

Modern trace visualisation methods for examining shells and bullets

commissioner mgr inż. Robert Arciszewski¹

ORCID 0009-0004-7464-1430

¹ The Forensic Laboratory of the Provincial Police Headquarters in Gdańsk, robert.arciszewski@gd.policja.gov.pl

Abstract

The purpose of the article is to present the research opportunities, using visualization methods, provided by the use of state-of-the-art digital microscopy equipment on the equipment of the Forensic Laboratories of the Provincial Police Headquarters. The methods presented in the article allow for the analysis of traces in a way that provides new opportunities in conducting research in the course of performing forensic weapons and ballistics expertise, and thus have a significant impact on the inference of evidence and the course of the event.

Keywords: digital microscope, identification research, trace visualization

With Poland's accession to the European Union and the Schengen zone, guns from all over the world began to flow into the hands of sport shooters, hunters and collectors. There has been the opening of borders and the free flow of goods, which has also greatly facilitated opportunities for its smuggling. Not insignificant in the increase in the number of weapons available on the market were also changes in the provisions of the Law on Weapons and Ammunition of May 21, 1999, which came into force in 2011, concerning access to firearms and the possibility of owning them. This variety of types, designs and calibers of firearms is also used for criminal actions carried out with them, which in turn makes the identification of the weapon used in criminal actions increasingly complicated and time-consuming. In the forensic examination of shell casings and bullets, the key element is to reveal the traces left by the mating firearm components of loaded ammunition and, subsequently, to observe and compare their characteristics. Identification involves comparing the characteristics of traces revealed on shell casings or bullets secured at the scene with the characteristics of those traces mapped on ammunition components obtained through laboratory tests from the firearm specimen submitted for such tests. Ballistics, on the other hand, is the science of projectile motion. It mathematically describes all the chemical and physical phenomena

involved in the movement of a projectile, from their initial phase through their development to their effects. Depending on the research methods used, the field of ballistics is divided into theoretical and experimental. In the course of ongoing research based on these phenomena, we can determine where the shot was fired, the distance from which it was fired and many other parameters. In the field of ballistics we distinguish: internal ballistics - which describes the processes of ignition of the initiating mass, the propelling mass, the formation of the conditions that give motion to the projectile and the various phases of its movement in the barrel tube, transitional ballistics - which describes the processes that occur when the projectile leaves the barrel exit, external ballistics - which deals with the trajectory of the projectile, and terminal ballistics - which describes the processes that occur from the moment the projectile reaches the target, through penetration into the target, behavior in the target, until stopping or leaving the target.¹

Technology development

With the development of advanced technology in the field of optics and image recording, methods of digital image processing are also developing, providing new research opportunities for precise ballistic analysis and characteristics of forensic traces. Microscope

¹ Lampel, Mahrhold, *Leksykon Broni od A do Z (Lexicon of Weapons from A to Z)*, Muza SA, Warsaw 2006, p. 18.

camera software with HDR (High Dynamic Range) functions, which is the assembly of images with different exposures into a high tonal range image, avoids overexposed and underexposed areas. Focus Stacking, i.e., assembling a stack of microscope images stored in the “Z” axis into an image with an extended depth of field, is one of the basic functions not possible in analog microscopy, which has a significant impact on introducing a new quality in microscopic observation and analysis, while generating 3D images, already provides a completely different view and wide possibilities in this area. Modern digital cameras equipped with sensors characterized by very high sensitivity and low noise provide great opportunities for further image processing, including the possibility of taking advantage of rich additional functions, such as functions that enable linear measurements in high resolution of the observed image, with automatic edge detection, as well as measurements of the depth of the observed structures, as well as a number of other geometric measurements. Also, the analysed 3D image of the trace contains information that allows measurement in any position, which makes it possible to analyse the actual shape in any range.

Investigating the impact marks of a firing pin using a microscope Olympus DSX110



The Olympus DSX110 optical-digital microscope, configured with polarization, the ability to measure generated 2D, 3D images, magnification of up to 386x, and Coaxial illumination, makes it possible to observe and analyse the image of a cartridge primer and the traces

of a double-strike, in this case, the impact of the firing pin's mainspring (trace A, trace B).

High-resolution digital image processing, the ability to zoom in, rotate it in any configuration and measure it make it possible to reveal such characteristics of the needlehead traces, and their mutual „overlapping”, which allow to infer, among other things, the direction, dynamics and sequence of their formation, and further to determine which trace is a primary trace and which originated as a secondary trace, and further allow to authenticate the forensic version of the event resulting from the testimony of witnesses.

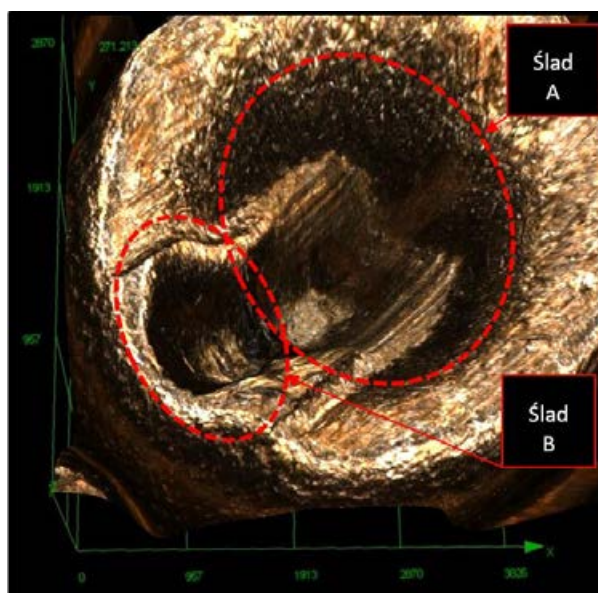


Fig. 1. Traces of a firing pin hitting the cartridge primer twice

In the case presented above, the research allowed inference:

- The first pressure on the trigger tongue occurred when the victim grasped the gun held by the suspect in such a way that, as a result of this grasp, there was a partial unholstering of the weapon, and consequently, after pressing on the trigger tongue to fire a shot. It turned out that from the evidence weapon, despite having a fuse against premature firing, with a minimal lowering of the cartridge chamber such a shot is possible.
- Due to the locking of the breech with the hand, there was no ejection of the cartridge case from the cartridge chamber, the breech retracted to a distance that allowed the tension of the impact mechanism, and when the trigger tongue was pressed again, the firing pin's mainspring struck the cartridge primer (central impact mark).
- A digital microscope with measurement functions additionally makes it possible to obtain a measurement of the depth of the individual strikes of

the mainsail, the displacement of one strike relative to the other, and thus a measurement of the displacement of the cartridge chamber relative to the firing pin, and provides a starting point for further experimental studies of the possibility of firing such a shot. It also allows comparative imaging of the finest surface irregularities.

Ballistic analysis using a universal medical image viewer EXHIBEON 2.4.1.

To determine the trajectory of the bullet and analyse the course of events at the scene of the use of firearms, the tools of the universal medical image viewer „Exhibeon” and „head CT scan image” can be used. Specialized tools provided in the viewer’s software allow a number of measurements to be made, including the distance between points and the angle between the guiding lines. Already in 2011, in the case analysed in the laboratory of weapons research and ballistics of the LK KWP in Gdansk, using the analysis of the image of the head CT scanner, in conjunction with the analysis of the case file, the research conducted allowed to conclude that a single shot was fired at the deceased. The exit of the gun barrel was on the left side of her head, behind her back. The trajectory of the bullet was at an angle of about 46° to the sagittal plane and at an angle of about 21° to the horizontal plane, from the left posterior temple toward the right frontal pole of the head, from bottom to top. The bullet then bounced off the inner lamina of the right frontal pole of the cranial bone at an angle of about 40° in the horizontal plane, changing its trajectory in the appendicular direction. This type of analysis, allows us to infer the credibility of the version of the event presented by the witness indicating that the person at the time of the shot was in a standing position, with the head slightly tilted forward, washing dishes at that moment (i.e., about 21° to the horizontal plane), then the barrel outlet of the evidence weapon was at the same height from the ground,

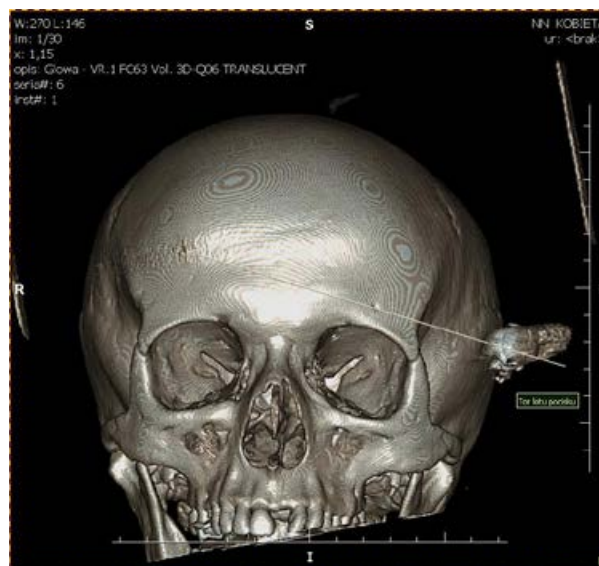


Fig. 2. The analysis of gunshot injuries using the CT scan

as the gunshot wound to the head. The person firing the shots held the weapon in a typical manner with his upright hand raised, and the trajectory of the bullet was parallel to the ground, taking into account the specifics of the scene, other anthropometric data and the type of weapon used. Currently, the „Exhibeon” browser is available in version 3 introducing many even more advanced tools.

Examination of gunpowder grains using a digital microscope KEYENCE VHX-7000

Among the wide range of advanced tools of the KEYENCE VHX-7000 microscope, the „Automatic area measurement and particle counting” function deserves special mention. This function allows performing grain size analysis in accordance with ASTM E1382 and DIN EN ISO 643. This proves to be a very useful tool in testing the grains of smoky (black) gunpowder for determining grain size and the consistency of the results obtained with the grain gradation indicated by



Fig. 3. The analysis of the bullet trajectory using the universal medical image viewer Exhibeon 2.4.1.

the manufacturer of the substance. There is a wide range of different grades of gunpowder available on the market, most commonly defined by the following division.

Table 1. Catalogue gradation of gunpowder grains

Symbol	Grain diameter [mm]	Symbol	Grain diameter [mm]
FG	1.190-1.680	1FG	1.2-1.6
FFG	0.590-1.190	1.5FG	0.85-1.2
FFFG	0.297-0.840	2FG	0.65-1.2
FFFFG	0.149-0.420	3FG	0.5-0.8
		4FG	0.25-0.5
		OB	0.19-0.23

Area measurement and grain counting can be easily done within the range specified for the sample. The automatic edge detection function eliminates discrepancies due to misidentification of sample edges. The shape is distinguished from the detected points using the least-squares method, which eliminates human error from the measurement activities. Using the available automatic tools, we can obtain measurement results in a 2D view such as the counted number of grains, their height and width, as well as the grain area.



Fig. 4. Isolating and counting gunpowder grains

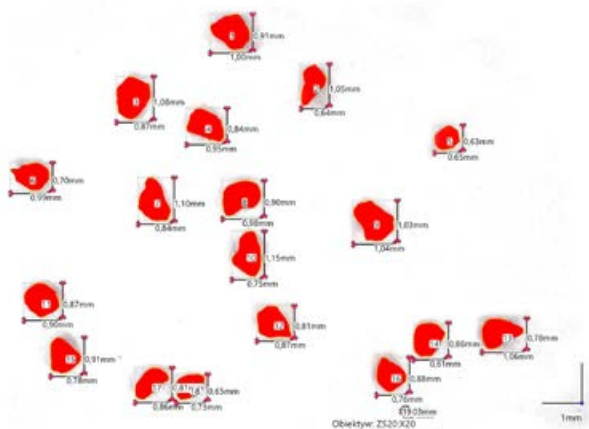


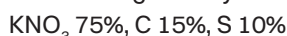
Fig. 5. Measuring gunpowder grains

Table 2. The results of automatic measurements of gunpowder grains

Title	Automatic area measurement result data					
	Area	Unit	Circumference	Unit	Maximum diameter	Unit
Average	0.45	mm ²	2.78	mm	0.97	mm
Standard deviation	0.2	mm ²	0.97	mm	0.32	mm
Max	0.94	mm ²	5.5	mm	1.75	mm
Min	0	mm ²	0.09	mm	0.03	mm
Total	15.95	mm ²	97.27	mm	33.78	mm
Count	35	mm ²				

The tool available in the microscope application will also present us in a table of results the average values of the measurements obtained, which we can compare with the manufacturer's data, and this already allows us to draw the right conclusions about the contents of the package and brings us closer to obtaining an answer to the question of whether the smoke powder (black) supplied for testing has the gradation indicated by the manufacturer on the package and was made in the factory or directs further research.

As we know, smoke gunpowder is a mixture of potassium nitrate, sulphur and coal. Saltpeter (KNO_3) gives off oxygen during the reaction, which helps burn coal and sulphur. Sulphur binds the other components together, reduces the sensitivity of gunpowder to moisture, making it easier to ignite, also due to its lower flash point. The percentage composition most generally is as follows:



The grains of factory-made smoky gunpowder are gray in colour with a dull sheen, and have an abnormal, pearly shape. In the production process, they are subjected to pressing to a density of 1.7g/cm^3 and the appropriate gradation and polishing, so that the grains are smoothed and the substance becomes more resistant to moisture and crumbling. It is further graphitised, which makes the grains shiny by reducing mutual friction and reducing the formation of dangerous gunpowder dust and thus susceptibility to uncontrolled ignition.² The observational tools of digital microscopy can be used to determine the type of gunpowder by observing the characteristics of its grains. By conducting an expert examination of smoke gunpowder, we can observe the shape

and colour, and then conduct ignition and combustion tests, as well as solubility in water, where, due to the easy solubility of potassium nitrate, its grains disintegrate. If necessary, the chemical composition should also be determined in the course of further studies.

Examination of gunshot damage on clothing using digital microscope KEYENCE VHX-7000



The KEYENCE VHX-7000 optical-digital microscope, configured with a special stand with an extension arm for convenient observation of the test material and a lens that allows operation at a short working distance of the head from the observed object, becomes a very convenient tool for observing and analysing the image of clothing damage.

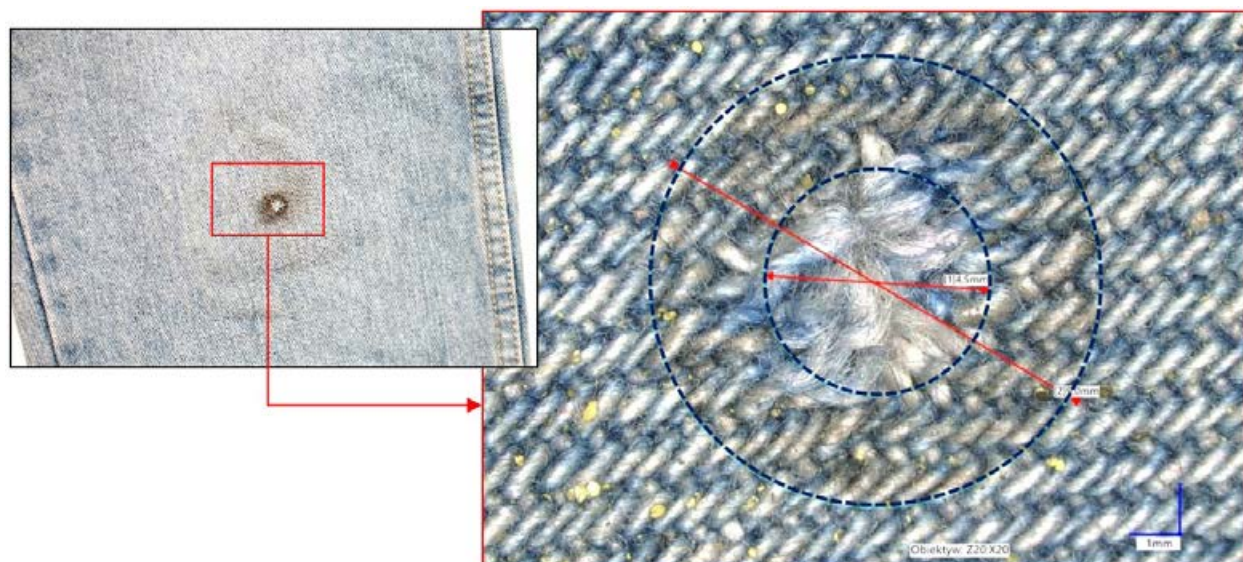


Fig. 6. Microscopic analysis of clothing damage caused by a gunshot

² G. Nowak, *Strzelanie z broni odprzodowej (Shooting muzzle-loaders)*, Galaktyka, Łódź 2006, p. 13

In the forensic investigation of damage to clothing as a result of gunfire, elements of the essence of the problem are the determination of the dimensions of the damage, the direction of the alignment of the damaged ends of the fabric fibres, and visual inspection to reveal post-shot residue, as well as the thermal effects of the phenomena accompanying gunfire, or to reveal a possible dirt seam at the entrance hole. Taking into account the nature of the damage to the test material, we can infer the type of weapon used, the direction of the projectile, what kind of flare charge the damage was caused by, such as shot, bullet, its caliber, etc. In the expert opinion of firearm damage, the so-called „close range” shots include those where the mechanical action of gunpowder gases is no longer observed on the obstacle material, as in the case of appendage shots. These are shots, as a result of which traces of the thermal action of gunpowder gases, soot deposition, unburned powder grains and traces of their mechanical action can be revealed around the entrance hole. The magnitude, intensity and shape of the representation of these factors on the obstacle is closely related to the distance from the barrel exit.³ When there is no sign of a close shot, we call it a long-range shot.

In the observed case, the use of digital microscopy made it possible to analyse the damage in detail, including taking precise measurements, which in turn made it possible to infer the damage as being caused by a bullet fired from a firearm caliber of approximately 9 mm, and, after selecting a specific specimen and firing comparison shots, which produced results that coincided with the distribution of gunshot residue on the evidence, to determine the distance of the shot. The thermal effect of gunpowder gases on the fabric, the unburnt powder grains, their area of occurrence and their mechanical effect were observed, as well as a seam of dirt on the edges of the damage, the fiber ends of which were deformed in the direction of the bullet action. Due to the elasticity of fabrics, the entry holes on clothing are generally smaller than the calibre of the bullet, and the actual value of the bullet is indicated by the outer diameter of the dirt seam.⁴ This brings many problems in properly estimating the correct result. Using digital microscopy with the ability to contrast and take measurements, we can easily pinpoint this value accurately as being around 9 mm in this case.

3 G. Bogiel, *Vademecum Kryminalistycznych Badań Broni (Vademecum of Forensic Testing of Weapons)*, CLKP, W-wa 2021, p. 124

4 S. Kustanowicz, *Badania Broni Palnej (Firearms Research)*, Zakład Kryminalistyki KGMO, Warsaw 1956, p. 277

Examination of gunshot damage on clothing using a CRIME-lite 82s device

The CRIME-lite 82S range includes an IR illuminator, a 5MP IR-sensitive camera for visualization and digital image capture, and a Panasonic FZ-G1 tablet PC, among others. The CRIME-lite 82S is a versatile tool for forensic examination both at the scene and in the testing laboratory. Thanks to the full spectrum of available wavelengths, it is intended not only for revealing gunshot residues, but also for genetics or dactyloscopy.

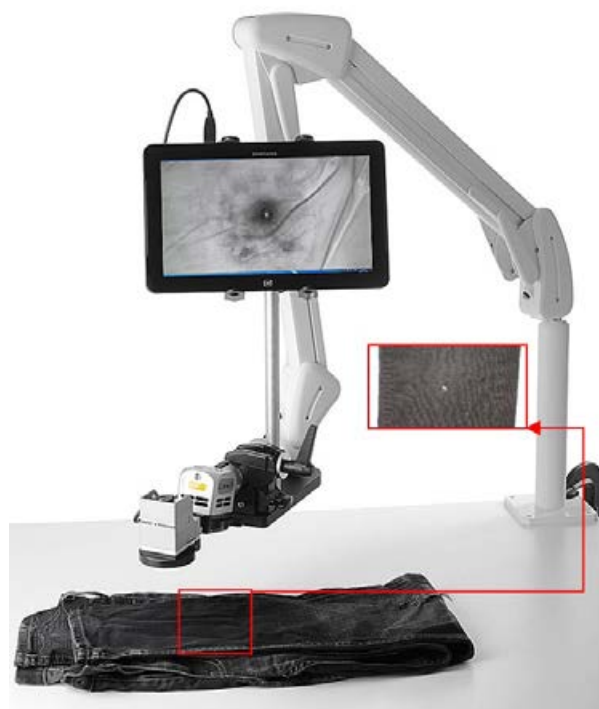


Fig. 7. the analysis of clothing damage caused by a gunshot in IR

If on light-coloured objects the gunshot residue, called scorching and containing primarily carbon, is clearly visible as a dark grey deposit, on dark-coloured objects it may no longer be visible in visible light. Of the currently known methods for revealing gunshot residue on dark-coloured materials, the infrared observation method is the most significant. This method is based on the properties of a coating of gunshot residue on clothing containing heavy metals that absorb infrared rays. As a result, the material of the garment creates a white background in the photo, and the tarnish of the shot – a dark stain. The device can therefore be used to determine the presence and nature of sediment distribution around the hole, which, as illustrated above, already makes it possible to determine which damage is an outlet hole and which is in the nature of an inlet hole. Illumination of the test material does not give the desired effect in cases where

the dyes also include heavy metals, such as iron, copper, zinc, etc.⁵

Conclusions

The development of technology in image capture whether digital microscopy or radiology allows further processing, processing, observation and analysis using advanced graphic and measurement tools. These tools greatly expand the possibilities for trace identification with digital functions to aid in trace observation, such as folding images with different exposures into an image with a wide tonal range to avoid overexposed and underexposed areas, and folding a stack of microscope images into an image with an expanded depth of field, among others. As well as high-resolution 3D visualization with the ability to digitally zoom, rotate and measure in any configuration, it reveals characteristics of trace features that were previously impossible to achieve. This entire palette of new developments greatly facilitates and expands the possibilities of modern forensic research, which affects the avoidance of errors in the analysis and correct inference of evidence. The research methods and examples of the use of digital image recording devices in modern ballistics, presented above, are only a small part of the possibilities brought by the development of technology in the study of forensic traces. These methods can be applied both as a solution to separate problems, as well as to complex issues in many areas of forensic science.

Source of figures:

- author,
- product catalogue KEYENCE, OLYMPUS, FOSTER + FREEMAN

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⁵ S. Kustanowicz, *Badania Broni Palnej (Firearms Research)*, Zakład Kryminalistyki KGMO, Warsaw 1956, p. 261