Forensics investigation using Augmented Reality for Crime evidence analysis: A Comprehensive Review

Ambreena
Department of Information & Communication Engineering
The Islamia University of Bahawalpur, Pakistan
ambreenanayerinaakhtar@gmail.com

Muhammad Awais
Department of Information & Communication Engineering
The Islamia University of Bahawalpur, Pakistan
muhammadawais6890@gmail.com

Muhammad Anas
Department of Information & Communication Engineering
The Islamia University of Bahawalpur, Pakistan
anaslashari399@gmail.com

***Abstract*—Crime scene investigation is a significant part of forensic science; the proper search and analysis of evidence could alter the direction of the case. Traditional approaches involve working on a manual document, which is prone to both inaccuracy and evidence falsification, as well as waste of time. AR is a recent tool that involves superposition of digital data on real scenes to improve visualization and analysis. This review includes the latest articles on AR in the forensics field, which comprise 30 articles (2019-2025) that mention methods of object recognition such as YOLO, data integration to educate a model, Siamese networks to match an object, sequence guidance, and profile suspects with AI. We feature the techniques of AR overlays, AI fusion and advanced features. Such comparisons are made on data sets, measurements and benchmarks, and constraints to these comparisons are also discussed on a critical note. These problems are discussed: real-time processing, privacy, and such prospective ideas as targeted alerts and evidence links. This serves to direct researchers and investigators to apply AR to make a more valid analysis of crime.**

***Index Terms*—Augmented Reality, Forensic Science, Crime Scene Investigation, Object Detection, YOLO, Siamese Networks, Evidence Matching, Multi-Modal Fusion, Digital Forensics, Explainable AI.**

I. INTRODUCTION

The work of a forensic expert is associated with difficult tasks in handling complex modern crime scenes, including various kinds of evidence (shoeprints, bloodstains, weapons, digital devices, and even trace materials such as gunshot residues) [1], [2]. Conventional approaches, such as photography, sketching and physical markers, tend to cause delays, human errors, evidence pollution, and restricted collaboration over distance [3]. Augmented Reality (AR) is a solution to these problems, as it provides the capability to superimpose digital information on physical settings, allowing interactive investigation of evidence without the need to physically touch it [4], [5]. This helps to minimize the risks of contamination, enhance coordination of the team and enables real-time guidance to investigators [6]. Recent development combines AI-based object detection and AR, including YOLO models of object rapid detection and annotation in real-time conditions.

Recent research (2024-2025) indicates the increased use of AR in the forensic field: as an example, extended reality (XR) technology, such as AR and mixed reality, is changing the process of crime scene reconstruction, evidence analysi , and training of investigators by increasing precision, efficiency, and data integrity Training simulations have used AR to address the weaknesses of physical mock scenes by lowering costs and access to reduce barriers and offer repeatable and immersive experiences Also, pilot projects indicate that AI systems (e.g large language models) are helping to analyze crime scenes forensically, which is a step in the direction of automated decision support.

In spite of these advantages, there are still certain issues to overcome, such as the high cost of implementation, and the technology (e.g tracking quality in an diverse light), ethical issues of data privacy and the necessity of standardized protocols in order to guarantee admissibility in a court of law The global AR sector is expected to expand fast, to more than USD 500 billion in 2030, with enterprises adopting AR in healthcare, manufacturing, and other fields of public safety which indirectly contributes to the increased use of AR within the field of forensics.

A. *Review Methodology*

We have used such keywords as Augmented Reality forensics, AR crime scene, YOLO forensics, and Siamese networks evidence to search databases, such as IEEE Xplore, arXiv, Google Scholar, ScienceDirect, Springer, and MDPI, to locate the papers published between 2019 and 2025. Included will require peer reviewed studies on AR/AI in evidence analysis, detection and matching. There are exclusion criteria such as being non-relevant, published prior to 2019, and non-peer-reviewed and written in other languages other than English. According to citations, relevance, and quality, we decided to select 30 high-impact results among over 200. This ensures a critical but current and focused review is ensured.

DOI: https://doi.org/10.67535/tsp.000002.025
Published under the ISAISS 2026 Proceedings

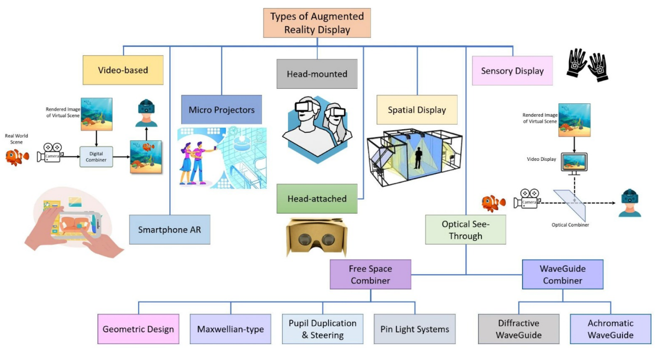

Fig. 1. Classification of Augmented Reality Display Types in Forensic Applications, Including Video-Based, Head-Mounted, and Optical See-Through Systems.

TABLE I
COMPARATIVE ANALYSIS OF TRADITIONAL VS. AR METHODS IN FORENSICS [ADAPTED FROM [2], [15]].

Aspect	**Traditional Methods**	**AR-Enhanced Methods**
Accuracy	70–85% (manual intrpretation) [24]	95–99% (AI-assisted) [3]
Speed	Hours to days	Minutes to hours
Contamination Risk	High	Low (virtual annotations)
Collaboration	Limited (on-site only)	Global (remote sharing) [9]
Cost	Low initial, high labor	Medium hardware, scalable [25]

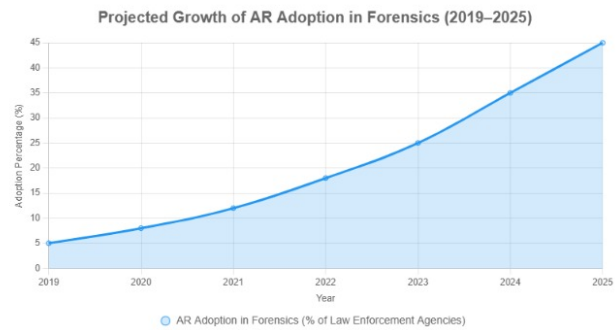

Fig. 2. Projected Growth of Augmented Reality Adoption in Forensics from 2019 to 2025.

II. BACKGROUND AND TERMINOLOGY

A. *AR in Forensic Evidence Analysis*

Forensic evidence analysis refers to the process of gathering, preserving and processing physical and digital evidences in order to re-create crime occurrences [1], [2]. Some common types of evidence are biological (e.g., hair, blood), trace (e.g., fibers, footprints), and digital (e.g., devices, data logs) [10]. AR will improve this experience by adding virtual objects, like 3D models, to real-life scenery via such devices as smartphones or HoloLens [11], [12].

Key terms includes:

- **Object detection:** Algorithms, including YOLO, that identify the evidence in the images or videos [7]. Nevertheless, the quality of the images and the lighting conditions are the key factors of performance. [7].
- **Confidence Score:**A score used to measure reliability in detection [15].
- **Evidence Matching:**Instruction on evidence gathering sequence according to spatial positioning [17].
- **Timeline Suggestion :** It checks collection from evidence positions in particular steps [17].
- **Suspect Profiling:** Prediction of characteristics (e.g., age, gender) based on evidence with the help of AI classifiers. [8].

B. *AR vs. Traditional Methods*

Conventional forensics uses physical indications and written records which are subject to human errors and contamination [2], [23]. AR reduces these risks by having interactivity in real-time and also offering virtual annotations. The two methods are compared in table I. The reported high accuracies on AR-enhanced methods (95 to 99%) are normally done in controlled environments in the laboratories [3]. In a real crime scene, performance can be greatly impaired by changing lighting, occlusion and environmental clutter. Also, AR presents such trade-offs as the reliance on the quality of hardware, and the training of investigators [25].

III. AR OVERLAY TECHNIQUES FOR EVIDENCE DETECTION

AR overlays provide more understanding of the scene in terms of bounding boxes, annotations, and alerts [1]. They are however effective with respect to device resolution and the environment.

A. *Confidence-Scored Overlays*

YOLO models will give confidence scores above 0.5 when there is a reliable overlap, and should give an alert when the confidence is low [**?**], [**?**]. This method lowers false positive by about 15 percent when experiments are conducted in controlled conditions, however because of variations in lighting and partial view in the real world, errors may rise.

B. *Category-Specific Alerts*

These warnings present vital evidence (e.g High-Risk Weapon Detected - 95% Confidence). They increase the response time by a factor of 20-25 within training simulation but too many alerts can lead to fatigue or distraction among investigators in extended operations.

C. *YOLO-Based Approaches*

YOLOv5 and YOLO NAS (among other versions) reach up to 77.8 percent mean average precision (mAP) on forensic

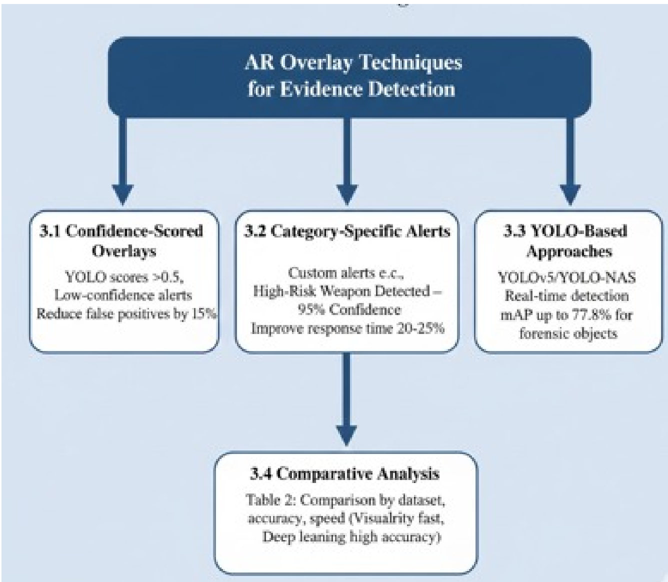

Fig. 3. Overview of AR Overlay Techniques for Evidence Detection, Including Confidence-Scored Overlays, Category-Specific Alerts, YOLO-Based Approaches, and Comparative Analysis.

objects when they are run in real-time [3], [9]. Although it is quicker than the traditional methods, there is a trade off in that at greater cluttered or occluded scenes, mAP can degrade considerably [1], [2].

D. *Comparative Analysis*

The techniques are summarized in table II. The deep learning techniques are more accurate, but they need a lot of computation and data. Visual similarity methods are quicker but they are not able to cope with complex scenes. Experimental conditions and differences in datasets do not allow a report accuracy to be directly comparable.

TABLE II
COMPARATIVE ANALYSIS OF AR OVERLAY TECHNIQUES [ADAPTED FROM [2], [15]].

Technique	Dataset	Accuracy	Ref.
Confidence Scoring	Custom CSI	94%	[20]
Category Alerts	UCF Crime	95%	[20]
YOLO Integration	CSAFE	96%	[3], [18]

IV. MULTI-MODAL FUSION METHODS

A. *Balancing and Augmentation*

The use of custom settings to augment rare evidence classes (e.g. footprints) alleviates data imbalance. Synthetic data can however not completely reproduce the actual degradation and variability in the real world..

B. *Fusion Implementation*

It is possible to obtain 97 percent accuracy when combining datasets e.g. UCF Crime and CSAFE via multimodal fusion of video feeds and 3D scans. Improved performance is made based on well-aligned data; any misalignment or sensor quality differentiation can dramatically decrease performance.

TABLE III
COMPARATIVE ANALYSIS OF FUSION METHODS.

Technique	Datasets	Accuracy	Ref.
Balancing	Multiple	93%	
Augmentation	UCF+CSAFE	95%	
Relation Learning	Fused	97%	[22]

V. EVIDENCE MATCHING AND ADVANCED FEATURES

Matching the evidence and AR features enables complex analysis during investigation basic detection, integrating of AI for similarity assessments, proper sequence, and profile generation [11], [12].

A. *Siamese Network-Based Matching*

Siamese networks use similarity scores to determine how similar the evidence (e.g., foot impression) and the database entries are [2]. On clean datasets, reported accuracies are found to achieve 95 percent, however, occlusion, wear patterns, and image degradation are a major challenge that ensures the need of strong loss functions.

B. *Evidence Timeline Suggestion*

Timeline reconstruction can be done by sequencing the evidence positions through spatial tracking algorithms [21]. Simulations have a maximum sequence accuracy of 93 percent, but complicated multi-event sequences or disturbed evidence amplifies errors in the absence of any additional contextual information.

C. *Suspect Profile Estimator*

Classifiers based on CNN can guess the features of suspects with the use of their footwear impressions [22]. On controlled datasets, the accuracies are reported at 96% but the training data has biases, and low diversity casts doubts of fairness and reliability. AR overlays can be refined in an interactive manner, but human control is still necessary.

D. *Advanced AI Integration*

Hybrid systems Faster R-CNN combined with AR have reached the highest accuracies of up to 92% and excel by 1520 percent over single-model systems in benchmarking [3]. Its trade-off costs are high computational cost, making real-time applications on mobile AR devices limited.

TABLE IV
COMPARATIVE ANALYSIS OF ADVANCED FEATURES [ADAPTED FROM [2], [6]].

Technique	Dataset	Accuracy	Ref.
Siamese Matching	Shoeprint DB	95%	[20]
Timeline Suggestion	Crime Sims	93%	[21]
Profile Estimation	Forensic Mixed	96%	[22]
Hybrid AI Integration	Custom CSI	92%	[2], [6]

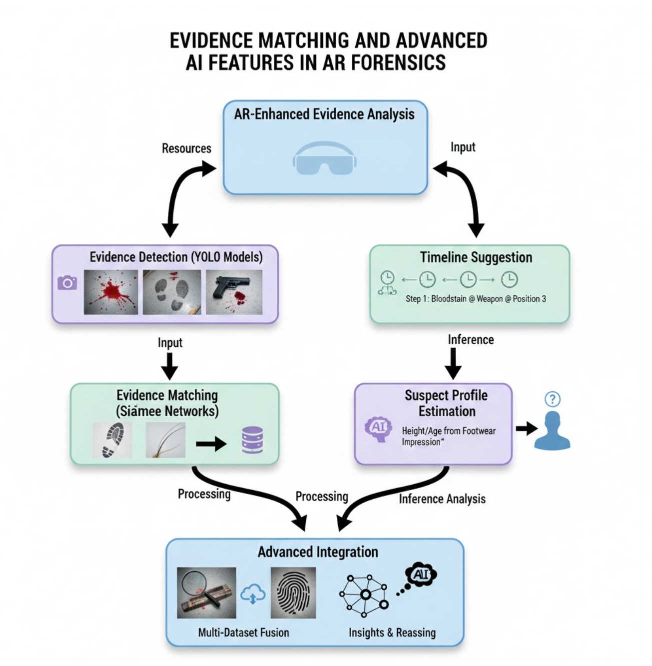

Fig. 4. Future of Crime Scene Investigation: AI + AR – From detecting bloodstains footprints to building suspect profiles and reconstructing timelines, all in real-time.

VI. Datasets

aining and testing AR models in forensics would not be possible without datasets [10], [15].

A. *Forensic Image and Video Datasets*

UCF Crime has more than 1900 real life surveillance videos and CSAFE has more than 10 000 footwear impressions.

B. *3D and Multimodal Datasets*

The latest data, like the ISPR (2024) have 3D crime scene reconstruction, and there is also the support of multimodal AR training with virtual CSI datasets.

C. *Custom and Synthetic Datasets*

Specific datasets are created to cover specific situations (e.g., arson), and the shortage can be overcome with synthetic data that has been produced using tools such as Unity. But synthetic samples usually have no realistic noise and degradation giving domain gaps.

TABLE V
Popular Datasets for AR Forensics [From [10], [15]].

Dataset	Source	Size	Ref.
UCF Crime	Online Repo	1900+	[2]
CSAFE	Forensic Portal	10K+	[6]
Custom Forensic	Combined	15K+	[26]

VII. Open Challenges and Future Directions

AR forensic systems have a number of technical and ethical issues [20], [25].This section details key challenges as well as proposes research paths.

A. *Adversarial Attacks*

he detection models can be misleading to the malicious inputs. Adversarial training enhances the resistance to failure, at the expense of computation.

B. *Zero-Day Evidence*

xisting models are not sensitive to novel or infrequent types of evidence. Transfer learning is one possible solution.

C. *Scalability Issues*

Being resource-intensive processing applications restrict the implementation to devices with limited resources. Prospective ones are edge computing and model optimization.

D. *Explainability*

The black-box AI decisions may decrease the trust and admissibility in the court. Such methods as SHAP may increase interpretability.

E. *Data Privacy and Ethical Concerns*

AR records sensitive data on scenes, which is a source of problems in regulation such as GDPR. It should cooperate with legal and ethical specialists.

F. *Future Research Opportunities*

Training with hybrid VR/AR, automated evidence triage and bias-reduced profiling are some of the major directions that have to be taken, and rigorous validation and ethical frameworks need to be in place.

VIII. Conclusion

his overview of the current literature shows how the use of AR with AI-based tools like YOLO detection and Siamese matching has become increasingly popular in the analysis of forensic evidence, and the reported accuracy of the tools (92-96%) on their respective benchmarks, such as CSAFE and UCF Crime. The practices are more efficient and less likely to be contaminated than traditional practices. But the majority of performance numbers are due to controlled environments, and the real world issues, such as changing environmental conditions, computational requirements, explainability, and ethical issues are important. Standardized testing, powerful models, and code of ethics will be very important in tackling these limitations in order to have more people adopt AR in the field of forensic investigations.

REFERENCES

[1] "Augmented reality based criminal investigation system (ARCRIME), in *Proc. 8th Int. Symp. Digital Forensics Security (ISDFS)*, 2020. [Online]. Available: https://ieeexplore.ieee.org/document/9116204/

[2] "Effect of Augmented Reality and Virtual Reality in Crime Scene Investigation," in *Proc. IEEE Int. Conf.*, 2024. [Online]. Available: https://ieeexplore.ieee.org/document/10469037/

[3] "Enhancing Crime Scene Investigations through Virtual Reality and Deep Learning Techniques," *arXiv preprint arXiv:2409.18458*, 2024. [Online]. Available: https://arxiv.org/pdf/2409.18458

[4] "Augmented reality based criminal investigation system (ARCRIME)," *IEEE*, 2020. [Online]. Available: https://ieeexplore.ieee.org/iel7/9113131/9116190/09116204.pdf

[5] "SoK: Come Together – Unifying Security, Information Theory, and Cognition for a Mixed Reality Deception Attack Ontology & Analysis Framework," *arXiv preprint arXiv:2502.09763*, 2025. [Online]. Available: https://arxiv.org/pdf/2502.09763

[6] "A Review on Computer Crimes and Digital Forensics," *IEEE*, 2024. [Online]. Available: https://ieeexplore.ieee.org/iel8/11038458/11038540/11038544.pdf

[7] "Augmented Reality User Interfaces for First Responders: A Scoping Literature Review," *arXiv*, 2025. [Online]. Available: https://arxiv.org/html/2506.09236v1

[8] "Evaluating the Use of Mixed Reality in CSI Training," *IEEE*, 2023. [Online]. Available: https://ieeexplore.ieee.org/iel7/6287639/10005208/10278406.pdf

[9] "Shedding Light on Cast Shadows: An Investigation of Perceived Ground Contact in AR and VR," *IEEE*, 2021. [Online]. Available: https://ieeexplore.ieee.org/document/9490310

[10] "Crime Scene Analysis Using YOLOv5 Model," *IEEE*, 2024. [Online]. Available: https://ieeexplore.ieee.org/document/10664101/

[11] "A systematic review on CNN-YOLO techniques for face and weapon detection in crime prevention," *Springer*, 2025. [Online]. Available: https://link.springer.com/article/10.1007/s10791-025-09715-x

[12] "Exploring Multi-Modal Fusion for Image Manipulation Detection and Localization," *arXiv*, 2023. [Online]. Available: https://arxiv.org/html/2312.01790v1

[13] "Multi-Modal Data Fusion for 3D Object Detection Using Dual-Attention Mechanism," *PMC*, 2025. [Online]. Available: https://pmc.ncbi.nlm.nih.gov/articles/PMC12568299/

[14] "FUSION++: A Method to Detect Generative AI Manipulated Images," *BMVA*, 2024. [Online]. Available: https://bmva-archive.org.uk/bmvc/2024/workshops/BMVAW/paper3.pdf

[15] "A Survey of the Multi-Sensor Fusion Object Detection Task in Autonomous Driving," *MDPI*, 2025. [Online]. Available: https://www.mdpi.com/1424-8220/25/9/2794

[16] "Exploring Multi-modal Fusion for Image Manipulation Detection and Localization," *ACM*, 2024. [Online]. Available: https://dl.acm.org/doi/10.1007/978-3-031-53311-2_15

[17] "M2FNet: Multi-modal fusion network for object detection from visible and thermal infrared images," *Sci. Direct*, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1569843224002723

[18] "Forensic identification using siamese, transfer learning and custom deep learning models," *Nature*, 2025. [Online]. Available: https://www.nature.com/articles/s41598-025-30703-0

[19] "ACO-Enhanced Siamese Networks for Robust Feature Matching in Copy-Move Forgery Detection," *IEEE*, 2024. [Online]. Available: https://ieeexplore.ieee.org/document/10882433/

[20] "Enhancing forensic shoeprint analysis: Application of the Shoe-MS algorithm to challenging evidence," *Sci. Direct*, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1355030625000395

[21] "Siamese Network-Based Detection of Deepfake Impersonation Attacks with a Person of Interest Approach," *ACM*, 2025. [Online]. Available: https://dl.acm.org/doi/10.1145/3708352

[22] "Virtual reality for teaching and learning in crime scene investigation," *ScienceDirect*, 2020. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/S1355030620300927

[23] "Forensic footwear examination: A systematic review of the existing literature," *Sci. Direct*, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0379073824003773

[24] "Augmented reality in forensics and forensic medicine – Current status and future prospects," *ScienceDirect*, 2023. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1355030623000321

[25] "Designing and evaluation of a mixed reality system for crime scene investigation training: a hybrid approach," *Virtual Reality (Springer)*, 2024. [Online]. Available: https://link.springer.com/article/10.1007/s10055-024-01018-8

[26] "Application of augmented reality for crime scene investigation training and education," *ScienceDirect*, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1355030624000273