RESEARCH ARTICLE

Digital Imaging for Ballistic Proofing Ranges

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Digital Imaging for Ballistic Proofing Ranges

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Traditionally, ordnance proofing has been split into two main areas: Instrumentation and photography. Instrumentation was more focused on the collection of analytical data from various instruments, for example, Doppler radar, yaw screens (for pitch and yaw), and velocity traps (i.e. skyscreens or acoustic triggers). Whereas, photography was more concerned with getting high-quality, perfectly illuminated and composed images for qualitative analysis. The photographs were obtained using an assortment of high-speed film cameras, often requiring one expert to setup the camera and a skilled photographer to compose the image, organize the lighting and take the picture.

The introduction of the high-speed ballistic digital range camera in 1988 (Hadland Photonics BR553 Ballistics Range Camera) marked the beginning of the demise of the high-speed film camera. These early cameras provided almost instant viewing of near photographic quality results that allowed ballisticians to make changes to development rounds without having to wait sometimes several hours for films to be developed. The digital images also provided a means of making measurements directly from the images without the need for the time-consuming manual digitization techniques previously employed.

The ensuing two decades have seen the introduction of many major products that have helped revolutionize the way proofing ranges operate. Today the two main areas of ordnance proofing are instrumentation and post-production.

Digital imaging, with the ability to post-process images has allowed instrumentation personnel to now also take on the tasks previously handled by dedicated photographers. New post-production operations, including collation and analysis, enable presentation of the digital data in an appropriate and appealing format for the ordnance manufacturers and test sponsors.

Since the introduction of the early ballistic range cameras, the quality and versatility of these instruments has gradually improved with advances in CCD sensor technology and improvements in image intensifiers (both of which are key elements in the capture of extremely short exposure still images). An example of a state-of-the-art ballistic range camera today is the SIR2 ballistic range camera (**Figure 1**). This new camera is capable of shuttering speeds as short as 20ns enabling blur-free image capture and analysis of objects travelling at up to 4,000 m/s. Offering 11 million pixel resolution images, the quality of results from the SIR2 are fast approaching film quality.

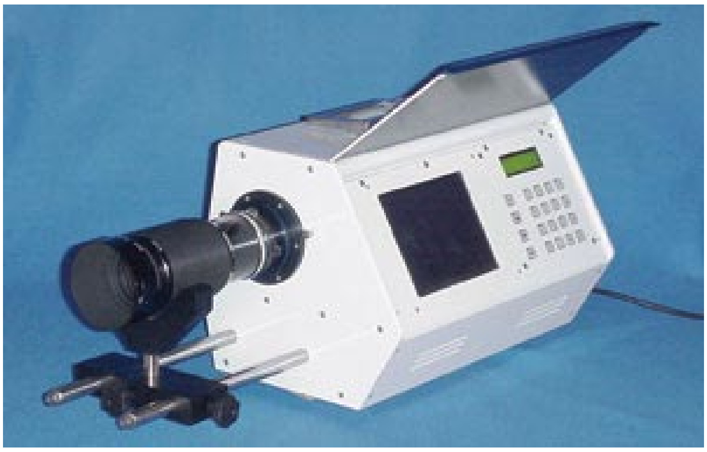


Figure 1. *An example of a state-of-the-art ballistic range camera today is the SIR2 ballistic range camera.*

Today, while a well-composed and properly illuminated picture is certainly appreciated by ballisticians, they consider a much more important factor to be the analytical data derived from that image, such as velocity, spin rate and pitch. With this in mind the SIR2 camera was developed with the unique ability to take a second full-resolution image (within 200µs) so that analytical

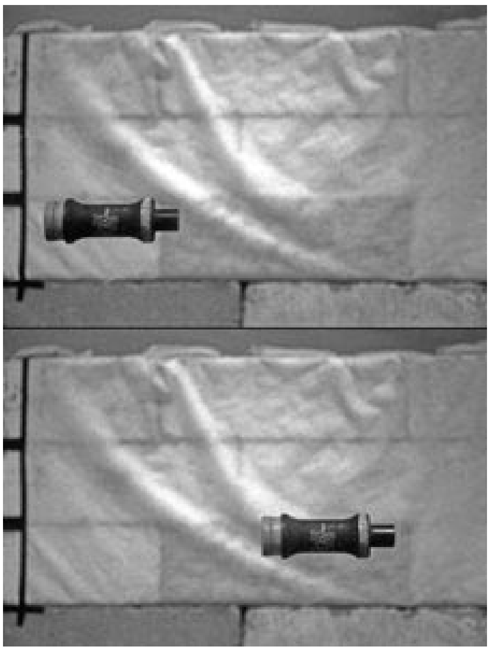
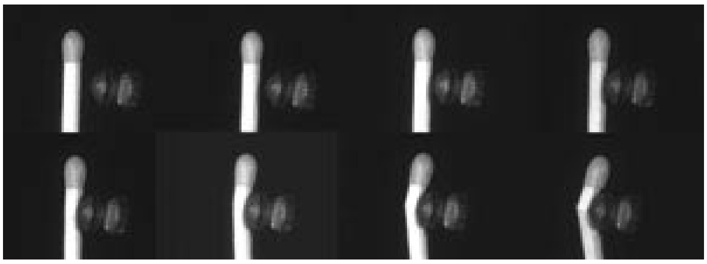
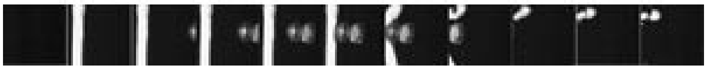


Figure 2. *SIR2 Double image of projectile travelling at 1000m/s.*





Top - **Figure 3***. 8 Frame SIM image sequence at 400,000 fps (1200 x 960 resolution). Bottom -* **Figure 4***. Same event as Fig 2 using a Phantom V7 High Speed video Camera at 60,000fps (256x256 resolution).*

measurements from the images could be extended into the time domain without any loss of quality, and without the additional investment of a second camera. Another advantage of the second image facility is the ability to see if there is a failure mode further into the flight path.

Capturing Data

The mid-1990s saw the introduction of high-speed video cameras onto the proofing ranges in place of high-speed film cameras. The new high-speed video cameras were used to look at a multitude of events ranging from firing pin behaviour, barrel flexing, muzzle-blast formation, and terminal and impact ballistics. Initially terminal and impact ballistic events were often far too fast for the early cameras, but nowadays with the best high-speed video cameras capable of reaching 250,000fps, the study of these events is more feasible.

The number of frames that a high-speed video can record offers a range of test scenarios that cannot be achieved using a single-shot camera. For example, sub-microsecond accuracy triggering usually is not required with high-speed video systems since they can be triggered to stop recording after an event, whereas using a single-shot high-resolution still camera necessitates extremely precise triggering to even guarantee seeing the subject within the field of view.

While high-speed video cameras can offer many modes of operation, users need to be aware of the limitations of these instruments, and that the wrong combination of shutter speed, frame rate and image field of view can result in not capturing any usable data at all. Often the compromises that need to be made to acquire images at an appropriate rate (e.g. reduction in image size to achieve image rate or increase in exposure to achieve sensitivity) may result in failure to produce the required data from a high-speed sequence.

Ultra-high-speed cameras with a limited number of images (such as the SIR2 ballistic range camera or the SIM multiple-framing camera) have the ability to capture an image or sequence of images at exactly the time when it is needed, with extremely high resolution and timing accuracy. Recognizing the benefits and limitations of high-speed video cameras, Specialised Imaging Ltd. recently developed a gated image intensifier system that will interface to any high-speed video camera. The benefits of using a gated image intensifier in front of a high-speed video camera are two-fold. First, the gating function of the image intensifier allows shuttering speeds down to 20ns to be used, which can remove motion blur of projectiles or fragments travelling at speeds of up to 4,000m/s. Secondly, the image intensifier can be used to provide optical gain, essential when trying to acquire short duration exposures at high frame rates, and often in areas where supplementary illumination is difficult or even impossible to provide.

Figure 5. *Driven by the limited amount of data that can be extracted using this method, Specialised Imaging in 2006 introduced a Trajectory Tracker system that allows a high-speed video camera to record over a large part of the flight path or any portion of the flight path that is of interest.*

Modern high-speed video cameras have allowed ordnance test directors and engineers to broaden the scope of ballistic testing, and to consider detailed recording of many aspects of ballistics which were beyond the realms of possibility even as recently as five years ago. Unfortunately, this broadening of requirements sometimes means that the capability of the high-speed video camera is over-stretched resulting in a poor quality result, and the inability to extract meaningful data from the recorded sequences. An example of this is where the test engineers want to study a projectile travelling over several meters and yet need at least 10,000fps (100µs) to minimize the

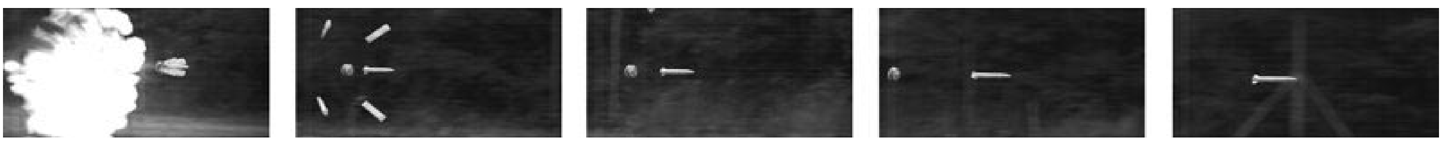


Figure 6. *Sabot separation sequence. Projectile travelling at 800m/s.*

projectile motion blur to an acceptable level. This field of view will produce a very small image of the projectile in each frame of the video and together with the residual motion blur adding to the uncertainty in projectile position and attitude this will reduce the accuracy of any data that can be extracted from the sequence.

Overcoming Distortion

Today and in the future, more images with more usable data points are, and will be required by ballisticians to develop new ordnance or to understand failure modes with existing ordnance. This has caused the parallel development of ideas to further enhance the ability of users to extract data from fast ballistic events. One example of this is producing a digital streak camera that sweeps the image at a constant speed across a CMOS sensor to produce a long record-time image.

This method was first introduced as a smear camera in the days of film, where film was moved past a narrow slit to develop the image of a projectile as it moved past the recording point. These cameras tend to give a distorted image if the film speed is not matched to the projectile velocity, and the peripheral components (such as sabots, driving rings, pusher plates, etc.) were usually distorted due to the difference in speed from the main projectile.

Driven by the limited amount of data that can be extracted using this method, Specialised Imaging in 2006 introduced a Trajectory Tracker system (Figure 5) that allows a high-speed video camera to record over a large part of the flight path or any portion of the flight path that is of interest. The Trajectory Tracker employs a triggered scanning mirror that is programmed to scan in synchronism with a passing projectile so that it relays the image of the subject into the high-speed video camera.

Because the mirror is programmed to match the motion of the projectile, motion blur is eliminated, enabling the high-speed camera to now operate at a much more modest frame rate that only needs to eliminate any vertical movement. Realistic framing rates are typically less than 6,000fps, giving better resolution, (image size does not have to be reduced to allow very high framing rates) and sensitivity, (longer exposures allow more light to fall on the image sensor leading to improved image quality).

Often it is desirable to observe projectile behaviour as close to the launcher as possible. This has previously required an accurate estimate of the projectile velocity. If the velocity is incorrect then the projectile is soon lost from the field-of-view. With experimental or failing projectiles where the velocity is unpredictable, it has been necessary to use a wide field-of-view or accept that the projectile is lost from view after a few metres. Introduced as a new feature on the Trajectory Tracker—”corrected tracking”—starts following the projectile from close to launch at an estimated velocity.

A few meters down range, a second detector measures the velocity and the scan rate is corrected to enable precise tracking of the projectile. Using “in-flight tracking correction,” more detectors can be used along the flight path to provide true tracking of the projectile trajectory.

High speed still and film cameras have been superseded by high-speed digital imaging cameras which provide high resolution results and rapid data analysis. The double shot SIR2 camera is ideally suited for the early stages of external ballistics, whereas the multi-channel SIM framing camera is better suited for terminal ballistics. A combination of the framing camera with a pulse X-ray system will allow the study of internal and transition ballistics. The Trajectory Tracker is ideal for observing in-flight projectile behaviour.

Obtaining more analytical data from higher resolution, better quality images is the continuing way forward for most ballistic events. Multiple cameras are being deployed more frequently in order to fully analyse behaviour in three dimensions, with more and more sophisticated software. Specialised Imaging, along with other partners, is now working toward providing accurate 3D analysis for in-flight ballistics using the Trajectory Tracker.