APPLICATION NOTE

FAST Thermal Imaging: Muzzle Flash Analysis

Abstract

Significant technical challenges need to be overcome when it comes to detection, location, and identification of small caliber hostile gunfire. The key characteristic for the detection of a small caliber gunfire, which also leads to the most obvious technical challenge, is its short, few milliseconds long, muzzle flash. Other technical challenges include the detection of the fast moving target and the detection of a high energy event, in real-time while covering a large area (Field of View or FOV).

This application note presents results of measurements performed on small caliber muzzle flash using the Telops FAST-IR 1000 high-speed and high performance infrared camera.

Introduction

Muzzle flash infrared signature description

It is interesting to analyze muzzle flash in the Mid-Wave (MW) infrared spectral band since the in-band infrared signature is significantly larger and more pronounced than the visible signature. Moreover, the four main muzzle flash characteristics are easily detectable in the MW infrared band. Figure 1 describes the typical muzzle flash characteristics.

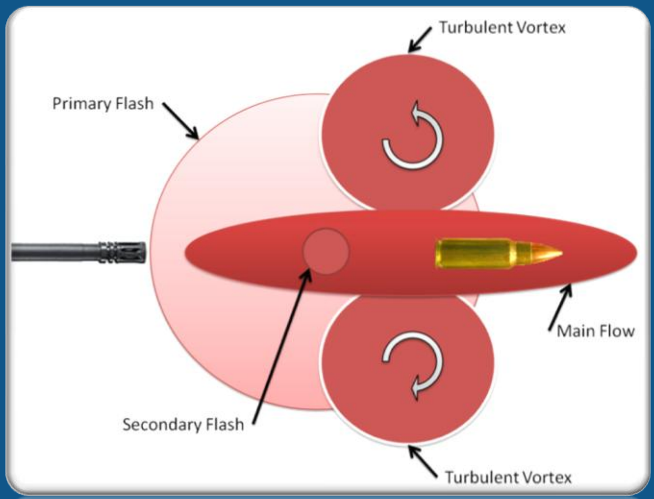

Figure 1: Infrared muzzle flash characteristics

The Primary flash is produced by high temperature and high pressure gases leaking between the projectile and the barrel inner diameter. The MW infrared signature of the primary flash is extremely pronounced.

The Turbulent vortex appears behind the projectile and results from the high speed motions of the projectile into the primary flash combustion gases.

The secondary flashes are mainly created by high-speed fuel gases escaping from the muzzle and the projectile which exploded when mixed with the atmosphere oxygen. They appear as small circular discs in front of the firearm muzzle and behind the projectile.

Following the dissipation of the muzzle flash, the main flow resulting from the bullet thermal signature and fluid dynamic appears.

Finally, powder and heated material fragments or residue are ejected from the muzzle and appear as flashes in front of the muzzle.

Ideal muzzle flash system functionalities requirement

Ideal muzzle flash detection system functionalities include the capacity to detect, locate, measure, and image the gun fire. The ability to detect means that the system must be able to spot small arms fire quickly and at a distance. It also means that it must confirm whether it is an enemy or friendly fire. Locate implicates that it must give the origin of the gun fire. Measure implicates that it can supply decision quality data for future validation and documentation. Finally it must image or display the event to an operator.

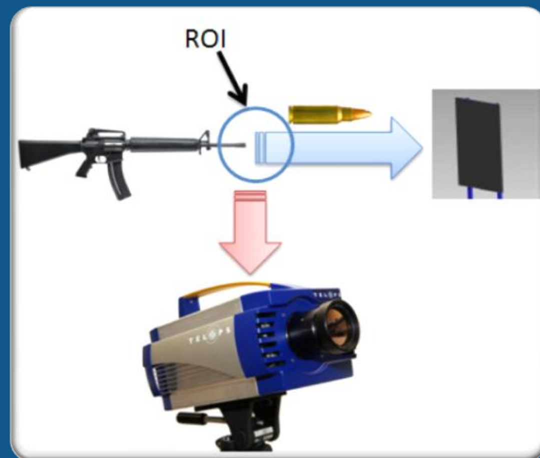

Figure 2: Field testing setup

Experimental information

Figure 2 presents the experimental setup used to demonstrate all the benefits of analyzing a muzzle flash with a FAST high performance thermal imager. In this study a M16 rifle using 5.56 mm caliber bullets was used to fire shots. The Telops FAST-IR 1000 camera was set-up to point at the firearm muzzle perpendicularly at a distance of 5 meters. Detailed test setup parameters are listed in table 1.

Parameters	Unit	Value
Bullet diameter	mm	5.56
Bullet mass	g	4.1
Bullet entry speed	m/s	905
Camera frame rate	Hz	1000
Spatial resolution	Pixels	320x256
Camera FOV	° (HxV)	2.7x2.2
Camera sensitivity	mK	< 20
Distance to target	m	5

Table 1: Experiment parameters

Results & Discussion

The results from the measurements clearly reveal the key muzzle flash characteristics identified in the previous paragraphs. Figure 3 introduces the step by step thermal signature evolution of a M16 muzzle flash.

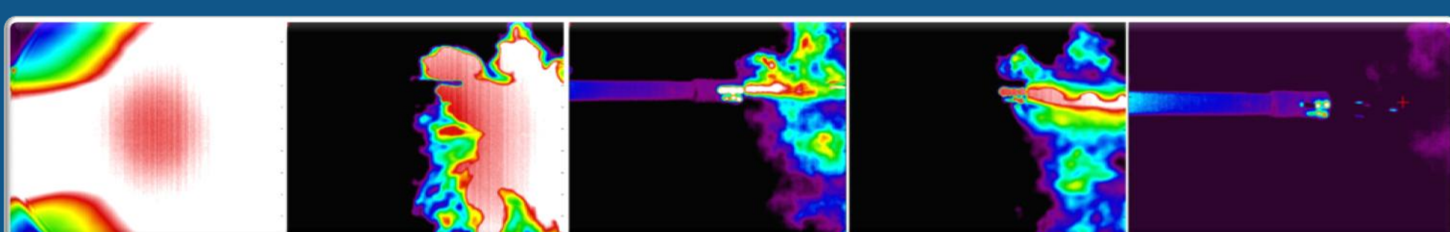

Figure 3: Step by step M16 muzzle flash

The first two images of the sequence undoubtedly illustrate the primary flash while the fifth one presents some metal residue exiting the firearm muzzle. The third and fourth images give a lot of information relating to the M16 muzzle flash infrared signature. As presented in Figure 4, all stages of a typical muzzle flash can be observed and quantified. The main flow, the secondary flash and, both turbulent vortex are well defined. Moreover, even the projectile MW infrared signature is noticeable. The projectile signature includes the barrel skin as well as the dynamic flow surrounding the in-flight projectile.

Figure 5 illustrates the laminar flow layer nearby the barrel. At approximately ¾ the length of the projectile (starting from the right of the projectile) the boundary layer separation can be noticed leading to the transition from laminar to turbulent flow.
The last and probably the most important muzzle flash characteristic leading to the unconditional detection and identification of hostile gunfire is the transient analysis of the muzzle flash. After analyzing more than 10 different shots, it was found that the typical M16 infrared muzzle flash signature lasts less then 6 ms, where more than 80% of the total in-band radiance dissipates in less than 3 ms. This information indicates that to properly capture a M16 muzzle flash infrared signature, the acquisition frame rate needs to be at least 1000 Hz when synchronization is not available. Otherwise, the temporal resolution will not be sufficient to accurately integrate the total infrared signature. Figure 6 shows a typical M16 fire transient temperature evolution. The green curve in the chart presents the minimum temperature over the A line segment shown in the image, while the blue curve presents the maximum temperature over the same line segment in the image. One interesting noticeable feature is the ability to detect the projectile. It is important to clearly detect the projectile in order to estimate the bullet trajectory leading to the gun fire origin and sniper position.
All these infrared signature analysis can be used to build better, more efficient detection and identification muzzle flash systems.

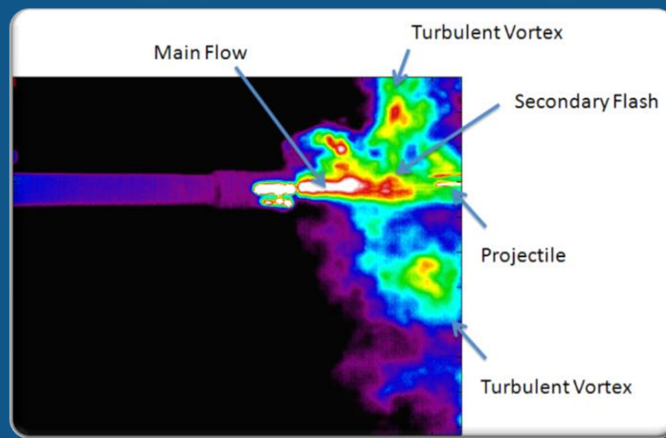

Figure 4: M16 muzzle flash 0.003s after ignition

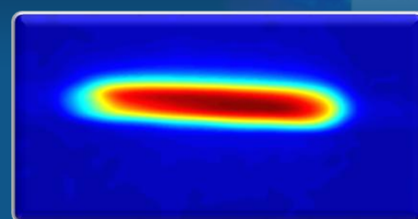
Figure 5: M16 projectile IR signature (speed of 905 m/s)

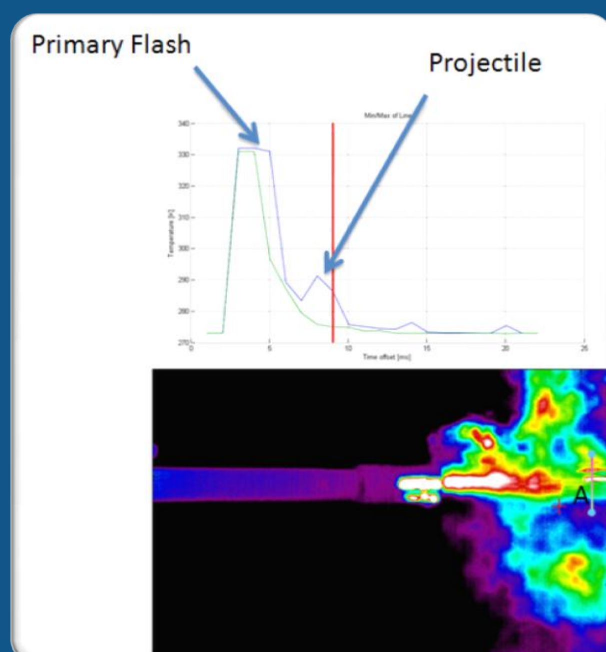

Figure 6: M16 muzzle flash transient behaviour

Conclusion

The Telops FAST-IR 1000 is the perfect infrared camera for muzzle flash signature analysis and for integration into a complete muzzle flash detection system. The ability to detect, identify, image and track the bullet while offering an unprecedented wide field-of-view makes it unique in this market. The most obvious benefit, due to its unique high frame rate, is that it allows to accurately measure the infrared signature of the muzzle to improve detection and identification.