field of view. Sensors may be stationary or “on the move.” WeaponWatch can identify individual weapons fired during simultaneous fire from dozens of weapons. It locates fired weapons by translating azimuth, elevation and range to actionable geocoordinates. WeaponWatch integrates with the platform's guidance system to adjust for velocity and aspect and classifies detected weapons using a vast database of weapon fire signatures for small arms, sniper rifles, machine guns, RPGs, MANPADs, tanks, mortars, artillery and others. WeaponWatch can detect fire from each of these weapons from beyond its effective range. System responds instantaneously with the detected weapon’s type and geolocation, cuing integrated sensors, weapons and other systems while transmitting detection and response event data to command and control systems. WeaponWatch’s user interface delivers detailed visual information with man-in-the-loop engagement control.

Detecting and responding to enemy weapon fire, WeaponWatch combines infrared sensor fidelity and super high-speed data analysis to enable warfighters to instantaneously detect, locate and classify firings of a broad range of weapons. The basic elements of this system are shown in Fig. 2. Warfighters and security personnel are under increasing risk from sniper fire and drive-by shootings. These terrorist acts succeed largely because of the difficulty in detecting and locating the enemy fire. Forces engaged with Operation Iraqi Freedom (OIF) are employing this system today to provide exacting targeting information in both urban and open terrain.

Fig. 2. The elements of Weapon Watch system.

WeaponWatch picks up on the infrared signature of every weapon the moment it is fired, instantly identifying it from a database of thousands of weapons muzzle flashes and relaying its position on screen. It has already proven itself in combat. The older, fragile, 400 pound version of this system was tested in Iraq, on top of a building where there was a high concentration of insurgent gunfire. Within a few days it turned out that American troops were able to use WeaponWatch to return fire more rapidly, resulting in a noticeable drop in enemy attacks [1].

No anti-sniper system is perfect, of course, and any system can be fooled or exploited once enemies get a good enough sense of what it can and can’t do. The potential of combination of acoustic Boomerang and infrared WeaponWatch sensors, however, may give American forces the multi-modal capability they need.

The REDOWL system, presented in Fig. 3, is another, mobile sniper detection system. It features an Acoustic Direction Finding (ADF) system developed by BioMimetic Systems. The ADF is based on advanced "neural circuits" emulating human hearing and provides accurate detection and bearing information in high background noise environments. System uses laser pointer and illuminator, acoustic localizer and classifier, thermal imager, GPS positioning, an infrared and daylight camera and two wide-angle cameras. In addition to providing its PackBot robot platform, iRobot developed the software and behaviors for the robot. Insight Technology, a manufacturer of high-performance visible and infrared laser and illuminator systems, is heading up the development of REDOWL's optics systems. BioMimetic Systems, a Photonics Center portfolio company, is responsible for REDOWL's acoustic detection and location systems. The Army Research Laboratory is the primary source of funding for this project.

REDOWL is a remote, deployable sensor suite designed to provide early warning information, gunshot detection, intelligence, surveillance and targeting capabilities to military forces and government agencies. The REDOWL equipped PackBot has been field-tested for the Army's Rapid Equipping Force at a rifle and trapshooting range. Of the more than 150 rounds fired from 9 mm pistols, M-16 and AK-47 rifles from over 100 meters, the REDOWL system located the source of the gunfire successfully 94 percent of the time [2].

The iRobot PackBot is a Tactical Mobile Robot that can be hand-carried and deployed by a single soldier. Proven in Afghanistan and Iraq, PackBot searches dangerous or inaccessible areas, providing soldiers with a safe first look so they know what to expect and how to respond.

Fig. 3. REDOWL system mounted on PackBot tactical mobile robot.

REDOWL features an array of optics and acoustic detection systems including a laser pointer and illuminator, acoustic localizer and classifier, thermal imager, GPS positioning, an infrared and daylight camera and two wide-angle cameras. When integrated with the PackBot, these systems enable the robot to accurately detect, locate and identify the origination point of hostile gunfire. These systems also make REDOWL ideal for day and night urban surveillance, reconnaissance, hostage/barricade situations, forward observation outposts and perimeter protection missions

3. Laser active systems for detection of sniper

The active optical sensors for the aims of sniper detection are based on the retro reflection (cat-eye) phenomena. This phenomena occurs when illuminated objects reflects the light in the direction of the source of light (backwards).

Laser counter-sniper systems can illuminate analyzed area of space and detect possible retro reflections produced by optical elements of sniper equipment (scopes, binoculars, etc.) These instruments, defined as optical augmentation systems, have the advantage of possibility of sniper detection before he fires his weapon.

The laser signature, or optical signature, can be defined in terms of the single parameter the *effective laser target cross section* commonly labelled A_Δ. This parameter describes the amount of laser radiation reflected from a target which is illuminated with a laser source. Starting with the laser radar equation A_Δ can be identified according to

$$P_{rec} = \frac{P_L \eta_L}{\Omega_L R^2} \cdot A_\Delta \cdot \frac{A_{rec} \eta_{rec}}{R^2} \cdot e^{-2\sigma R} \tag{1}$$

where P_{rec} is the power reflected from the target captured by the laser sensor (optics detection system), P_L is the laser power, R the target distance, Ω_L the solid angle of the emitted laser radiation, η_L is the transmission of the laser optics, η_{rec} is the transmission of the receiver channel and σ is the atmospheric attenuation. The first factor in eq. (1) defines the amount of laser radiation distributed over the target at a specific range, A_Δ gives the effective laser cross section and the third factor defines the reflected radiation of the target captured by the optical receiver of the laser sensor. The effective laser target cross section is defined in units [m^2/sr]. Consequently, if A_Δ is known for a specific target the system performance can be calculated using the laser radar equation. A_Δ provides a characteristic parameter which is unique for a specific optical target e.g. an optical sight.

Optical targets may have a large laser cross section due to the phenomenon of *optical retro reflection*, or the "cat-eye" effect. A typical example showing the strong signal from an optical target due to retro reflection is depicted in Fig.4, as well as the origin of the retro reflected signal in an optical sight. A part of the light captured by the optical aperture is retro reflected by a reticle located in an intermediate focal plane within the optical assembly. The retro reflected rays are parallel with the incident rays. The retro reflected signal consists of a specular and diffuse contribution whereas the specular is dominating in magnitude. One characteristics feature of the retro reflected signal is the narrow solid angle subtending the reflected laser radiation. In a first approximation the lobe of the can be approximated using diffraction theory i.e. the divergence angle can be estimated as $\theta \sim \lambda/D$ where λ is the wavelength of the interrogating laser sensor and D the target aperture diameter.

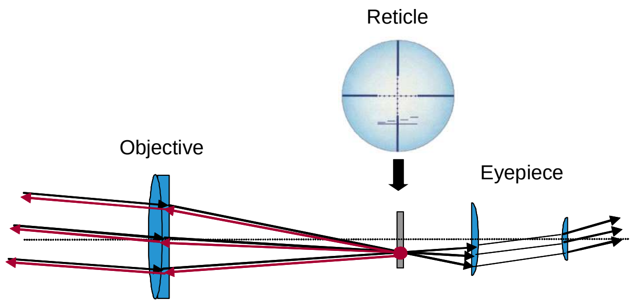

Fig. 4. Recorded retro reflection signal from an optical target and the illustration of reflected light from a reticle in an optical assembly describing a generic rifle sight.

The laser cross section may vary several orders in magnitude depending on the properties of the target. Parameters affecting the magnitude of A_{Δ} include the dimension of the target aperture and the reflection properties of the component located in the focal plane within the optical assembly. The magnitude of the laser cross section commonly varies within the target field of view of the due to the optical design and different lateral reflection properties of the component located in the focal plane. Typical values of A_{Δ} for optical sights range from 10 to 500 m^2/sr at near infrared (NIR) wavelengths. Depending on target properties considerably higher values can be observed in some instances. For comparison a typical corner cube reflectors have laser cross sections of the order 10^4 to 10^5 m^2/sr depending on the aperture dimensions.

In addition to real optical targets, such as e.g. optical rifle sights and binoculars, discussed above, the information about false target giving rise to reflection of laser irradiation is required. The information is needed for target discrimination and reduction of false alarms. The problem of false targets is most problematic in cluttered environments such as an urban scenario. In open terrain the presence of artificial reflectors is lesser and the optical target can often be discriminated more easily. Typical false targets in an urban environment include road signs, different type of reflectors (e.g. car light reflectors), reflex tape, camera objectives, CCD cameras and plastic reflexes.

Fig. 5. The Mirage system in its two configurations, hand-held (left) and stationary (right) [3]

The first system introduced here is the Mirage from LaserOptronix (Sweden). The system, shown in Fig. 5, is equipped with laser emitting impulses of radiation, a high sensitive detector and advanced filters to detect the retro reflexes from optical assemblies. The pulsed light admits the distance to target calculation on the basis of a time of flight measurements. The maximum detection range of Mirage system is 1200m. Mirage operates both at day time and night. In night system can also work as a night vision camera. Thanks to external video output the analyzed area can be seen on screens and monitors. The Mirage system can be configured in two types: an hand-held version, design for single operator and a stationary model designed specially for building protection [4].

Spectrum-RII (Russia) and JME Advanced Inspection Systems (UK) together place on the market a series of products for portable pointed optic detection in different applications (Fig. 6.). For example, the Antivid-2 and the Antiwatch-2 have been designed for the detection of small optic such as integrated video camera and spy camera at short distance (less than 15m). The system can detect and locate objective lenses as small as 1mm diameter. The purpose of such system is the detection of illegal recording in sensitive area or the repression of illegal movie recording in theaters.

Fig. 6. Antivid-2 (left) and SPIN-2 (right) systems for the detection of pointed optics [6]

For greater range of detection, these companies have developed the SPIN-L. This is a handheld system for sniper detection. The laser source can operate both in continuous and pulsed mode with power not less than 500mW. The laser beam pattern is vertical rectangular one with angle divergence of 1^ox3^o. This covers only part of screen visible through a viewfinder. The SPIN–L instrument can be useful both in conditions of complete darkness and in presence of intensive background light thanks to a set of narrow spectral bands filters. The instrument can be a handheld one or a version mounted on a tripod. When mounted on a tripod there is a possibility for horizontal scanning of the analyzed area [6].

3. Conclusions

Passive and active optoelectronic systems are effective weapon in anti-sniper operations. Its primary advantage is the capability of early detection of a potential threat. Such systems are versatile, they can operate as standalone devices or as a part of multi-sensor systems. The integration of different sensors into one detection system increases the probability of detection and reduces the false alarm rate. With the range matching the striking distance of sniper attacks, optoelectronic systems are very effective in modern battlefield conditions. Positive results of operational use of such systems prove that they provide a higher level of troops protection, especially in recent asymmetric conflicts.

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