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AI + ML for Forensic Scene Reconstruction: A Simulation-Based Study of Blood Spatter, Fingerprint, and Visual Evidence Mapping

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Abstract

The investigation of crime scenes plays a crucial role in the criminal justice system. Traditional forensic approaches rely heavily on manual inspection, documentation, and hypothesisbuilding based on physical evidence collected from the scene. These methods, although effective to a degree, are time-consuming, subjective, and susceptible to human error. As technological advancements continue to reshape various scientific domains, the integration of Artificial Intelligence (AI) and Machine Learning (ML) into forensic science has the potential to revolutionize the way crime scenes are reconstructed, analyzed, and interpreted.

This research proposes the development of a comprehensive AI and ML-based framework to facilitate forensic scene reconstruction using 3D modeling derived from 2D images. The system aims to automate the identification and tagging of forensic evidence such as blood spatter, fingerprints, and various visual clues using advanced computer vision and deep learning models. Through the application of 3D reconstruction techniques like photogrammetry and Structure-from-Motion (SfM), investigators can create accurate, virtual models of crime scenes that can be further enhanced by integrating ML algorithms capable of evidence detection and classification.

The study will utilize publicly available forensic datasets along with synthetically generated data to train and validate the AI models. A userfriendly interface will also be developed to enable forensic professionals and law enforcement to interact with and analyze the reconstructed scenes. The results of this research are expected to improve the efficiency of forensic investigations, reduce the scope for human error, and enable immersive courtroom presentations.

Key words: AI, ML, Reconstruction, scomputer vision, photogrammetry, Forensic, Crime, fingerprint, BSA

Introduction and Background

The dynamic and multifaceted field of forensic science is vital for upholding justice by gathering, preserving, and analyzing physical evidence from crime scenes. Traditional crime scene analysis often involves manual sketching, photography, physical measurement, and subjective interpretation by experts. These manual processes can be limiting in terms of precision, efficiency, and scalability— particularly in complex or degraded crime scenes.

In recent years, technological innovation has introduced possibilities for automating and enhancing forensic investigations. One such advancement is the integration of Artificial Intelligence (AI) and Machine Learning (ML) with computer vision for forensic scene reconstruction. When coupled with 3D modeling tools, this integration allows for the accurate simulation of crime scenes from photographs, enabling a digital twin that can be used for hypothesis testing and investigative reconstruction.

Computer vision techniques such as Structurefrom-Motion (SfM), photogrammetry, and stereo imaging facilitate the transformation of 2D photographs into 3D digital spaces. These reconstructed scenes provide spatial context, improve visualization, and help investigators identify inconsistencies. When AI-based object detection models are layered onto this framework, it becomes possible to automatically detect and tag key forensic evidence such as blood spatter patterns, fingerprints, and weapon outlines.

This approach significantly reduces human workload, enhances the accuracy of documentation, and provides a reusable model for courtroom presentations. The potential of this research extends to creating training simulators for forensic professionals and contributing to real-time crime analysis tools. Thus, this research proposes a simulationbased study using AI and ML techniques to develop a scalable and robust forensic reconstruction system. The ultimate goal is to assist law enforcement agencies in making accurate, data-driven decisions and improve the overall integrity of the forensic process.

Research Problem and Objectives Problem Statement:

Traditional crime scene reconstruction depends heavily on manual inputs, which makes the process time-consuming, subject to human error, and inconsistent. Reconstructing scenes based on physical measurements,

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sketches, and subjective interpretations does not provide the precision and repeatability needed for modern forensic analysis. There is a clear need for an automated, intelligent system that can analyze 2D crime scene images and generate 3D simulations while detecting and tagging forensic evidence using AI and ML algorithms.

Objectives:

1. To develop a scalable AI-driven framework for 3D reconstruction of crime scenes using 2D photographic inputs.
2. To design and train ML models capable of automatically detecting and tagging blood spatter, fingerprints, footprints, and weapons in reconstructed environments.
3. To simulate different crime hypotheses by performing spatial and temporal analysis on the reconstructed scene and the evidence locations.
4. To build a user-friendly interface that enables visualization, interaction, and presentation of reconstructed crime scenes.
5. To evaluate the accuracy, speed, and usability of the developed system using real and synthetic forensic datasets and benchmark against manual methods.

Literature Review

1. Smith, J. et al. (2023). "Deep Learning for Bloodstain Pattern Analysis." Forensic Science International. Link

2. This paper investigates the application of Convolutional Neural Networks (CNNs) to blood spatter pattern analysis. The authors propose a classification system capable of categorizing different types of bloodstain patterns (e.g., passive, impact, arterial). The study showed that CNNs outperform traditional image processing techniques in terms of classification accuracy and robustness, highlighting the promise of deep learning in forensic bloodstain interpretation.

3. Brown, L. et al. (2022). "3D Crime Scene Reconstruction Using Photogrammetry." Journal of Digital Forensics. Link

4. This paper demonstrates how photogrammetry can be used to reconstruct a crime scene in three dimensions using multiple 2D photographs. The methodology involves Structure-from-Motion (SfM) and Multi-View Stereo (MVS), producing dense point clouds that can be converted into textured 3D models. The research underscores the importance of accurate reconstruction for spatial analysis and contextual visualization in criminal investigations.

5. Chen, K. et al. (2021). "AI in Digital Forensics: A Review." IEEE Access. Link

6. Chen et al. provide a comprehensive review of AI techniques in digital forensics, covering evidence detection, pattern recognition, and image analysis. The study identifies key challenges in forensic AI such as dataset scarcity, interpretability of AI decisions, and real-time deployment. It highlights successful applications in face recognition, fingerprint matching, and surveillance video analysis.

7. Kumar, P. et al. (2023). "Fingerprint Recognition Using Deep Learning." Pattern Recognition Letters. Link

8. This paper presents a deep learning model that surpasses traditional minutiae-based fingerprint recognition systems in accuracy and robustness. Using a deep Siamese network, the model learns feature representations directly from raw fingerprint images, allowing it to work under varied conditions such as noise, rotation, and partial prints.

9. Li, H. et al. (2022). "Simulation-Based Forensic Scene Analysis." Computational Forensics. Link

10. Li et al. present a virtual simulation platform where different crime hypotheses can be tested based on spatial and forensic evidence. The study integrates digital modeling with scenario simulation, enabling a feedback loop where hypotheses are validated against evidence distribution. It underscores the benefit of using virtual simulations for crime scene analysis, training, and courtroom demonstration. Together, these studies validate the feasibility of integrating AI, ML, and 3D modeling in forensic applications. They emphasize the importance of accurate reconstruction, reliable evidence detection, and real-time simulation to enhance forensic science methodologies. The current research builds upon these foundations to create a unified system tailored for practical forensic investigations.

Research Methodology

This study employs a multi-phase research methodology involving data acquisition, preprocessing, model development, system integration, evaluation, and user interface creation. Each phase is carefully designed to meet the research objectives and ensure reproducibility.

1. Data Collection:

The research will use both public and synthetic datasets. For blood spatter analysis, datasets like fingerprints patterns and proprietary blood pattern databases will be used. For fingerprint analysis, datasets such as scene image dataset, synthetic spatter dataset and fingerprint spatter dataset will be employed. Simulated crime scene images will also be generated using mock setups and 3D rendering tools like Unity or Blender.

2. **Data Preprocessing**:
Collected images will undergo standard preprocessing steps including noise reduction, contrast enhancement, resizing, and annotation. Labeling tools like LabelImg will be used for object tagging (e.g., blood drops, fingerprints, weapons). These annotations will serve as ground truth for model training.

3. **3D Reconstruction**:
Tools such as Meshroom, or OpenMVG, OpenCV will be used to generate 3D models from 2D photographs. These tools apply Structure-from-Motion (SfM) and Multi-View Stereo (MVS) algorithms to construct dense 3D point clouds and textured meshes, which represent the crime scene.

4. **Evidence Detection**:
Deep learning models will be developed for detecting blood spatter (using OpenCV and CV2), fingerprints (CV2), and other objects (YOLOv8 and Open3D). The models will be trained using the annotated datasets and evaluated based on precision, recall, and F1 score.

5. **Integration:**
The outputs of the detection models will be spatially mapped onto the 3D scene. Evidence tagging will be embedded in the 3D environment using Open3D, allowing users to click on items for metadata.

6. **Simulation and Hypothesis Testing**: Spatial and temporal analysis will be performed using the 3D scene data. Investigators can simulate different crime hypotheses by manipulating the evidence configuration and observing alignment with real-world physics.

7. **Evaluation:**
The system will be evaluated using metrics such as detection accuracy, reconstruction fidelity (IoU, PSNR), and user satisfaction. Comparisons will be made against traditional forensic methods.

8. **User Interface:**
A front-end visualization tool will be developed using Unity or a web-based framework like Three.js. It will enable rotation, zoom, and interaction with reconstructed scenes. The UI will include layers for evidence visibility and a timeline for crime sequence simulation.

This methodology ensures the creation of a comprehensive, practical, and scalable solution for forensic scene reconstruction using AI and ML.

Expected Outcomes

1. A functional AI-ML framework that can reconstruct 3D crime scenes from 2D photographs.
2. Trained and validated deep learning models for detecting blood spatter, fingerprints, and forensic objects.
3. An interactive visualization platform where law enforcement can explore, analyze, and simulate reconstructed crime scenes.
4. A comprehensive comparison of traditional and AI-assisted forensic methods in terms of speed, accuracy, and usability.
5. A foundation for further research into real-time forensic AI tools, virtual courtroom presentations, and automated evidence classification systems.

Conclusion

This case study establishes a **foundation for the application of basic AI and ML in forensic science**. Although experiments were limited to **single-object and full-room images**, the results demonstrate the **feasibility and utility** of AI in object detection, blood spatter analysis, fingerprint demographic prediction, and footprint-based height estimation.

Future research can expand this work by:

- Scaling up object detection across complex scenes
- Improving blood spatter analysis with 3D modeling
- Enhancing fingerprint and biometric profiling
- Integrating multiple evidence types for **comprehensive crime scene reconstruction**
- Addressing ethical, legal, and practical considerations

Ultimately, this research highlights that **even simple AI models can significantly augment forensic investigations**, offering a roadmap for future studies to develop **more advanced, integrated, and real-world applicable AI solutions**.

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