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SYGNATURY WYSTRZAŁU W ZAKRESIE WIDZIALNYM I W PODCZERWIENI

Streszczenie: W artykule omówiono problematykę sygnatur wystrzału z broni strzeleckiej. Opisano zjawiska fizyczne będące wynikiem wystrzału, wykorzystywane do wykrywania strzelca w zakresach widzialnym i w podczerwieni. Opisano metodykę rejestracji sygnatur wystrzału, użyte do rejestracji narzędzia pomiarowe oraz sposób analizy zarejestrowanych danych. Zaprezentowano przykładowe sygnatury wystrzału z broni kalibru 5,56 mm oraz 7,62 mm, zarejestrowane w czasie badań laboratoryjnych i poligonowych w Wojskowej Akademii Technicznej. Badania miały na celu potwierdzenie użyteczności czujników elektro-optycznych do wykrywania strzelca wyborowego oraz opracowanie metodologii pozyskiwania sygnatur dla takiego zadania.

VISIBLE AND INFRARED SIGNATURES OF THE SHOT

Abstract: The paper presents the signatures of the gun shot. The phenomena associated with the shot were described, that can be used for the detection of the shooter in visible and infrared spectral range. The methods of shot signature measurements are described, along with the recording equipment and algorithms for data analysis. Sample signatures of muzzle flash from military weapons are presented, including most popular calibers of 5,56 mm and 7,62 mm. The signatures were recorded under field and laboratory conditions at the Military University of Technology. The research work was aimed at the verification of the usability of electro-optical sensors for sniper detection and at the methods of signature acquisition for this particular detection task.

1. Introduction

There is increasing interest in shooter detection devices in the recent years. At first, such devices were built using acoustic sensors. Nowadays the electro-optical sensors, working in visual and infrared spectral ranges, are also used for this purpose. Such sensors locate the shooter mainly by detecting the muzzle flash. The basic properties of muzzle flash signatures are here being considered. The problem with the muzzle flash has been known since the middle ages and has been persistent throughout history. Only in modern time has it been known that the flash can be controlled to some extent by chemical additives and mechanical adaptors. Small caliber weapons are often fitted with a flash reduction device while larger caliber weapons are supplied with an attachment for reducing the momentum of the exit flow. In the latter case, the muzzle flash can be appearing in the backflow with considerable intensity. Additives however not only affect the gun muzzle signature but also the gun performance. The muzzle flow field is rather complex, transient, turbulent and reacting.

Muzzle flash suppressors and momentum reducers also complicate the flow field substantially making modeling of firing signatures extremely difficult. Careful observation of signatures from firearms of different calibers and barrel length might however make empirical modeling doable. Any modification such as attachment of a muzzle flash suppressor or muzzle breaker will influence the signature to a large extent and has to be modeled separately. Not only the temporal development of the flash is affected by the attachment but also the spectral content is affected. Flash suppressors are most effective in the visible spectral region.

The muzzle flash mechanism can be studied in sequential time-resolved imaging. An example of such a sequence is shown below (Fig. 1) where the primary flash, the intermediate flash and the secondary flash can be observed. The secondary flash is suppressed by chemical additives. The radiation from each phase is governed by its specific chemical dynamics and that's why the spectral properties of the muzzle flash vary with time.

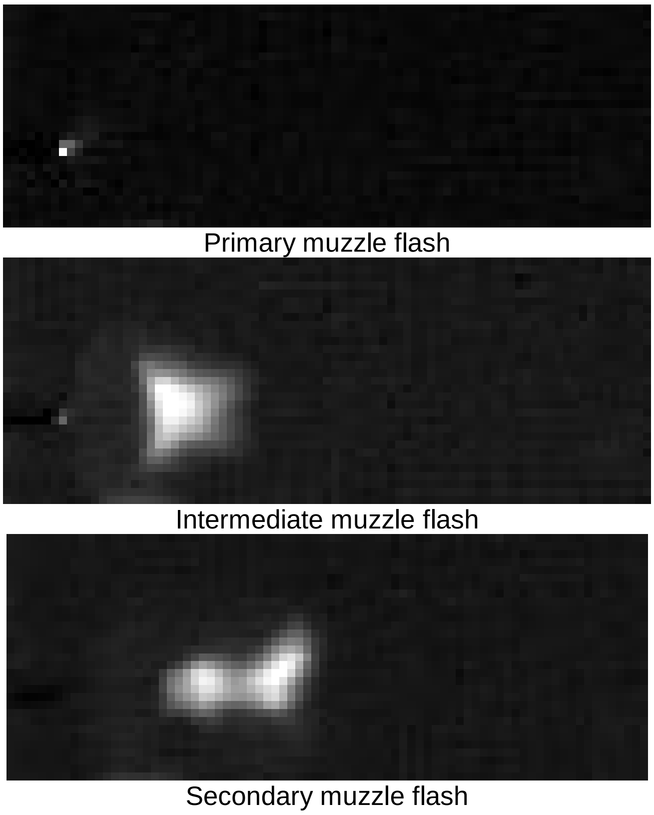

Fig. 1. Sequential registration of muzzle flash development obtained in the near infrared spectral region

The muzzle flash radiates from the UV spectral region to the thermal infrared spectral region with intensities governed by the chemical reaction and dynamics of the flash. The flash develops in three different regions called the primary flash, the intermediate flash and the secondary flash. Radiation to a lesser extent can occur outside this sequence but those effects are not discussed here. The primary flash is observed when the overheated gas together with the bullet is leaving the barrel. When the initially expanding gas is recompressed, the temperature is rapidly increasing and an intermediate flash is obtained. Further on, the un-combusted gas is mixed with air and can be ignited by the hot intermediate gas causing a flash of substantial magnitude depending on the efficiency of the flash suppression. If the weapon is fitted with a momentum reducing attachment, the diverted exhaust gas can be mixed with the ambient air and a substantial secondary flash can be observed.

The flash spectrum varies with the chemical reactions but consists generally of a continuum and various line and band spectra. Line spectra in the visible and near infrared are often caused by sodium and potassium, parts of the flash suppressants. Band spectra are observed in the short and mid wave infrared spectral region due to hot water vapour and heated carbon dioxide. The gas leaving the combustion area is still hot and stays for a time much longer than the flash duration. This radiation can be detected in the thermal spectral region and does not require the same temporal resolution.

Visual image intensifiers, and vision sensors are dependent on ambient illumination for signature generation. They depend both on a reflectance difference between the target and the background to create contrast and on the availability of sufficient reflected ambient illumination to create an adequate signal level. Given adequate illumination, visible and near-infrared signatures ultimately depend on the spectral reflectivity differences between the target and the background in the sensor response band. Visual sensor can use photopic color differences as a discriminant. Image intensifiers extend the visual spectrum out to approximately 0.9 μm or into the near infrared. So do vision sensors than can use silicon detectors with response out to approximately 1.1 μm. These near IR sensors can exploit the high reflectivity of live foliage and the low reflectivity of conventional paints to see a large negative contrast difference between the target and its background. Fig. 2 and Fig. 3 present sample sniper pictures registered at visible and IR spectra.

Fig.2. Visible images of sniper registered by visible camera

Fig. 3. Thermal signatures of sniper before and during shooting

2. Signature measurement

Laboratory and field tests measurements were carried out in order to determine reference temperature distribution associated with the shot event [1]. MUT has specialized laboratory facility for the recording of rapid processes accompanying the shot from weapons up to 0.50 caliber [2]. The recordings in wide spectral area can be performed as well as the measurement of other parameters, projectile velocity included. The measurements and recordings were carried out in visual, SWIR and LWIR ranges [3, 4].

The main objective of the laboratory tests was to gather data for the determination of the discriminative features of thermal signatures of the shot without the disturbing effects of atmospheric influence. The objective of the field tests was the same as at laboratory tests but in the real environment.

The recordings of sample thermal images were performed in the SWIR and LWIR ranges at laboratory test stand. The: Thermal cameras operating in ranges $3.7 \div 4.8$ μm and $7.5 \div 13$ μm and a super-fast visible camera were used for the recording of shot images, which made it possible to observe range-dependent differences. Four measurement devices were used:

- IR camera SILVER (Flir System – Cedip) 3.7 – 4.8 μm [5];
- IR camera TITANIUM (Flir System – Cedip) 7.5 – 11.5 μm [6];
- IR camera P640 (Flir System) 7.5 – 13 μm,
- VIS camera Phantom - 0.9 μm [7].

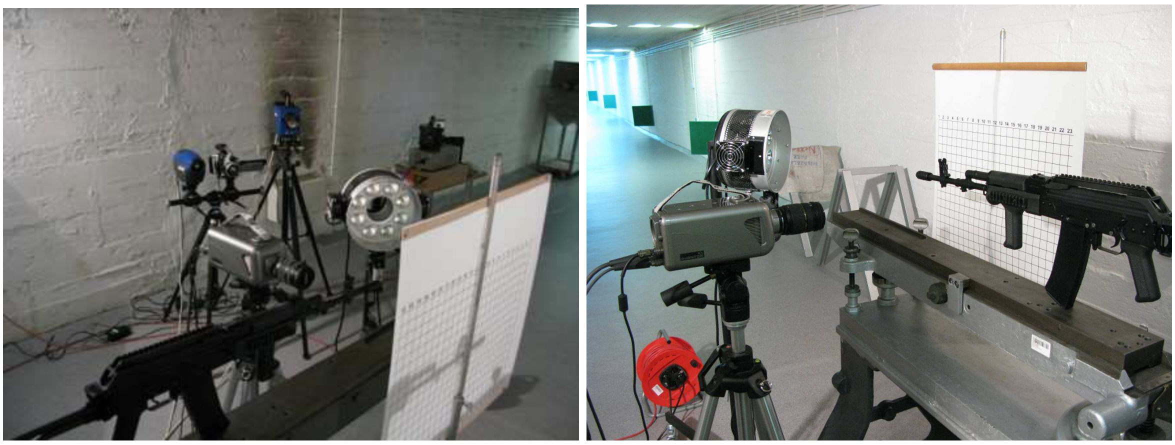

Fig.4. The laboratory stands for the measurement of the shot signatures

Two different calibers was tested:

- cal. 5.56 – different weapons (Beryl);
- cal. 7.62 – different weapons (AK 47, SVD).

The laboratory measurements were performed in two stages. During the first stage the shots were registered from 1 meter distance at an angle of 90 degrees, with frame rates up to 870 Hz. Shots were repeated in 3 minute intervals. The shooting were registered by all infrared cameras with the same FOV. In the next stage the measurement distance was 10 meters and an angle between cameras and gun barrel was 25 degrees. Again, the shots were repeated in 3 minute intervals and the shooting were registered for all infrared cameras with the same FOV. The frame rates were up to 500 Hz.

All recorded data were catalogued, included in the database and the appropriate documentation was worked out. The temperature histograms for the selected areas were calculated for the quantitative analysis of the power of IR emission. The magnitude of the areas of uniform temperature was calculated by counting the corresponding number of pixels and using the geometric relations between the angular dimension of a single pixel and the distance to object. The histogram was calculated on the basis of the whole visible target area and representative part of surrounding background. The thermal images were converted, for the need of numerical calculations, into matrixes of irradiance at the detector plane. As a result, object thermal signatures were obtained. The changing of temperature during the time was also calculated, which gives the answer about sniper signature before, during and after shooting. The results of registrations were evaluated using the ALTAIR and ThermaCAM REASERCHER Pro software.

2.1 The shot signatures

The sample images of thermal signatures of the gun shot are presented in Fig. 5 to Fig. 7. The presented images was recorded in the 3 – 5 μm and 8 – 12 μm spectral range and they show the shots form AK 47 (cal. 7.62 mm), BERYL 96 assault rifle (cal 5.56 mm) and SVD sniper rifle (cal. 7.62 mm). The data analysis of IR image from Fig. 7 was presented in Fig. 8.

Fig.5. The SVD shot registered in IR at laboratory stand

Fig.6. The sniper during shot: distance to sniper 30 m, caliber 7.62 mm, IR camera 3 - 5 μm

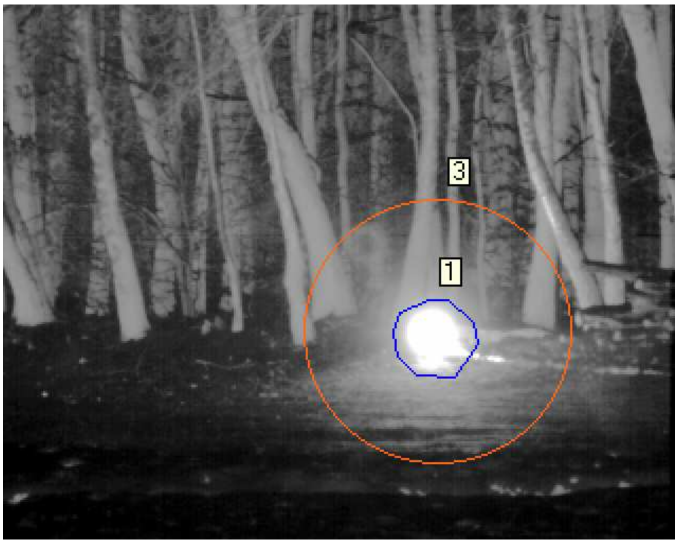

Fig. 7. The sniper during shot: distance to sniper 50 m, caliber 7.62 mm, IR camera

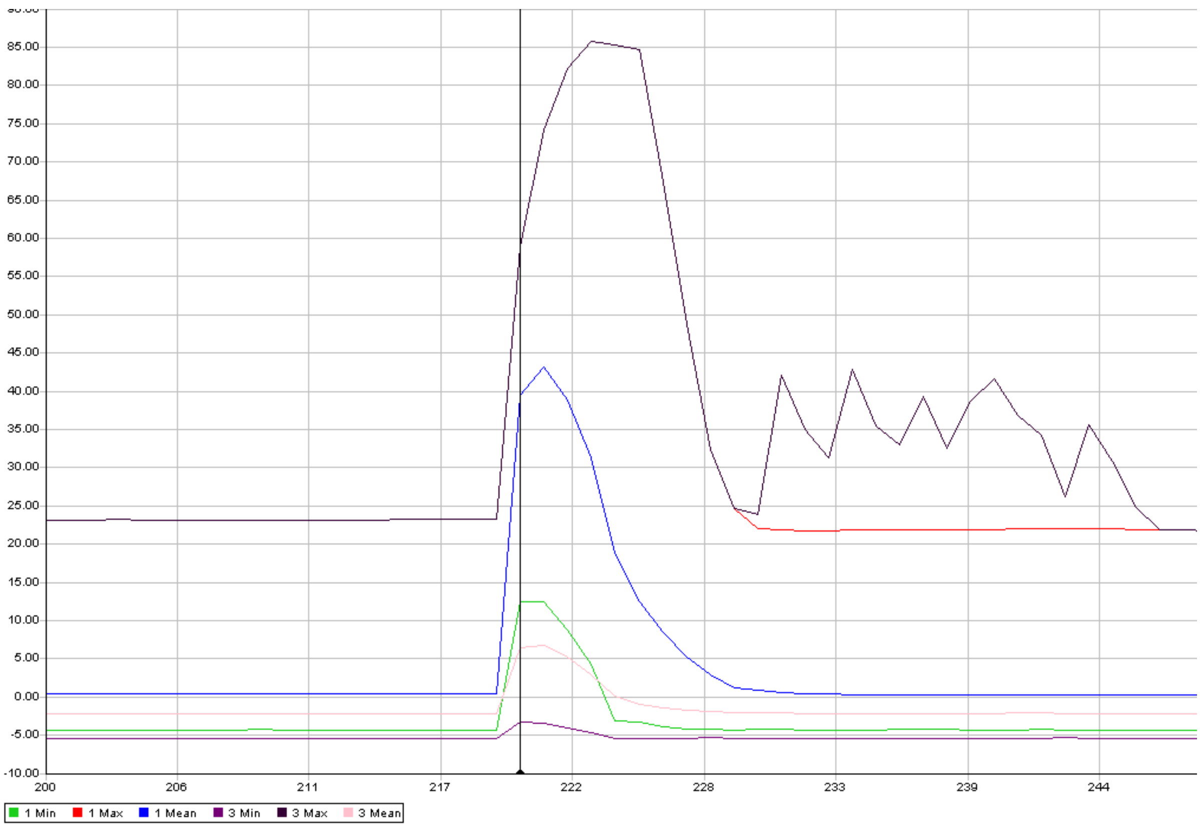

Fig. 8. Changes in temperatures before, during and after shot

The majority of muzzle blast energy falls into SWIR spectral range. The example of muzzle flash hyperspectral signature is presented in Fig. 9.

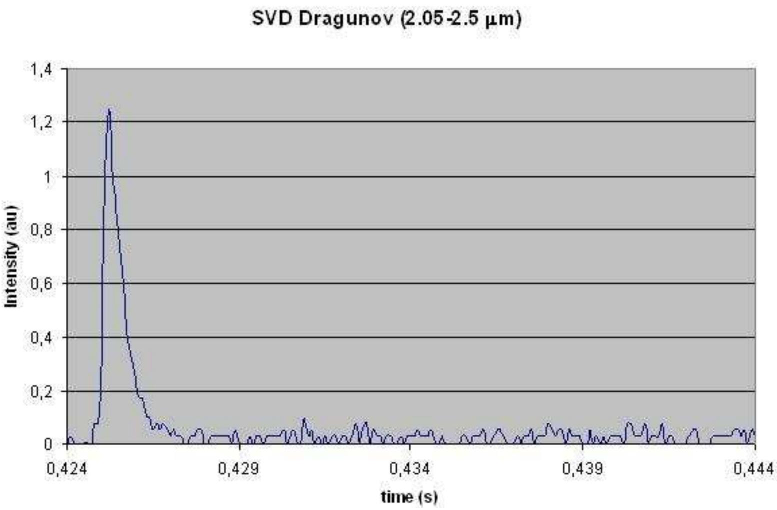

Fig. 9. Muzzle flash characteristic (intensity versus time) recorded during the shot from 7,62 mm SVD Dragunov in the spectral range 2.05-2.5 µm

In the visible range mainly the cloud of exhaust gases can be seen (Fig. 10).

Fig.10. The sniper during shot: distance to sniper 50 m, caliber 7.62 mm, visible kamera

Although it is possible to detect the shot in the visual spectral band, the results recorded in the IR range are much more promising as far as sniper detection accuracy and probability is concerned.

2.2 Signatures of a flying projectile

No bullet signatures were recorded because of high velocity of a projectile and limitations introduced by frame rates of available thermal cameras. An ultra-fast thermal camera is required for such recordings and the acquired signature is of limited usability, as the application of such camera in the sniper detection system would raise the overall costs several times. There are other sensors much better suited for bullet detections than IR camera-based solutions (e.g. radar systems).

Bullet signatures were recorded during laboratory measurements using an ultra-fast Phantom visible camera. Sample image is presented in Fig. 11.

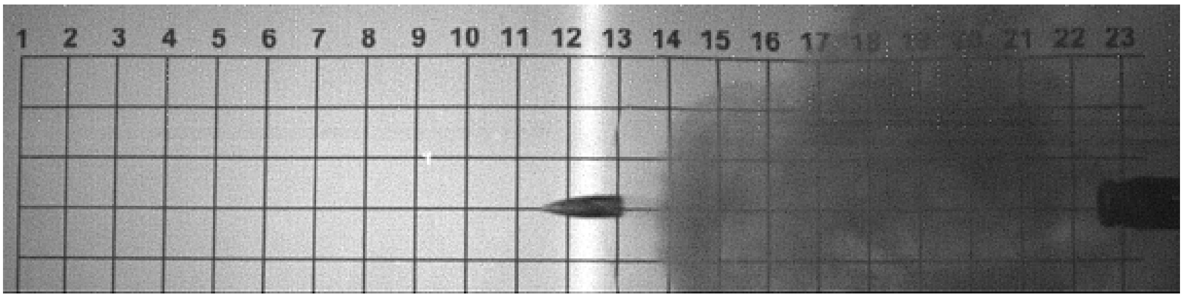

Fig. 11. The bullet fired from SVD sniper rifle

However, as the visible image relies on the ambient scene illumination, it is virtually impossible to record fast-moving object (which implies very short shutter speeds) in a wide FOV in a real sniper detection system. Cost-wise is the same situation as in case of thermal camera. As a result, projectile signatures in the visible spectral range will not be further considered.

3. Conclusions

The analysis of data recorded during the experimental measurements shows, that the detection of a gunshot in visible and infrared spectral band is not a very complicated task. The effective usage of both spectral bands for the shooter detection require, however, considerable amount of experimental data for full description of the real shot parameters. Such data, called signatures, are the basis for the development of efficient algorithms for shot detecting devices.

The results presented in the above paper are the effect of the research project No A-0376-RT-GC SNIper POsitioning and Detection SNIPOD, funded by the European Defense Agency EDA.

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