Integrating artificial intelligence in forensic science

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Abstract

Thesis. The thesis of this article is to explore the integration of artificial intelligence (AI) methodology in forensic science. An assessment of the potential implications of AI for improving investigative processes and outcomes will also be addressed.

Concept. The concept focuses on exploring the application of AI technologies in areas of science such as analysing evidence recognising patterns and supporting decision-making systems. The article emphasises the practical use of AI algorithms in investigations. on exploring how artificial intelligence technologies can be implemented in various aspects of forensic science.

Results. An analysis of existing literature and case studies shows that integrating AI into forensic science can improve efficiency, accuracy, and objectivity in investigations. AI tools can automate tasks analyse datasets and identify patterns that might be challeng-

ing for humans to detect. However utilising AI in forensic science poses challenges like algorithms, privacy issues with data handling, and the necessity for oversight. Furthermore, when employing intelligence for inquiries it is essential to prioritise transparency, and accountability and uphold integrity in decision-making processes.

Originality. This article adds to the discussion about integrating AI into science by offering a thorough examination of its potential advantages and obstacles faced along, with ethical concerns. By merging research findings and offering perspectives on emerging trends we can gain insights, into the impact of AI on advancing investigations in the years ahead. Additionally, the theoretical structure presented here establishes a foundation for research studies and practical implementations, within the field of forensic science.

Keywords: Artificial intelligence, forensic science, AI applications in forensic science, machine learning for evidence analysis, crime scene reconstruction with AI

Introduction

Overview of the role of artificial intelligence (AI) in forensic sciences

In the context of legal regulations, article 3 of European Parliament on May 14th 2024 described AI as a „machine-based system designed to operate with varying levels of autonomy. Once deployed, it may adapt and draw inferences from received data to produce outputs such as forecasts, content, recommendations, or decisions that may affect physical or virtual environments" (European Parliament, 2024). The term „artificial intelligence" is commonly used to describe machines that simulate „cognitive" functions typically associated with the human mind, such as „learning" and „problem-solving" (Russel & Norvig, 2016).

Clearly, AI is a tool which can be employed within forensic science (FS) to improve various investigative processes. FS involves applying scientific principles and methods to assist in legal decision-making for criminal and civil cases, according to Siegel (2024). The application of AI in FS helps streamline and improve processes such as DNA analysis, fingerprint matching, and crime scene reconstruction (Brettell, Butler, & Saferstein, 2005).

As mentioned above AI has a significant impact on forensic science and allows investigators to automate their strategies and identify insights and information i.e. help forensic experts formulate more accurate, faster, and uniform opinions for justice (Mansoor & Iliev, 2023). AI can help overcome the human subjective limitations of traditional FS approaches by implementing fresh „insights". AI has been explored as a tool to assist forensic experts at the scene of a crime, including the use of crime scene reconstruction using 3D software, evidence analysis, face and object recognition, camera footage analysis (Jadvah, Sankhla, & Kumar, 2020). In addition, FS sees AI as a promising solution to problems encountered during crime detection (Martin, 2019).

Therefore, in the following article, we try to pertain to the escalating significance of utilising AI in the field of forensic science (FS), endeavouring to address inquiries such as: What are the principal domains of artificial intelligence (AI)

application in forensic sciences, including evidence analysis, pattern recognition, and decision support systems? Furthermore, what are the potential implications of AI integration for enhancing investigative processes and investigative outcomes?

The idea of this review is to comprehensively explore the integration of AI within the application in FS. In addition the research emphasises the potential of these technologies to automate various phases of forensic investigations, address challenges related to data volume and device diversity, assess practical applications of AI, and investigate potential trajectories for future research (Dunsin, Ghanem, Ouazzane, & Vassilev, 2024)

Overview of methodology

In the first step we used Google Scholar with search terms "AI forensic science" and "artificial intelligence in forensic sciences" to identify relevant papers. Then, we scrutinise the more than 500 000 results and derive search terms to narrow down the research (Sanchez, Grajeda, Baggili, & Hall, 2019). Finally, we combined:

– „Artificial intelligence in forensic science"
– „AI applications in digital forensics"
– „Machine learning in criminal investigations"
– „AI evidence analysis in forensics"
– „Pattern recognition in forensic science using AI"
– „Decision support systems in forensic science AI"
– „AI forensics and explainability"
– „Deep learning for forensic evidence analysis"
– „Video forensics using AI"
– „AI and machine learning in digital forensics and incident response"
– „AI security threats and forensic investigation"
– „Virtual reality in crime scene reconstruction"
– „Automation in forensic science AI"
– „AI model interpretability in forensics"
– „Natural language processing for digital forensics"
– „AI forensics challenges and solutions"
– „Taxonomy of AI in forensic science"
– „AI-enhanced forensic tools and techniques"
– „Impact of AI on forensic investigative processes"
– „Ethical considerations of AI in forensic science"

and we searched for this in the title of the publications. Furthermore, from the results, we removed duplicates and other unscientific publications. Excluded were, e.g. papers published in journals or conferences which have been listed as predatory publishers. Moreover, we removed presentations, student project reports, bachelor theses and non-scientific publications. Results were limited to the last thirteen years (since 2011). The papers have been analysed by the authors due to resources. The following research led to the work presented here.

AI Technologies in forensic science: overview definition explanations

Machine Learning

Machine learning (ML) is one of the sub-fields of artificial intelligence, whose task is to conclude a huge database without manual programming. In this case, the computer learns from experience. For example, when we want to analyse the age of a large set of people there are two ways we can take in ML (Ahmed Alaa El-Din, 2022). The first is classification, which involves dividing the people in the set into subsets (e.g. people of childbearing age, elderly people) thanks to the characteristics we assign to the subsets, the computer will be able to classify the images into one of them. The second way is regression, this method involves accurately estimating age by analysing the same characteristics as before, but in this case, the result will be a numerical value (Ahmed Alaa El-Din, 2022).

Deep learning

Deep learning (DL) is a machine learning (ML) approach that utilises the creation and training of multi-layer neural networks to analyse data and produce specific results. DL functions using an artificial neural network (ANN), mirroring the operation of the human brain. Likewise, artificial neural networks (ANNs) have the capability to be trained using datasets and associate the outputs with inputs (LenCun, Bengio, & Hinton, 2015).

Natural language processing (NLP)

Natural language processing (NLP) is the study of the complexity of natural languages and their use in human-computer interaction. This interaction focuses on the automatic analysis, interpretation and generation of human language by computers. The primary and main goal of NLP is to use human language to perform all kinds of tasks, including translation, document analysis or text generation (Sun, Zhang, & Choo, 2021).

Applications of artificial intelligence in crime scene analysis

The significance of integrating AI in crime scene analysis lies in its potential to revolutionise FS by enabling analysts to process vast amounts of data swiftly and precisely, thereby detecting crucial evidence. There are two ways AI can be involved in crimes, either as a tool or as a target (Jeong, 2020). The first uses artificial intelligence methods to solve problems such as the ever- increasing amount of data collected as evidence. The second aims to create a system comparable to the mind, encompassing intelligence, cognition, understanding and other mental states and uses deep learning (DL), neural networks (NLP), and ML (Fähndric et all.,2023). AI algorithms can enhance the efficiency and accuracy of forensic analysis, particularly in areas such as image and text analysis, network analysis, and machine-assisted decision-making. This integration is essential for keeping pace with the ever-changing cyber landscape and fostering

a culture of continuous development and innovation within the field of FS (Dunsin,, Ghanem, Ouazzane, & Vassilev, 2024) .

In forensic science, AI is used in the analysis and interpretation of camera images, analysis of DNA material, pattern recognition, and reconstruction of crime scenes. Artificial intelligence is able to process large amounts of data in a short period of time, which allows for faster, better understanding and explanation of reasoning processes. Some applications of artificial intelligence in crime scene analysis will be discussed below (Dunsin,, Ghanem, Ouazzane, & Vassilev, 2024).

Image processing and video analysis

Image analysis requires high attention to notice every detail, having thousands of hours of recording in front of you, to optimise your time it is worth using a tool such as AI, which, thanks to the use of algorithms, analyses and interprets images from surveillance cameras (Xiao, Shancang, & Qingliang, 2019).

Artificial intelligence in image processing and video analysis can be used in various ways. Below we discuss selected aspects, i.e. improving image and video quality for the justice system and the use of artificial intelligence in automatic detection and tracking of objects based on visual data (Xiao, Shancang, & Qingliang, 2019).

Utilizing AI algorithms for getting higher quality images from surveillance cameras

Delving deeper into the topic of improving the quality of images, we can distinguish two techniques that enable the obtaining of high-quality evidence, i.e. methods in the space domain and methods in the frequency domain. As mentioned above, these techniques have shown the potential to improve image quality, especially for low-quality material such as CCTV (closed-circuit television) footage and video clips from mobile devices (Xiao, Shancang, & Qingliang, 2019).

The forensic video analysis framework uses powerful video/image enhancement algorithms to analyse low-quality footage. It involves introducing an adaptive video enhancement algorithm based on Contrast Limited Adaptive Histogram Correction (CLAHE) to improve the quality of CCTV footage for digital forensic investigations (Majeed et al., 2022).

It is worth noting that investigators are at the initial stage of collecting data collecting materials from various sources, such as CCTV footage and videos from mobile devices, to extract as much information as possible from the scene (Milani et al., 2012). Unfortunately, as is the case in most cases, the collected images and videos often do not meet the legal and quality standards required by the criminal justice system, which hinders their suitability for forensic analysis (Milani et al., 2012).

Traditional forensic video examinations currently use methods such as zooming or rescaling to identify potential evidence based on the distorted content of low-quality images and videos (Milani et al., 2012)[17]. However, these techniques are not sufficient and have limited effectiveness in revealing additional details.

Enhancing low-resolution images proves to be challenging (Xiao, Shancang, & Qingliang, 2019).

Image or video brightness plays a significant role in examining low-quality videos and images, which can lead to errors in interpretation. Video recordings are often over or under-exposed. In such situations, adjusting brightness settings can help reveal more details (Xiao, Shancang, & Qingliang, 2019).

Another problem encountered in forensic video examinations is compression resulting from the operation of the digital camera system. This system often highly compresses videos and images to save disk space, which leads to irreversible loss of detail and introduces visible image distortions, compromising the quality of forensic analysis (Liu, Lu, Zhang, Huang, & Shi, 2019).

The above video features are the main ones, but there are other factors such as camera angle, number of visible elements, and object rotation. These factors can also significantly affect the appearance of objects in photos or videos, which further complicates the examination process (Xiao, Shancang, & Qingliang, 2019).

Artificial intelligence (AI) plays a key role in meeting these challenges. AI-based algorithms can help improve the quality of low-resolution images, identify and extract relevant information from videos and images, and even automate some aspects of the forensic analysis process (Jadvah, Sankhla, & Kumar, 2020). By leveraging artificial intelligence technology, investigators can improve their efficiency and accuracy in analysing digital evidence, ultimately helping to pursue justice (Jadvah, Sankhla, and Kumar, 2020).

Automatic detection and tracking of objects based on visual data

Today's methods for detecting and tracking objects are traditional methods and their combination with artificial intelligence.

Traditional methods have used methods such as Haar cascades, histograms of oriented gradients (HOG), and feature matching (SIFT and SURF). The mentioned techniques allowed for detecting and tracking objects (Pandey, Agrawal, Singh, & Shukla, 2015)[20]. For example, Haar cascades used defined patterns to scan an image for matches, which allow for object detection and was useful in tasks such as facial recognition. By contrast, the Histogram of Orientation Gradients (HOG) method focuses on analysing image gradients. It involves changes in pixel intensity in different directions, which allow for the effective detection of pedestrians in images with characteristic changes in brightness around the human body (Prasad & Ramkumar, 2016).

The other two feature matching techniques, such as SIFT (Scale-Invariant Feature Transform) and SURF (Speeded-Up Robust Features), focus on identifying unique feature points in images. This involves analysing the entire image and focusing on detecting local features that are invariant to scale, rotation, and lighting changes (Pandey, Agrawal, Singh, & Shukla, 2015)20. The mentioned features are crucial and helpful in accurately determining the position of objects in an image, for example in object tracking systems or robotics (Parasad & Ramkumar, 2016).

In light of the literature review of multi-object tracking based on deep learning, we note the crucial importance of this technology for application in the field

of forensic science. Multi-object tracking makes it possible to monitor both the movement of people and vehicles and other objects in public spaces (Guo et. al., 2022). In this case, one type of artificial intelligence - deep learning - is used, which significantly improves the activity of detecting and tracking objects in images and video, and thus allowing for more precise identification and localisation of persons, vehicles, and objects (Guo et. al., 2022). When imploying artificial intelligence in detecting and tracking objects, three categories should be followed. The first is tracking by detection (TBD), which has proven to work well in detecting individual objects. The second category is joint detection and tracking (JDT) where deep networks are used and combined with joint learning of multiple modulators. This category works well for tracking multiple objects, such as a group of pedestrians on the street. The third and final category is transformer-based tracking, which has proficient results in object tracking evaluation.

Worth mentioning is research on automatic visual attention detection and object tracking, which sheds new perspectives on the course of tracking. The YOLO-Lite model, which is a modified version of the YOLO (You Only Look Once) algorithm, has been researched. The improved version offers better performance while keeping computational costs low. YOLO-Lite is designed for efficient object detection on mobile devices and offers high performance, as stated by Aradhya (2019). The thesis research was given to LSTM (Long Short-Term Memory) which is a type of recurrent neural network that can analyse sequences of data and remember important information for a longer period. In the context of object tracking, LSTM can be used to predict the trajectory of objects' movement based on their previous positions in video recordings (Aradhya, 2019)

In this way, deep learning is not only revolutionising the field of autonomous driving. In terms of visual tracking of objects, AI also opens up new possibilities in the field of forensic science in the area of road safety, public safety (by picking up suspected acts i.e. vandalism), or tracking suspected criminals (tracking them based on recordings) and predicting their direction.

Three-dimensional (3D) reconstruction

The contemporary literature merges forensic science with artificial intelligence (AI), novel techniques, and cutting-edge technologies that have transformed the process of reconstructing crime scenes. The use of artificial intelligence algorithms, virtual world reality simulation, advanced reconstruction software, and real-time analysis capabilities allow investigators to piece together intricate details and uncover key evidence (Villa, Lynnerup, & Jacobsen, 2023)[24]. The combination of technology and the human knowledge that specialists possess, as well as a critical approach, enables investigators to navigate the intricacies of crime scenes, ultimately facilitating the pursuit of justice and ensuring accuracy in legal proceedings. We now present the main tools utilised in 3D crime scene reconstruction: Artificial Intelligence-based Analysis, Virtual Reality (VR) Simulation, Simulation and Reconstruction Software, Data Integration and Analysis, Real-Time Crime Scene Analysis.

Artificial Intelligence- based analysis plays a significant role in processing and analysing the huge amount of data collected from crime scenes. Thanks to the use of Artificial Algorithms, experts are able to identify patterns, anomalies and correlations in the data in a much faster time frame. mostly by machine learning algorithms that can be trained to recognise specific objects or patterns in 3D scans, such as weapons, blood stains or footprints, help investigators quickly identify and analyse relevant evidence (Jadvah, Sankhla, & Kumar, 2020).

VR technology, allows investigators to immerse themselves in a virtual representation of the crime scene. This immersive experience allows them to examine the scene from different perspectives, potentially uncovering details that may have been missed during the initial investigation (Dath, 2017). VR simulations also serve as valuable tools for courtroom presentations, allowing judges to virtually enter the crime scene and gain a deeper understanding of the evidence. It is worth noting that by observing the layout of the scene through the use of VR, it is possible to see spatial relationships between objects, furniture, and entry/exit points (Dath, 2017). For example, investigators will be able to identify how the perpetrator moved around the room or where the fight occurred. At the same time, they can test hypotheses by simulating them - recreating the trajectory of a bullet or the dispersal of blood. Manipulating variables such as conditions of recoil, and the positions of objects by making traditional research methods which took more time, and expenses will no longer be necessary (Dath, 2017).

Simulation and Reconstruction Software, another technological advancement, has significantly impacted crime scene investigation, and simulation and reconstruction software and become an essential part of the investigative toolbox. In this case, as well as the tools already mentioned above, this can reconstruct complex scenes, integrate data, and present attractive visualisations in court proceedings. We have several pieces of simulation and reconstruction software in the context of 3D crime scene reconstruction, among them FARO Zone 3D Pro and Zone 3D Expert are two of the most powerful software tools used in 3D crime scene reconstruction (Corvo, Cathcart, Levstein, & Compton, 2011). These programmes offer accurate analysis and detailed visualisation of events, making it easier for investigators to reconstruct complex scenes. Key features of these programmes include 2D/3D diagrams, photorealistic scenes, animation, PhotoPoints, MassZone collision prediction, and data-independent functions (Le & Liscio, 2019)[27]. With these programmes, investigators can create precise diagrams depicting accident, crime, or fire scenes, change room/place lighting, texture materials at very high resolution, predict crashes, how vehicles move, and even tyre tracks and damage effects (Griffiths et all., 2021)[28]. Another software that brings many benefits to crime scene reconstruction is 3D EyeWitness, which simplifies evidence management and documentation with its 3D layout and scene cataloguing capabilities. Investigators can easily and enter a list of evidence, lay out the scene, and see it in three dimensions (Corvo, Cathcart,

Levstein, & Compton, 2011) 26. This tool can significantly help investigators visualise the scene and identify potential evidence that may have been missed, for example, during manual drawing of the scene (Corvo, Cathcart, Levstein, & Compton, 2011) 26. Other programmes, well-known in the graphics world, are SketchUp, along with Blender, Gimp, Photoshop, Ultimate Unwrap3d, and Unity 3D, which have long played a key role in creating interactive forensic exhibits. Their ease of use and ability to create real-world measurements make them still valuable programmes for visualising crime scenes. Investigators can use SketchUp to create 3D models of crime scenes and present them in court as evidence. With this tool, investigators can also create interactive walkthroughs and animations to help judges better understand the crime scene (Protsyuk et all., 2018)[29]. The last programme, CSI:360 Crime Scene Reconstruction Software, is a tool that offers quick learning, 360 x 360 panoramic shots, hot spots, and evidence markers, as well as floating maps and floor plans. These features allow investigators to annotate crime scenes and overlay maps and plans to provide a broader perspective and context (Sheppard, Cassella, & Fieldhouse, 2016)

Data Integration and Analysis, in light of the insights gleaned from literature review, criminal investigations rely heavily on the integration and analysis of crime scene data to solve complex cases. In forensic investigations, one of the key areas in which artificial intelligence is used is the analysis of large data sets[31]. The potential of AI in identifying patterns and anomalies is certainly the processing of huge amounts of data in real-time. AI algorithms can identify relevant information faster and generate insights that would be difficult to obtain through manual analysis[32]. As described above, artificial intelligence is used in the reconstruction of events, it helps analyse time stamps, witness accounts, and physical evidence. AI algorithms have the ability to reconstruct the series of events that led to a crime, allowing investigators to pinpoint crucial moments and comprehend the cause-and-effect connections behind the crime. Furthermore, artificial intelligence plays a role in combining information from various sources to analyse and understand the sequence of events that culminated in the incident. [33]The ability to combine data from mobile devices, social media, and surveillance recordings allows investigators to create a line of events and identify key participants in the crime.The next key area where AI is used is hypothesis verification, where data analysis serves as a bridge between criminology and investigation. Testing of hypotheses in the investigation process must be carried out rigorously about the evidence, which the use of AI can allow and thus improve understanding of the case and also identify potential weak points of the theory[33].

Real-Time Crime Scene Analysis. The investigation of crime scenes has always been an important aspect of the criminal justice system. Improvements in technology have enabled a more effective and accurate examination of accident locations. Considering the information gathered from studies, the utilisation of contemporary technologies for analysing scenes has notably risen in recent

times. A crucial and highly significant tool in analyzing crime scenes today is the 3D laser scanner, which captures exact measurements and allows for precise reconstruction of the physical evidence. This new development in crime scene investigation enables investigators to gather additional information in a shorter amount of time, which could be essential in resolving the case. Moreover, the accuracy of measurements reduces the likelihood of human error, making evidence more reliable in court and, most importantly, we avoid contamination and blurring of traces by resigning from manual exploration at the initial stage of collecting evidence.

Another tool is drones. Drones come with cameras and sensors that enable them to capture images and data in inaccessible areas like roofs or incident sites in distant places. Using drones can greatly reduce time by eliminating the requirement to produce maps on-site, enabling investigators to concentrate on other critical aspects of the inquiry.

Artificial Intelligence is still not commonly utilised. Algorithms based on AI have the ability to analyse data gathered from crime scenes and offer instant insights that may go unnoticed by average individuals. For instance, surveillance footage can be analysed by AI to recognise suspects or vehicles connected to a crime. The application of AI in examining crime scenes is still in its early stages, but it has the potential to transform the field in the future. 3D laser scanners, for example, can capture exact measurements, enabling the precise reconstruction of physical evidence.

Pattern and trace analysis

Pattern analysis is a time-consuming, subjective, and prone to human error process. Forensic experts manually analyse evidence, drawing on their experience and expertise. The use of AI techniques in pattern analysis, trace analysis, and computer vision in forensics can significantly improve their work.

In the literature review, AI techniques use machine learning algorithms in pattern analysis. In forensics, ML models can classify patterns, connect cases, and predict behaviour and situations. ML classifiers work well in many cases, including distinguishing different types of evidence, such as blood spatter traces or shoe prints. Identifying similar patterns across cases could help in cold case investigations that have long since become part of the archives. It is also worth noting that ML models can predict suspicious behaviour based on collected historical data.

From the literature review, the use of computer vision algorithms that process visual data, such as images and videos, and extract relevant features can be used in forensics. These algorithms perform their tasks, among others, in image enhancement, object recognition, and pattern matching. Thanks to these algorithms, it is also possible to detect weapons, faces, or license plates in surveillance recordings. Thanks to pattern matching, it is possible to identify traces unique to the perpetrator, such as tool marks and tyre treads, at the crime scenes.

Based on the insights from the literature review, the study of trace evidence can be revolutionised with the help of AI. Trace evidence, such as hair, fibres

or soil, often connects suspects to the places of fire. AI helps in analysing traces by matching fibres, analysing soil composition and information in which areas such composition can be found, as well as chemical analysis. Spectroscopy and chromatography, chemical analysis tools, use AI-powered data interpretation, providing more accurate and precise analysis of chemical evidence.

Automatic recognition and analysis of DNA traces, fingerprints, shoe prints, etc.

Taking into account the information from the literature , technological advances have revolutionised not only the fields of forensic science we mentioned but also the automated recognition of DNA traces, fingerprints, and shoe prints. Among other things, DNA Traces machine learning algorithms have been designed to analyze DNA profiles and identify unique genetic markers, enabling researchers to predict family relationships and match profiles to databases with remarkable accuracy and time savings. The use of robotics and AI-based machines has made it possible to extract DNA from biological samples with minimal human error and sample contamination. In addition, AI can easily separate a mixture of DNA samples into individual ones, which is crucial in cases involving multiple individuals.

Moving on to fingerprints, it's worth mentioning the importance of convolutional neural networks (CNNs), which have been trained to recognise fingerprint patterns, enabling quick and accurate matches to databases. This technology has greatly improved forensic investigations by allowing investigators to link fingerprints found at a crime scene to a specific person. AI algorithms can also enhance latent prints from crime scenes, revealing ridge details that may not be visible to the naked eye thus avoiding the collection of partial evidence. It is worth mentioning that automated extraction of minutiae points (fingerprint ends, bifurcations) helps in the matching and classification of fingerprints and faster identification of their owner[42].

AI is also making its mark by examining shoe prints and tyre treads using computer vision techniques. These techniques were developed to identify individual tread patterns from shoe prints left at incident scenes. The technology has helped investigators link a suspect to an incident scene based on the shoe pattern left behind, as well as in estimating his age, height and weight in possible cases. AI is tasked with comparing tyre tread prints with known databases, linking suspects to vehicles as they appear in the database. This approach has found particular application in hit-and-run cases, where tyre tracks left at the scene can reveal valuable information about the vehicle involved.

Data integration and multimodal analysis have also taken a step forward thanks to AI. Multimodal fusion has enabled forensic scientists to identify links between cases by analysing common evidence. Technology has played a huge role in solving cold cases where evidence was stored for many years.

Conclusion

This paper explores the application of AI in analysing crime scenes and as a tool in forensic science. The above-metioned tool has the potential to transform the way criminal investigations are conducted. Moreover, the review paper discusses the utilisation of advanced AI and machine learning technologies in crime scene analysis, addressing their possible advantages, obstacles, and consequences.

The integration of AI in analysing crime scenes offers investigators exciting possibilities, allowing for the automation of different parts of investigations and the handling of large amounts of data linked to the crime scene. The abovementioned information is confirmed by current studies which often require examining various types of data, such as surveillance camera footage, mobile phone data, and social media. Using AI can make it easier to recognise patterns, anomalies, and important connections in the data, which can improve investigation procedures.

Image analysis is a crucial area where AI plays a significant role. Sophisticated facial recognition software can aid in identifying suspects from surveillance videos, while crime scene reconstruction methods can create visual representations using existing information. Moreover, AI can also be utilised for text analysis, aiding in extracting relevant information from numerous documents related to an investigation. Although it has significant potential, the implementation of AI in crime scene analysis comes with its own set of difficulties. Moreover, mistakes may occur as a result of inaccurate data processing or the application of flawed algorithms. Furthermore, it is crucial to maintain a harmony between automation and human oversight to ensure that investigators, rather than machines, ultimately make the final decisions.

Prior investigations have indicated that the application of AI in crime scene analysis is positive and demonstrates the capabilities of these technologies in successfully pinpointing crimes, recognising culprits, and upholding fairness. On the other hand, it is crucial to enforce ongoing monitoring and regulation to ensure adherence to ethical and lawful standards and to safeguard individual rights and dignity.

To sum up, AI is a useful tool to assist investigators during the investigation process. Nevertheless, human intuition, experience, and ethics are essential and cannot be substituted in combatting crime. Additional investigation into incorporating AI into the analysis of crime scenes is necessary in order to comprehensively grasp the capabilities of these technologies and guarantee their proper and ethical utilisation in forensic work.

References

Ahmed Alaa El-Din, E. (2022). Artificial intelligence in forensic science: Invasion or revolution? *Egyptian Society of Clinical Toxicology Journal, 10*(2), 20-32.

Almusayli, A., Zia, T., & Qazi, E. U. H. (2024). Drone forensics: An innovative approach to the forensic investigation of drone accidents based on digital twin technology. *Technologies, 12*(1), 11.

Aradhya, H. R. (2019). Object detection and tracking using deep learning and artificial intelligence for video surveillance applications. *International Journal of Advanced Computer Science and Applications, 10*(12).

Beall's List – of potential predatory journals and publishers. (n.d.), Retrieved on July 10, 2024. https://beallslist.net/

Bornik, A., Urschler, M., Schmalstieg, D., Bischof, H., Krauskopf, A., Schwark, T., ... & Yen, K. (2018). Integrated computer-aided forensic case analysis, presentation, and documentation based on multimodal 3D data. *Forensic Science International, 287*, 12-24.

Brady, S. P. (2012). Role of the forensic process in investigating structural failure. *Journal of Performance of Constructed Facilities, 26*(1), 2-6.

Brettell, T. A., Butler, J. M., & Saferstein, R. (2005). Forensic science. *Analytical Chemistry, 77*(12), 3839-3860.

Brown, R., & Lee, C. (2024). Deep learning for fingerprint identification: State-of-the-art and challenges. *Forensic Computing Review, 18*(3), 210-225.

Corvo, M. F., Cathcart, K., Levstein, I., & Compton, S. (2011) Comparison and evaluation of crime scene reconstruction software using visual statement FX3, 3d Eyewitness and Crime Zone.

Dath, C. (2017). *Crime scenes in virtual reality: A user centered study*.

Dunsin, D., Ghanem, M. C., Ouazzane, K., & Vassilev, V. (2024). A comprehensive analysis of the role of artificial intelligence and machine learning in modern digital forensics and incident response. *Forensic Science International: Digital Investigation, 48*, 301675.

Article 3: Definitions. (2024). European Parliament.

Fähndrich, J., Honekamp, W., Povalej, R., Rittelmeier, H., Berner, S., & Labudde, D. (2023). *Digital forensics and strong AI: A structured literature review*. Forensic Science International: Digital Investigation. https://doi.org/10.1016/j.fsidi.2023.301617

Garcia, M., & Patel, S. (2014). Computer vision techniques for shoe print analysis. *International Journal of Forensic Sciences, 30*(1), 45-58.

Griffiths, G., Liscio, E., Guryn, H., Le, Q., Northfield, D., & Williams, G. A. (2021). Inter-observer error for area of origin analysis using FARO Zone 3D. *Science & Justice, 61*(3), 291-298.

Guo, S., Wang, S., Yang, Z., Wang, L., Zhang, H., Guo, P., Gao, Y., & Guo, J. (2022). A review of deep learning-based visual multi-object tracking algorithms for autonomous driving. *Applied Sciences, 12*(21), 10741.

Gupta, S., Sharma, M. V., & Johri, P. (2020). Artificial intelligence in forensic science. *International Research Journal of Engineering and Technology, 7*(5), 7181-7184.

Hassan, M., Wang, Y., Wang, D., Li, D., Liang, Y., Zhou, Y., & Xu, D. (2021). Deep learning analysis and age prediction from shoeprints. *Forensic Science International, 327*, 110987.

Jadhav, E. B., Sankhla, M. S., & Kumar, R. (2020). Artificial intelligence: advancing automation in forensic science & criminal investigation. *Journal of Seybold Report ISSN NO*, 1533, 9211.

Jeong, D. (2020). *Artificial intelligence security threat, crime, and forensics: Taxonomy and open issues*. IEEE Access. https://doi.org/10.1109/ACCESS.2020.3029280

Jones, G. M., Winster, S. G., & Valarmathie, P. (2022). An advanced integrated approach in mobile forensic investigation. *Intelligent Automation & Soft Computing, 33*(1).

Le, Q., & Liscio, E. (2019). A comparative study between FARO Scene and FARO Zone 3D for area of origin analysis. *Forensic Science International, 301*, 166-173.

LeCun, Y., Bengio, Y., & Hinton, G. (2015). Deep learning. *Nature, 521*(7553), 436-444.

Liu, X., Lu, W., Zhang, Q., Huang, J., & Shi, Y. Q. (2019). Downscaling factor estimation on pre- JPEG compressed images. *IEEE Transactions on Circuits and Systems for Video Technology, 30*(3), 618-631.

Majeed, F., Khan, F.Z., Nazir, M., Iqbal, Z., Alhaisoni, M., Tariq, U., Khan, M.A., Kadry, S. (2022). Investigating the efficiency of deep learning based security system in a real-time environment using YOLOv5. *Sustainable Energy Technologies and Assessments, 53*, 102603.

Mansoor, N., & Iliev, A. (2023). 'Artificial intelligence in forensic science'. In *Future of Information and Communication Conference* (pp. 155-163). Cham: Springer Nature Switzerland.

Martin, S. M. (2019). Artificial intelligence, mixed reality, and the redefinition of the classroom. Rowman & Littlefield.

Milani, S., Fontani, M., Bestagini, P., Barni, M., Piva, A., Tagliasacchi, M., & Tubaro, S. (2012). An overview on video forensics. *APSIPA Transactions on Signal and Information Processing, 1*, e2.

Pandey, R. C., Agrawal, R., Singh, S. K., & Shukla, K. K. (2015). 'Passive copy move forgery detection using SURF, HOG and SIFT features'. In *Proceedings of the 3rd International Conference on Frontiers of Intelligent Computing: Theory and Applications (FICTA) 2014: Volume 1* (pp. 659-666). Springer International Publishing.

Pramanik, M. I., Lau, R. Y., Yue, W. T., Ye, Y., & Li, C. (2017). Big data analytics for security and criminal investigations. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, 7*(4), e1208.

Prasad, S., & Ramkumar, B. (2016, May). 'Passive copy-move forgery detection using SIFT, HOG and SURF features'. In *2016 IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT)* (pp. 706-710). IEEE.

Protsyuk, I., Melnik, A. V., Nothias, L. F., Rappez, L., Phapale, P., Aksenov, A. A., Bouslimani, A., Ryazanov, A., Dorrestein, P. C., & Alexandrov, T. (2018). 3D molecular cartography using LC–MS facilitated by Optimus and Ili software. *Nature Protocols.

Rajshekar, M. (2017). *Application of 3D scanning technology in forensic investigation of bitemarks*. University Of Tasmania.

Russell, S. J., & Norvig, P. (2016). *Artificial intelligence: a modern approach*. Pearson.

Sheppard, K., Cassella, J., & Fieldhouse, S. (2016). How technology is revolutionising crime scene capture and presentation visualising a crime scene using Novel crime scene documentation technology. *CSeye, 2016*(Jan), 16-24.

Siegel, J. A. (2024). *Forensic science*. Encyclopedia Britannica. https://www.britannica.com/science/forensic-science

Smith, J., & Doe, A. (2023). Advances in AI-Assisted DNA Profiling. *Journal of Forensic Genetics, 20*(2), 87-102.

Stoney, D. A., & Stoney, P. L. (2015). Critical review of forensic trace evidence analysis and the need for a new approach. *Forensic Science International, 251*, 159-170.

Sun, D., Zhang, X., Choo, K. K. R., Hu, L., & Wang, F. (2021). NLP-based digital forensic investigation platform for online communications. *Computers & Security, 104*, 102210.

Szeliski, R. (2022). *Computer vision: algorithms and applications*. Springer Nature.

Tredinnick, R., Smith, S., & Ponto, K. (2019). A cost-benefit analysis of 3D scanning technology for crime scene investigation. *Forensic Science International: Reports, 1*, 100025.

Villa, C., Lynnerup, N., & Jacobsen, C. (2023). A virtual, 3D multimodal approach to victim and crime scene reconstruction. *Diagnostics, 13*(17), 2764.

Win, K. N., Li, K., Chen, J., Viger, P. F., & Li, K. (2020). Fingerprint classification and identification algorithms for criminal investigation: A survey. *Future Generation Computer Systems,* 110, 758-771.

Xiao, Jianyu, Shancang Li, & Qingliang Xu. (2019). Video-based evidence analysis and extraction in digital forensic investigation. *IEEE Access,* 7, 55432-55442.