,PhD Thesis Summary

INNOVATIVE IMAGING TECHNIQUES

AND METHODS USED IN FORENSIC INVESTIGATION

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The doctoral thesis analyzes the importance of imaging in the field of forensic science, highlighting the evolution of image capture and analysis technologies used in crime scene investigation and the examination of physical evidence. The study aims to demonstrate the impact of modern technologies on the investigative process and to provide a methodological framework for their application in forensic work. In this context, emphasis is placed on innovations brought by multispectral imaging methods, LiDAR technologies, 3D analysis, and the integration of artificial intelligence in the interpretation of forensic images. These elements have revolutionized the forensic domain, enabling the detection and analysis of traces that were previously difficult to identify using conventional methods.

Another major objective of this work was to identify the most effective methods for integrating new technologies into the workflow of forensic examinations and to assess their impact on current working procedures and the objectivity of judicial analyses. As traditional methods are increasingly complemented or even replaced by innovative solutions, forensic science is at a critical transition point toward complete digitization.

In the first chapter, we presented a brief retrospective of the imaging techniques developed over time. We consider these techniques as the starting point of our research and aim in the following chapters to advance scientific investigation and explore the new opportunities opened up in forensic documentation. While in past decades imaging at the crime scene and in the

laboratory was seen as an emerging field in which the scientific community placed great trust, today we observe a well-established technical branch of forensic science, requiring highly trained specialists in each specific area. The modern concept currently dominant worldwide is that of Forensic Science. There is a broad acceptance of the term Forensic Science, which generally encompasses all scientific disciplines that contribute to establishing the judicial truth. In this sense, forensic science appears as an exact, autonomous science based on the processing and adaptation of positive sciences for the discovery and analysis of macro- and micro-traces, including the identification of individuals by fingerprints, physical features, biological traces, etc.

The analysis of photographic techniques applied in forensic science demonstrates the essential importance of imagery in documenting the crime scene, preserving evidence, and providing objective means of analysis within the judicial process. Over its evolution, forensic photography has undergone a series of fundamental transformations, from the rudimentary techniques of the 19th century to advanced digital systems and modern technologies such as 3D reconstruction and virtual reality.

The need for technical knowledge and adaptation has led forensic science to what we now call adaptability and innovation. Through this work, we aim not only to bring innovations to the field but also to initiate a new stage of development. The new type of forensic specialist must thoroughly master various technical skills in this domain—skills that may determine the course of an investigation. Individual professional training will stimulate each forensic expert's desire for knowledge, allowing innovations to advance to a higher level.

The theoretical analysis of the technical domain of forensic science highlights that technological progress plays a key role in developing methods of crime investigation and evidence substantiation. The evolution of this branch has allowed the creation of more precise, objective techniques tailored to the modern requirements of justice.

We conclude that the technical branch of forensic science is a fundamental element in the judicial process, providing scientific support for the discovery and interpretation of evidence. Its contribution to the entire forensic system is indisputable, having a direct impact on the efficiency of investigations and the establishment of judicial truth.

A crucial aspect of this domain is forensic imaging, an indispensable tool in documenting the crime scene and evidentiary elements. Its importance lies in its ability to record individual details, allowing meticulous subsequent analysis and facilitating the reconstruction of events.

Imagery not only supports the investigative process but also becomes a credible form of evidence used in judicial proceedings to establish the truth.

Over time, the photographic techniques used in forensic science have evolved significantly, transitioning from classic black-and-white methods to high-resolution digital technologies, multispectral imaging, and AI-based analysis. This evolution has improved image capture and processing, reduced human error, and increased the objectivity of visual evidence.

We conclude that the technical branch of forensic science is a vital component of the judicial process, offering indispensable scientific support for the discovery, interpretation, and validation of evidence. The continuous evolution of technologies used in forensic science has led to a significant increase in the accuracy and efficiency of investigations, reducing error margins and strengthening the objectivity of truth-finding processes. This interdependence between technological progress and investigative methods underscores the essential role of innovation in strengthening the criminal justice system.

Forensic imaging is more than a simple visual recording tool—it becomes an analytical instrument that not only supports investigation but also contributes to clarifying the circumstances of a crime. In judicial procedures, images and graphic representations of the crime scene, biological traces, or trajectory reconstructions help elucidate critical aspects of investigated cases, offering courts a detailed and convincing perspective on the evidence.

In conclusion, integrating advanced imaging methods and technologies into forensic science not only optimizes investigative processes but also reinforces the scientific character of the evidence presented in court. As emerging technologies like artificial intelligence and LiDAR sensors become increasingly applicable in this field, the possibilities for better interpretation and validation of evidence continue to expand. This evolution highlights the need for an interdisciplinary approach and ongoing specialist training to fully harness the technological potential in the service of justice. At the same time, the relevance of forensic imaging in various branches of judicial investigations is highlighted, including the documentation of biological traces, crime scene analysis, and the three-dimensional reconstruction of criminal events. The importance of standardizing the process of image capture and archiving is emphasized, considering the judicial system's requirements for validating visual evidence.

The analysis of imaging techniques used in on-site and laboratory forensic investigations demonstrates the importance of a well-founded methodological approach, based on the correct

selection of equipment and capture parameters. The wide variety of cameras and sensors available on the market allows the adaptation of photographic techniques according to the specific nature of each investigated case.

Accurate capture of essential details requires a deep understanding of image formation principles, sensor characteristics, and the parameters that influence the final image quality. Choosing the correct camera, lens, and related settings is essential for obtaining precise and detailed results.

Regarding image formation, understanding how light is captured and processed by the camera sensor is critical for optimizing evidentiary details. The choice of camera type—whether Medium Format, Full Frame, APS-C, or Micro Four Thirds—affects image quality, level of detail, and light management in difficult conditions.

Image sensors play a key role in forensic documentation, determining the ability to capture fine details and the camera's performance in low-light conditions. The crop factor must be taken into account when selecting a camera, as it influences image composition and lens usage.

Another essential aspect is the image sensor itself, which directly influences photo quality through its capacity to record details accurately and manage light effectively. The crop factor alters the field of view and must be considered when selecting the appropriate lens for forensic documentation. Similarly, a camera's dynamic range determines its ability to capture details in both highlights and shadows, which is crucial for photographing high-contrast scenes.

White balance and color temperature affect the faithful rendering of tones, which is essential when photographing biological evidence or traces under different light spectra. The color space used in image processing determines the accuracy of tone and hue representation, which benefits forensic analysis.

Technical parameters such as ISO value and depth of field influence the sharpness and graininess of the obtained images. ISO value plays a critical role in maintaining image quality, requiring constant optimization to avoid digital noise that could compromise the visibility of fine details. Additionally, depth of field—affected by aperture, focal length, and crop factor—is a crucial element in controlling image clarity, especially when photographing small-scale evidence.

Finally, photographic lenses used in forensic imaging must be strategically chosen based on the type of photography and the evidence to be examined. By optimally integrating these factors, forensic photography becomes a particularly important tool in the documentation and

analysis of evidence, contributing to the creation of a representation as close to reality as possible—an essential aspect in criminal investigations.

Technological advances in image sensors and their impact on the precision of forensic analyses are emphasized. Aspects such as crop factor, dynamic range, white balance, color space, and ISO sensitivity are analyzed, all of which are essential for obtaining high-quality images for forensic purposes. The lenses used, their advantages, and their applicability in documenting the crime scene are presented.

A comparison is made between ultra-wide-angle lenses, telephoto lenses, and macro lenses, highlighting how each can influence the perception of trace details. Additionally, differences between mirrorless and DSLR technologies in the context of forensic photography are analyzed, emphasizing the advantages of mirrorless systems in terms of capture speed, sensor sensitivity, and compatibility with auxiliary lighting and spectral filtering equipment.

Currently, forensic science employs a wide range of imaging techniques that vary depending on the types of cases handled by each scientific police department or the financial resources allocated to this field. Imaging is both a technical and tactical field, with methodological and adaptive tools that each forensic expert often has at their disposal.

Forensic photography is not limited to image capture alone; it represents an essential scientific method in the investigation and reconstruction of criminal events. Operational forensic photography and the types of forensic photographs used at crime scenes demonstrate the need for a systematic approach in evidence documentation. From orientation photographs, which provide spatial context, to sketch and detail photographs, each technique plays a well-defined role in ensuring complete documentation. Additionally, trace photography and the imaging of main objects are indispensable in forensic examination, offering critical data to correlate physical evidence with the circumstances in which the crime occurred.

A fundamental aspect of a subchapter in this thesis was the analysis of differences between image sensors, demonstrating their impact on the quality and fidelity of forensic photographs. Medium Format, Full Frame, APS-C, and Micro Four Thirds sensors behave differently based on light sensitivity, crop factor, and dynamic range, all of which influence the clarity and level of detail in captured evidence. This differentiation is crucial for selecting the right equipment for various investigative scenarios.

Equally important, the chapter presented specialized photographic techniques and procedures, including advanced methods for capturing traces on difficult surfaces, using controlled lighting to eliminate reflections, and applying post-processing techniques to enhance detail visibility. These modern approaches ensure the maximum evidential value of images, reinforcing the role of forensic photography as a vital tool in judicial investigation.

Following a complex analysis conducted over recent years, we conclude that current photographic genres and techniques should be revised and refined. The discovery of new photographic methods—often beyond the rigidity of current standards—offers new perspectives for evolution. We must move beyond the stage of analyzing printed forensic photographs on paper, known as the photographic panel. A digital photograph conveys far more than its printed counterpart.

For these reasons, we propose changing the photographic panel in both form and content and replacing it with a "Photographic Report." This report should include all photographs taken during a crime scene investigation or laboratory examination, in digital format. These can be stored on media such as USB sticks, external HDDs, SSDs, or in a secure national database accessible to judicial authorities. The advantages of having raw photographs that depict the crime scene are numerous. For instance, a judge could directly observe a three-dimensional crime scene and form their own conclusions. This would provide access to unprocessed photos from both the field and the lab, with no need for additional explanations as required in traditional photographic panels. Naturally, the order in which the photos are taken and the phases of the crime scene investigation would remain unchanged. This way, the subjective role of the forensic investigator in creating a narrative via photos with accompanying explanations can be eliminated. We also remove the risk of visual artifacts introduced through printing. Moreover, sharing photographic evidence with other experts becomes significantly easier.

The adaptation of Deep Learning and Deep Seek technologies in forensic imaging represents a fundamental innovation that can enhance the detection of latent traces, crime scene reconstruction, and the authentication of visual evidence. As these technologies evolve, it is essential to integrate them within an ethical and regulated framework to ensure precision, transparency, and reliability in forensic investigation.

This innovative approach could redefine current methods of forensic image analysis, offering a new standard in judicial sciences and digital evidence investigation.

Another practical study in the thesis highlighted the major impact of forensic photography, advanced image capture methods, and emerging technologies—such as 3D scanning, multispectral imaging, and artificial intelligence—on improving the efficiency of forensic investigations. The integration of these technologies in trace analysis demonstrated significant potential in enhancing the accuracy and reliability of results, allowing for more rigorous and objective interpretation of evidence.

A key focus of the research was the comparative analysis of different imaging systems used in forensic investigations—from conventional cameras to full-spectrum devices, RUVIS systems, and 3D scanning technologies. The study's findings revealed that modifying cameras for full-spectrum capture can yield results comparable to or even better than those obtained with specialized equipment like RUVIS, offering a more accessible and versatile alternative for investigators.

Another central point of the thesis was the integration of 3D technologies in crime scene documentation and digital reconstruction of crime scenarios. 3D LiDAR scanning, photogrammetry, and computerized reconstruction demonstrated the ability to deliver precise and detailed representations of crime scenes, facilitating comparative analysis and the long-term preservation of evidence integrity. These technologies not only improve investigation quality but also allow for the three-dimensional reconstitution of incidents, enabling courts and experts to visualize and analyze evidence in a more intuitive and objective manner.

Furthermore, the study emphasized the importance of forensic image processing software, such as AMPED FIVE, Lucia Forensic, and EvoFinder, which allow advanced image analysis, detection of digital manipulation, and enhancement of evidence clarity. These tools are becoming essential in the digital age, where the increasing volume of CCTV footage and images from multiple sources requires reliable, automated forensic analysis methods.

Another important research direction was the role of UV, IR, and X-ray radiation in forensic investigations, demonstrating their effectiveness in revealing latent traces, gunshot residues, post-mortem tattoos, and other details invisible to the naked eye. Using full-spectrum cameras and appropriate filters enabled a more detailed level of forensic investigation, confirming that multispectral imaging is an indispensable tool in forensic medical examinations and the analysis of suspicious materials.

A significant development in modern forensic imaging is the integration of LiDAR technologies and drones in documenting crime scenes and reconstructing criminal scenarios in 3D. 3D LiDAR technology has shown a remarkable ability to precisely capture topographic details and generate 3D maps of crime scenes, allowing for detailed and reproducible documentation of the investigated environment. These data are essential not only for forensic analysis but also for accurately reconstructing incidents in court.

Simultaneously, the use of drones equipped with high-resolution cameras and multispectral sensors has revolutionized forensic aerial photography, offering a broad and detailed perspective of crime scenes. This method enables investigators to quickly cover large areas, obtain a complete view of the crime scenario, and generate precise 3D models without disturbing the scene. Moreover, LiDAR-equipped drones play a key role in rapidly scanning difficult or inaccessible terrain, enabling fast digital mapping of evidence.

Therefore, the integration of LiDAR and drones into forensic science opens new opportunities for the digitized analysis of crime scenes, providing fast, accurate, and objective methods for capturing and interpreting evidence. These technologies improve not only investigative efficiency but also the judicial system's ability to visualize and evaluate evidence more accessibly and convincingly.

In this context, the thesis proposes the establishment of a new branch of forensic science—Geospatial Forensics, an innovative concept combining all three existing branches with new methods for researching and reconstructing crime scenes.

Geospatial Forensics, as a new interdisciplinary domain, could revolutionize the investigation of complex crimes such as terrorism, aviation accidents, and organized crime. It would merge current forensic methods with 3D and spatial reconstruction technologies, advanced computer techniques, and remote sensing.

By using remote sensing, material analysis, photogrammetry, and 3D modeling, this method would allow the precise investigation of structures involved in criminal events. For instance, in the case of a terrorist attack on a building, Geospatial Forensics could digitally reconstruct the explosion's evolution and its effects on surrounding structures, helping to determine the initial detonation point based on data collected through photogrammetry and other drone-mounted sensors.

Hence, society needs a much greater capacity to prevent and investigate criminal acts in order to protect organizations and citizens. This creates an urgent need for proactive reform in forensic science to significantly enhance our ability to cope with the pressures of crimes evolving in the era of digital transformation.

The future of forensic science starts here and now, marked by a combination of opportunities and challenges. It is essential to make the use of digital technologies more difficult for criminal purposes while leveraging their advantages for victims, law enforcement agencies, companies, and organizations. As digital technologies continue to evolve, we must stay up to date with the latest developments to effectively investigate and prosecute crimes in the digital age.

There is a growing reliance on digital evidence, and the volume of such evidence in criminal cases is steadily increasing. As a result, forensic techniques are becoming more sophisticated and play an increasingly important role. However, this scientific field is extremely vast, often surpassing the capacity of most forensic laboratories to keep up with the rapid pace of technological advancement.

In addition to the urgent need to bring this issue to the attention of decision-makers in our country's justice system, the thesis discusses examples of potential solutions to these challenges—such as expanding international cooperation, encouraging and facilitating education and training to manage the rapid development of technologies, creating methods for explaining and visualizing digital evidence to improve legal understanding, and fostering collaboration between product developers and forensic investigators to enable rapid innovation in digital forensic tools and methodologies in the face of emerging threats.

This study presented concrete examples in which modern digital techniques are used to solve crimes committed in both the physical and digital realms.

Today, global society is undergoing a complex process of systemic transformation, marked by interconnected challenges, including climate change, global health crises, increasing geopolitical tensions, and the acceleration of digitalization. These factors deeply influence economic structures, governance mechanisms, and social models, requiring a reassessment of traditional paradigms and continuous adaptation to new realities.

Therefore, it is imperative that society develops regulatory and adaptive mechanisms to ensure a fair and sustainable transition to a digitalized world. Developing solid ethical and legal frameworks, promoting algorithmic transparency, and strengthening digital education are essential

to prevent technological abuses and ensure that digital transformation serves the collective interest—and not just a technological elite. Ultimately, the balance between innovation, security, and social equity will determine the sustainability of this new societal model.

The thesis demonstrates that the implementation of advanced technologies in forensic imaging enables the optimization of investigative processes, reduction of analysis time, and increased precision of visual evidence. The adoption of automated image processing methods, the integration of artificial intelligence, and the use of 3D technologies lead to a modern, efficient, and objective forensic science. Therefore, we emphasize the need to standardize the use of new technologies in judicial investigations and to implement legislative frameworks that regulate the admissibility of visual evidence in court.