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*Original*

Active Thermography for Gunshot Residue (GSR) Pattern Estimation on Textiles / Medici, V., Paone, N., Pandarese, G., Castellini, P., Olivieri, M., Spinelli, V.A., Rizza, G., Riccio, G., Martarelli, M.. - (2023), pp. 104-109. (2023 IEEE International Workshop on Technologies for Defense and Security, TechDefense 2023 Roma 20 - 22 November 2023) [10.1109/TechDefense59795.2023.10380912].

*Availability:*

This version is available at: 11566/327236 since: 2025-11-19T07:40:25Z

*Publisher:*

Institute of Electrical and Electronics Engineers Inc.

*Published*

DOI:10.1109/TechDefense59795.2023.10380912

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# Active Thermography for Gunshot Residue (GSR) Pattern Estimation on Textiles

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**Abstract**— Gunshot residue (GSR) analysis on textiles plays a crucial role in forensic investigations. Gunpowder residues vary in size and shape depending on the firing distance; this relationship is evaluated. By integrating active thermography with image processing techniques, the contrast between gunpowder particles and the cloth background is enhanced, facilitating reliable detection and analysis. The observed thermal patterns provide insights into the behavior and distribution of gunpowder dispersion, aiding in determining shooting distance. Comparison between different shooting distances reveals an increasing trend in the distance from which gunpowder residues have detected, demonstrating the effectiveness of active thermography in detecting gunshot residue patterns up to a firing distance of about 30 cm. Beyond this distance, the signal-to-noise ratio decreases significantly, presenting problems in accurately identifying the presence of residues. The advantages of active thermography are underlined, including its non-intrusive nature and the elimination of the necessity for chemical reagents, simplifying the analysis process as potential tool for determining shooting distance.

**Keywords**—Gunshot Residue, shooting distance, active thermography.

## I. INTRODUCTION

Gunshot Residue (GSR) refers to the microscopic particles produced upon the discharge of a firearm. Its main components are lead, barium, and antimony, which are common components found in ammunition. The detection and analysis of GSR play a crucial role in forensic science as they aid in reconstructing crime scenes and determining the potential involvement of individuals. In particular, the analysis of the composition, the morphology, and the distribution of GSR makes it possible to obtain valuable information on the distance of the gun from the surface, enables discrimination between multiple gunshots, and allows people to be associated from the firing phenomenon [1].

Research related to gunpowder examination focuses on identifying the substances present, organic, and inorganic. Conventional approaches comprehend chromogenic methods and instrumentation-based analysis [1], such as scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDX), that allow identification and characterization of the particles. Different approaches are possible to identify individual gunshot residue particles through both morphological and elemental characteristics [3].

The evaluation of shooting distance based on the generated pattern is another important topic of the field. This estimation is based on the examination of the appearance of the bullet entrance hole and the one of the GSR patterns around the hole [4]. Gunpowder residues vary in size and shape depending on the firing distance. At close distances, residues will be larger and more concentrated, while at longer distances they will decrease in size and become more widely distributed. Also, the overall shape of the residue scattering pattern can provide clues to the firing distance. Traditionally, chemical reagents have been employed to enhance the visibility of substances present in cotton under visible light, allowing visual rather than chromogenic methods. However, scientists are continuously exploring new methods to improve the reliability, speed, and user-friendliness of GSR estimation. For example, by observing the cloth in the infrared spectrum instead of the visible spectrum, the need for these reagents becomes unnecessary.

In this experimental study, active thermography offers an efficient and non-contact analysis method, designed for calibration purposes. The focus is on a promising approach based on active thermography, which offers a non-destructive and real-time analysis of gunshot residue patterns. By utilizing thermal imaging, active thermography captures and analyzes the thermal patterns generated by GSR. By utilizing thermal imaging, the heat signatures left by the residue can be visualized and analyzed. The temperature variations associated with the residue patterns can provide insights into

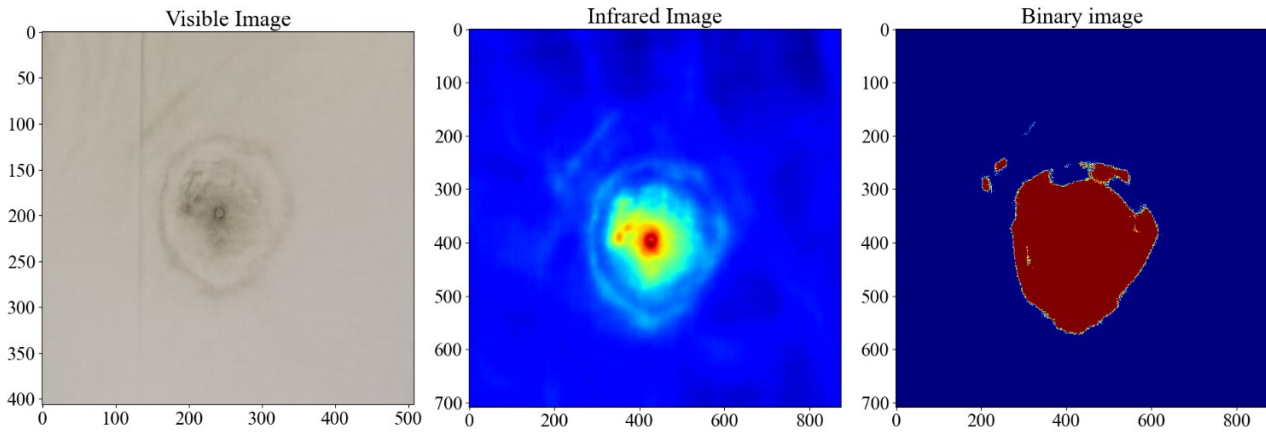


Fig. 1 - Example of cotton cloth for 15 cm shooting distance - Visible image (left), contrast thermal image (center), and binarized image (right).

the distance from which the firearm was discharged. At close distances, the residue patterns may exhibit higher temperature concentrations and distinct shapes, whereas at longer distances, the patterns tend to disperse and display lower temperature differentials.

Compared to chemical techniques, active thermography provides benefit such as rapid examination, real-time analysis possibility, and the possibility of not using chemical reagents to enhance the cotton-powder contrast. The main advantage is the non-destructive nature of the method, which ensures repeatability of the measurement, a key feature in forensics. By employing thermal imaging in the analysis of residue patterns and integrating active thermography with other analytical techniques, forensic experts can gather valuable data to calibrate and establish correlations between the observed thermal patterns and the distance of the firearm discharge. This integrated approach enables a more comprehensive understanding of gunshot residue (GSR), leading to enhanced forensic investigations and more accurate evidentiary analysis.

## II. MATERIALS AND METHODS

In this study, active thermography has been utilized to investigate the behavior of gunpowder dispersion on cotton cloth samples. The thermal camera employed for data acquisition is the Infratec VarioCam HD. It features a

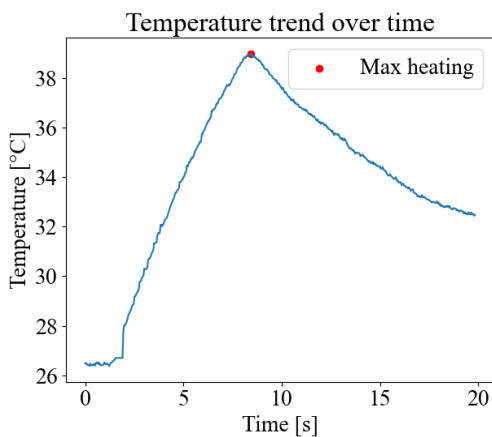


Fig. 3 - Temperature over time.

microbolometer uncooled FPA detector with a spectrum range of 7.5 – 14  $\mu\text{m}$  and a resolution of 1024 x 768 pixels.

The firearm used to shoot the textiles is the Beretta 92 SB pistol, a semi-automatic handgun. The ammunition employed for the experiments is Fiocchi GFL 9 x 19 mm NATO, featuring a Full Metal Jacket (FMJ) projectile weighing 8.0 grams (124 grains). The specific lot number of the ammunition used in the study was the 12/21, ensuring traceability of the bullets used for the analysis of gunpowder residue on the tissue.

Multiple samples have been examined, with each sample consisting of a cotton cloth that was shot at different distances, referred to as "shooting distances." The analyzed shooting distances were 5 cm, 10 cm, 15 cm (shown in Fig. 1), 20 cm, 25 cm, 30 cm, 35 cm, 40 cm, and 50 cm. The cotton cloth was stretched on a frame support with dimensions 350 x 390 mm.

By subjecting the samples to heating using lamps, that have a broad band emission up to the middle infrared, for about 10s (Fig. 2), the thermal patterns have generated, enabling the detection and characterization of gunpowder residues. During the heating phase, the gunpowder residues absorb thermal energy differently from the surrounding cloth material, resulting in localized temperature variations.

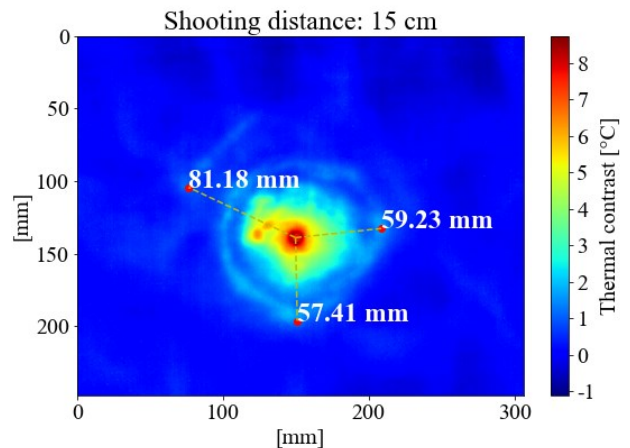


Fig. 2 – Example of computed contrast image when shooting distance is 15 cm.

The samples have observed during both the heating and cooling phases, and a sequence of images has captured at a rate of 30 Hz for 20 seconds. For each sequence, analysis has conducted on the image corresponding to the maximum temperature value, as depicted in Fig. 2. This maximum temperature value has been calculated on a selected pixel around the hole, where gunpowder residues are present. Then the images have processed to enhance the contrast between the dust particles and the background, facilitating image interpretation. Specifically, the absolute contrast has been calculated.

According to Maldague X. [5], the absolute contrast  $C^a$  represents the temperature difference between a suspected defective location (indexed as "def") and a sound area (indexed as "s") at a given time. It is defined as:

$$C^a(t) = \Delta T(t) = T_{def}(t) - T_s(t) \quad (1)$$

where  $T$  is the temperature signal and  $t$  is the time variable. Calculating the absolute contrast enhances the visualization of gunpowder particles in relation to the background. However, it is important to note that absolute contrast is also influenced by the energy absorbed, which can limit comparisons between different experiments.

After thermal contrast computation, the gunshot hole has first detected automatically, to evaluate the dispersion of gunpowder. Then, the dispersion of gunpowder particles from the gunshot hole has been quantitatively evaluated manually selecting different points on the thermal image, as Fig. 3

shows. Instead of manually selecting these points, the image could be binarized (Fig. 1) to make it easier to find the contours of the area with gunpowder. However, this contour becomes less and less obvious as the shooting distance increases, and increasing noise makes it very difficult to find a defined area with a simple threshold.

A reference checkerboard has been utilized for the pixel-to-mm conversion. The pixel/mm ratio determined is 0.35 pixels/mm.

### III. RESULTS AND DISCUSSION

The analysis of thermal patterns obtained using active thermography revealed that it is possible to detect the dispersion of gunpowder on the cotton cloth samples, without the help of any chemical reagent to enhance the substances. The results have demonstrated a clear and discernible pattern of gunpowder residue up to a shooting distance of about 30 cm, using these specific firearm and ammunitions. Beyond this distance, the signal-to-noise ratio deteriorated, making it increasingly challenging to distinguish the gunpowder residue from background noise.

A graph has been plotted (Fig. 4) depicting the distance from which gunpowder was detected at each shooting distance and showing an increasing trend as the shooting distance increases. At shooting distances within the range of 5 cm to 35 cm, the gunpowder residues exhibited a noticeable contrast against the cloth background, allowing for reliable detection

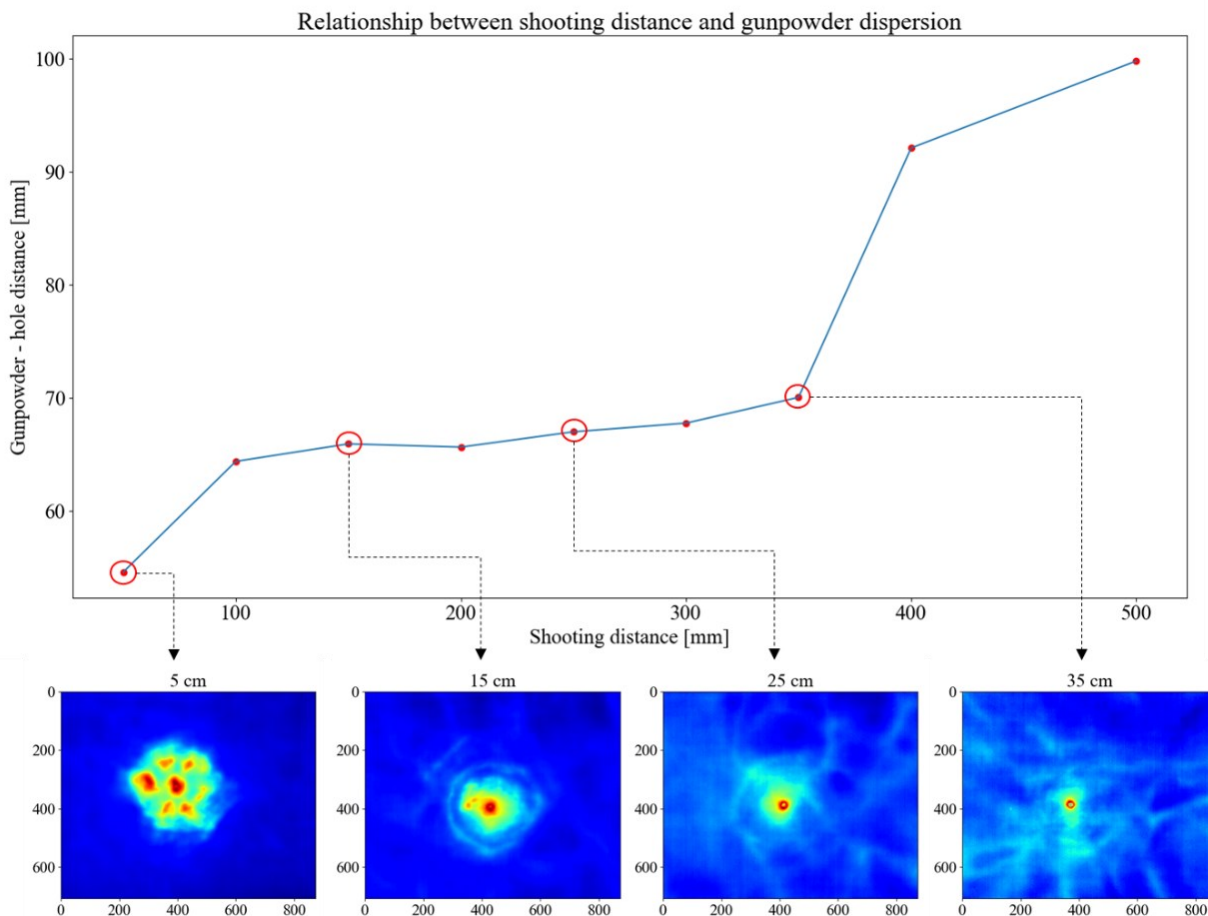


Fig. 4 - Correlation between shooting distance and detected gunpowder dispersion.

and analysis. However, beyond 35 cm, the signal of the gunpowder residue became increasingly obscured by noise, making it more challenging to accurately determine its presence.

These results suggest that this method is effective in detecting and characterizing the pattern generated by gunshot residue on cotton fabric samples at relatively close shooting distances.

#### IV. CONCLUSION AND FUTURE WORKS

The evaluation of shooting distance based on the generated pattern of gunpowder residue is significant aspect in forensic investigation, particularly as a method for calibration purposes. The size, the concentration, and the overall shape of the residue scattering pattern can provide valuable insight into the distance from which the firearm was discharged. This means that the method proposed is fit for an indirect measurement of the distance between the firearm and the target.

The results, obtained using active thermography, indicate that gunpowder residue patterns on cotton cloth samples can be visually detected and characterized without the need for chemical reagents to enhance the visibility of substances. The analysis of thermal patterns obtained through active thermography shows a clear and discernible pattern of gunpowder residue up to a shooting distance of approximately 30 cm. However, it is important to underline that these results are valid for this weapon and this ammunition; there is no evidence that the same pattern is identifiable with other firearms.

The integration of active thermography with other analytical techniques offers a comprehensive approach to determine shooting distance and enhance forensic investigations. The rapid and real-time analysis provided by active thermography, along with its ability to determine shooting distance, could surpass the limitations of traditional visual methods combined to colorimetric approaches. The non-destructive approach ensures repeatability of the method,

which is a key feature in forensic science, reduces the inspection time and would allow measurements also on the field, which is impossible for chromogenic chemical methods.

In summary, active thermography proves to be a valuable tool in the analysis of gunshot residue patterns on cotton cloth samples. It is indeed a non-invasive method for the indirect measurement of distance of firearm by targets. Further research and refinement of this technique hold promise for advancing forensic analysis and facilitating accurate estimations of shooting distance. For example, the full potential of thermography could be further explored by analyzing patterns on darker-colored textiles.

#### ACKNOWLEDGMENT

This activity has been developed within the Research and Service Center CARMELO – *Center for Advanced Research on Measurements for Engineering and Life Optimization*, which promoted this collaboration.

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