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Abstract

Quantitative Analysis of Flash-Pulse Thermographic Detection of Gunshot Residue†

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Abstract: This study addresses the detection of gunshot residue (GSR) around a bullet hole, which is one of the key forensic procedures for estimating firing distance. GSR was inspected using Flash-Pulse Thermography (FPT) with kurtosis statistical processing. The result of such an inspection is a pattern composed of numerous small indications distributed around the hole, attributed to gunshot residue particles. The number and spatial distribution of these indications depend on the firing distance. Analyzing such results based on individual indications is impractical, as the pattern must be evaluated as a whole. Therefore, quantifying the overall result can significantly improve the analysis of the firing distance estimation. This study presents a quantification procedure based on threshold-based mass-marking of indications and evaluation of several statistical characteristics. The correlation between these characteristics and firing distance is then analyzed. A strong but distinctly non-linear correlation was found between the firing distance and some simple quantitative characteristics, such as the total number of indications. However, the study shows that some derived characteristics, such as the contrast between marked areas and background, exhibit a near-linear correlation. These parameters are, therefore, promising for firing distance analysis based on FPT inspection of GSR on through-shot targets.

Keywords: Infrared thermography; gunshot residue; flash-pulse thermography; thermographic testing; thermographic inspection; active thermography; IRNDI, infrared nondestructive inspection

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1. Introduction

Gunshot residue (GSR) consists of substances expelled from a firearm when it is discharged [1]. It can subsequently be found on the gun, surfaces near a discharged firearm, or on a target surface. Identification of GSR belongs to one of the basic forensic examinations. Its detection is traditionally performed using chromogenic/chemical exposure or instrumental methods [1]. Although these conventional methods offer high performance, the analysis is often time-consuming, and the sample may be damaged during inspection. Thus, in addition to these methods, alternative techniques are also being developed that offer rapid and non-destructive identification of GSR. These approaches include, for example, optical or infrared thermography-based [2] methods. One of the fundamental parameters examined is the shooting distance, which can be estimated based on the distribution of GSR on the target [3]. Especially at short distances, the amount and spread of GSR can help to reveal the shooting distance.

This study investigates the potential of active thermography - infrared nondestructive inspection (IRNDI) methods for detecting GSR around a bullet hole on a fabric target, as well as the possibilities of quantifying the IRNDI results to estimate the firing distance.

IRNDI is a non-contact and nondestructive method for detecting near-surface discontinuities in materials [4]. Flash pulse thermography (FPT) [5], one of the very frequently used and thoroughly studied techniques [6], was used in this study. It uses a flash light pulse of a length typically lasting a few milliseconds to excite the inspected surface. An infrared camera then records the thermal response, which can reveal surface/subsurface discontinuities. These represent themselves as so-called indications - regions with different thermal contrast [7]. Different data processing methods are usually applied to enhance the contrast of the indications.

The study [8] showed that infrared imaging has significant potential in forensic work. However, the present work builds upon studies [9] and [10], where the applicability of IRNDI for gunshot residue detection on fabric targets was reported. Based on the results published in [10], we used flash-pulse thermography combined with kurtosis-based higher-order statistical evaluation [11]. IRNDI quantification procedures are usually focused on individual defects. However, the GSR indications form a complex pattern consisting of many small indications. Therefore, we proposed a post-processing procedure involving mass-marking and statistical characterization of the results. Subsequently, we analyzed the correlation between the statistical characteristics and the shooting distance.

2. Experimental procedure

IRNDI experiments were conducted on 15 samples, each approximately 25 × 25 cm in size, made of white bio-cotton fabric. The samples were mounted on a cardboard and shot through using a semi-automatic handgun CZ 75D Compact loaded with Full Metal Jacket 9mm Luger (Sellier Bellot) cartridges (in cooperation with the Institute of Criminalistics of the Police of the Czech Republic). The shooting was executed by hand, perpendicularly to the sample and approximately to its center, from distances of 20, 30, 40, 50, and 60 cm.

The through-shot samples were removed from the cardboard and mounted in a plastic frame for IRNDI inspection. The FPT inspection was carried out with a flash lamp Hensel EH Pro 6000 (maximum power of 6 kJ, pulse duration ~7 ms) and a FLIR A6751 infrared camera (cooled quantum detector-based IR camera, resolution of 640×512 pixels, waveband 3–5 μm, NETD of ≤20 mK, 25 mm lens). The flash lamp, equipped with a reflector 20 cm in diameter and 12 cm deep, was positioned approximately 36 cm from the sample in a perpendicular orientation. The IR camera was 48 cm from the sample at an angle of about 30°. The inspection was carried out using a hardware unit and the LabIR software, both developed at the University of West Bohemia. The integration time, frame rate, and resolution of the IR camera were 1.432 ms, 100 Hz, and 640×512 pixels, respectively.

After the thermographic sequence of the thermal response was acquired, the background was subtracted using an image before the pulse from the rest of the sequence. The subsequent postprocessing of the thermal results was performed by means of the higher-order statistics Kurtosis method [10], which resulted in a single output image (defectogram) with enhanced indications of the GSR particles. A total of 1500 frames of the response were recorded; however, 200 frames of the cooling stage of the sample after the flash pulse were only used for evaluation. Following processing and analyses were performed in the Gwyddion software [12], which is an open-source software for visualization and data analysis. It is primarily designed for microscopy, but it also supports general 2D data processing and analysis. It was also important that the software could handle actual IRNDI process data rather than only their image representation. We removed the perspective deformation of the image, cropped the "black-edges", corrected the size of the sample to 20×20 cm, and applied a zero-fix leveling. Then the GSR indications were marked by the Gwyddion threshold function setting Height and Slope parameters to 20 and 2%, respectively. These processing steps yielded a clean defectogram and an associated binary map indicating the presence of an indication at each location, which can be statistically evaluated.

Results and discussion

The final output included a Kurtosis-based map (defectogram) and a corresponding binary map indicating, for each pixel, the presence of an indication. It made it possible to evaluate and compare several statistical characteristics for each sample. Mean, Standard Deviation, Sum, Skewness, and Kurtosis were calculated for the full image, indication pixels, and background. Additionally, we evaluated the number of indications (pixels) and their ratio (in percent), and derived quantities:

- Relative Mean – indications mean divided by background standard deviation,
- Relative Skewness - image skewness divided by the skewness of indications, and
- Indications Contrast – difference between indications and background means, divided by background standard deviation (contrast-to-noise ratio of the indications).

Correlation analysis showed that most basic characteristics had either weak (e.g., Mean or Standard Deviation) or non-linear (e.g., number of indications) dependence on shooting distance. The strongest correlation with shooting distance (Pearson > 0.8, approximately linear relationship) was found for overall Skewness and the derived parameters: Relative Mean, Relative Skewness, and Indications Contrast. Thus, despite high variability in GSR patterns, these parameters appear promising for firing distance estimation, as illustrated by an example in Figure 1.

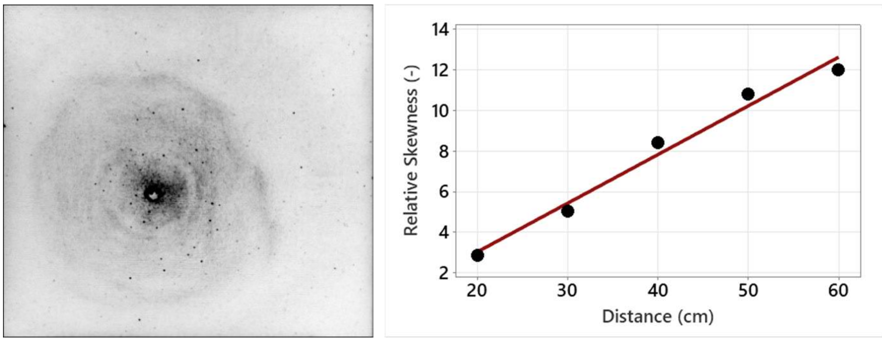

Figure 1. GSR defectogram at a shooting distance of 30 cm and the dependence of Relative Skewness on shooting distance.

Conclusions

This study confirmed that selected statistical characteristics derived from flash-pulse thermographic inspection of GSR—particularly Relative Mean, Relative Skewness, and Indications Contrast—correlated well with firing distance and appeared to be promising parameters for its estimation. Despite considerable scatter in individual measurements, these derived characteristics showed a reasonably linear relationship with shooting distance. The variation in the radial distribution of GSR from the through-shot at different firing distances was not addressed in this work. This parameter remains a subject for further investigation, particularly due to its potential to improve distance estimation accuracy.

Supplementary Materials: Not applicable.

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References

1. Charles, S.; Geusens, N.; Nys, B. Interpol Review of Gunshot Residue 2019 to 2021. *Forensic Sci. Int. Synerg.* **2023**, *6*, 100302, doi:10.1016/j.fsisyn.2022.100302.
2. Asirdizer, M.; Hekimoglu, Y.; Gumus, O. Usage of Infrared-Based Technologies in Forensic Sciences. In *Forensic Analysis - From Death to Justice*; Shetty, S.K., Padubidri, J.R., Eds.; IntechOpen: Rijeka, 2016; p. 23.
3. Zain, Z.M.; Jaluddin, S.N.; Halim, M.I.A.; Subri, M.S.M. The Effect of Type of Firearm and Shooting Distance on Pattern Distribution, Particle Dispersion and Amount of Gunshot Residue. *Egypt. J. Forensic Sci.* **2021**, *11*, 10, doi:10.1186/s41935-021-00225-7.
4. Vavilov, V.; Burleigh, D. *Infrared Thermography and Thermal Nondestructive Testing*; 1st ed.; Springer International Publishing: Cham, 2020; ISBN 978-3-030-48001-1.
5. Vavilov, V.P.; Burleigh, D.D. Review of Pulsed Thermal NDT: Physical Principles, Theory and Data Processing. *NDT E Int.* **2015**, *73*, 28–52, doi:10.1016/j.ndteint.2015.03.003.
6. Švantner, M.; Muzika, L.; Moskovchenko, A.; Pereira, C.M.C.; Das, S. Repeatability Study of Flash-Pulse Thermographic Inspection of Carbon-Fiber Composite Samples. *Infrared Phys. Technol.* **2022**, *126*, 104350, doi:10.1016/j.infrared.2022.104350.
7. Moskovchenko, A.; Švantner, M.; Muzika, L.; Skála, J.; Pereira, C.M.C.; Das, S. The Apparent Effusivity Method for Normalized Thermal Contrast Evaluation in Infrared Thermographic Testing. *Infrared Phys. Technol.* **2023**, *134*, 104931, doi:10.1016/j.infrared.2023.104931.
8. Edelman, G.J.; Hoveling, R.J.M.; Roos, M.; van Leeuwen, T.G.; Aalders, M.C.G. Infrared Imaging of the Crime Scene: Possibilities and Pitfalls. *J. Forensic Sci.* **2013**, *58*, 1156–1162, doi:10.1111/1556-4029.12225.
9. Medici, V.; Paone, N.; Pandarese, G.; Castellini, P.; Olivieri, M.; Spinelli, V.A.; Rizza, G.; Riccio, G.; Martarelli, M. Active Thermography for Gunshot Residue (GSR) Pattern Estimation on Textiles. In Proceedings of the 2023 IEEE International Workshop on Technologies for Defense and Security (TechDefense); IEEE, November 20 2023; pp. 104–109.
10. Moskovchenko, A.; Švantner, M.; Honner, M. Detection of Gunshot Residue by Flash-Pulse and Long-Pulse Infrared Thermography. *Infrared Phys. Technol.* **2024**, *140*, 105366, doi:10.1016/j.infrared.2024.105366.
11. Madruga, F.J.; Ibarra-Castanedo, C.; Conde, O.M.; López-Higuera, J.M.; Maldague, X. Infrared Thermography Processing Based on Higher-Order Statistics. *NDT E Int.* **2010**, *43*, 661–666, doi:10.1016/j.ndteint.2010.07.002.
12. Nečas, D.; Klapetek, P. Gwyddion: An Open-Source Software for SPM Data Analysis. *Open Phys.* **2012**, *10*, 181–188, doi:10.2478/s11534-011-0096-2.

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