

TECHNOLOGY AND ITS POTENTIAL APPLICATIONS IN REVOLUTIONIZING CRIME SCENE INVESTIGATION PRACTICES

Prachi Singh, Prashant Kumar

“Technology will integrate police, forensics, jails, and courts, and will speed up their work as well. We are moving towards a justice system that will be fully future-ready.” Prime Minister, Shri Narendra Modi.

Abstract: Crime Scene Investigation (CSI) has witnessed a long era of technological advancements going past the boundaries of traditional methods such as manual photography and fingerprinting. The increasing complexity of Modern crime and the need for precise and irrefutable evidence have grown to fill the gaps in conventional investigation techniques. The paper will explore how emerging technologies 3D scanning, drones, robotics, and artificial intelligence, have revolutionized CSI practices. 3D scanning enables a complete and reproducible digital record of crime scenes; Drones enable aerial forensics as well as mapping; Robots aid in hazardous environments as well as laboratory automation. The paper further shows how AI improves the analysis of digital, biological, and physical evidence. For example, these might include DNA phenotyping, automated fingerprint matching, and ballistics analysis. The paper covers areas such as crime scene reconstruction using virtual reality and the application of LIME for creating transparency through object recognition in crime scene images. Additionally, it will include the role of IoT devices, blockchain technology, and cloud computing in evidence collection and preservation, as well as the chain of custody. This paper ends with several case studies that portray instances where technology has played a significant role in resolving complicated crime investigations, along with noting some of the challenges that come with the implementation of such technologies, costs, and training, among others.

Keywords- CSI, VR, Aerial Forensics, LIME, Alternative Light Sources

I. INTRODUCTION

The area of Crime Scene Investigation (CSI) has undergone a significant change. Now, CSI has transitioned from relying on traditional methods to advanced technologies. Traditionally, investigations depended heavily on manual processes like photography, sketching, fingerprints, DNA profiling, and basic techniques for evidence collection. Also, traditional crime scene evidence detection methods are time-consuming and prone to human error, which hinders crime scene investigation. However, the increasing complexity of criminal activities in the digital era, along with the growing requirement for robust and irrefutable evidence, has necessitated the use of sophisticated tools and methodologies. The increasing use of modern technologies in committing crimes these days requires parallel advancements in the tools and techniques available to law enforcement agencies to maintain an effective investigative capacity. Only through the use of these advanced technologies in Crime Scene Investigation can we combat the criminal activities happening these days.

The application of modern technologies enhances the caliber of crime investigations. The importance of using visually engaging technologies that can effectively communicate complex information to a non-technical audience, consequently facilitating a clearer understanding of the evidence and its importance in legal proceedings. The main objective of crime scene investigation is to accurately reconstruct the dynamics and circumstances surrounding a crime. The new technologies will be helpful for crime scene investigators in reconstructing a crime based on rapid identification information that will be received during the crime scene investigation itself. Technological advancements such as 3D scanning are crucial in achieving “crystallizing the Crime Scene Investigation” by providing a comprehensive and reproducible record of the scene. For instance, by using virtual reality, we can accurately recreate the crime scene, which is helpful for forensic experts or attorneys to tell the jury what exactly happened or what did not happen at the crime scene. This also provides a thorough examination and understanding well beyond the original inquiry.

The law enforcement organizations can do their job more efficiently by predicting the crime scene. The major concern in most of the security and surveillance systems is the difficulty of recognizing objects of interest in videos and photos. When it comes to determining fingerprints, identifying perpetrators, and comprehending crime scenes, digital photographs and videos play an important part in forensic science. Moreover, by analyzing the spotted object in the picture, we can extract vital information. Through this technique, we can retrieve meaningful data in various cybercrime scenarios.

This paper will begin with a discussion about the importance of effective Crime scene management and what are the negative effects of the Crime Scene Management is ignored. It will then address the challenges in current crime scene investigation and how advanced technologies are transforming crime scene investigations by improving accuracy, speed, and the ability to recreate and study complicated events. Finally, it will discuss the challenges associated with adopting these technological tools-such as high costs, the need for specialized training, and concerns related to data privacy. The issues must be addressed for these technologies to be used effectively and widely in forensic investigations.

II. METHODS AND MATERIALS

This paper thoroughly used literature review methodology to explore the transformative impact of advanced tech on CSI. The research involved the systematic identification, selection, and analysis of scholarly articles, research reports, case studies, and other relevant publications focusing on the application of advanced technologies such as 3D scanning, drones, robotics, and artificial intelligence in Forensic science. The materials which are used in this research paper include peer-reviewed journal articles, case studies and legal documents, conference proceedings, and presentations. The literature review focused on identifying the benefits, challenges, and ethical implications of adopting advanced technologies in crime scene investigation. The findings from the reviewed materials were synthesized to provide a comprehensive overview of the current state and future directions of this rapidly evolving field.

III. IMPORTANCE OF CRIME SCENE MANAGEMENT

A crime scene holds the same significance as crime does. The preservation of the crime scene is crucial to fair and unbiased proceedings in a crime to serve the ends of justice. As the trial begins in court, the forensic science starts at the crime scene. It is the place of foremost importance as it is the first place visited by the investigating team after the crime is committed. However, a crime scene that is poorly judged, mishandled, or inadequately investigated can result in the loss of crucial evidence, leading to an incomplete or ineffective investigation. Even when investigating crime scenes was largely dependent on the intuition and observational skills of the police. Their judgments were based primarily on visible clues, witness statements, and basic analysis. Or, compared to today's time, forensic science has transformed this approach. Modern-day investigations rely on collecting and analyzing evidence such as DNA, blood spatter, hair, fingerprints, digital traces, and ballistic materials, which are then examined in well-equipped forensic laboratories. The crime scene is a cornerstone of criminal investigations in either situation.

Let's understand the importance of crime scene management with two prominent case studies within Indian jurisdiction.

Firstly, in the Arushi Talwar Murder Case, initially, when police were called to the crime scene, the police mishandling of the crime scene resulted in contamination of the crucial evidence. While collecting the evidence, police labeled the blood stain of both victims wrongly, the fingerprint from the murder weapon was not collected by the police officer properly, without identifying police at some place dismissed blood stains as paan stains, which were wiped and cleaned. When these compromised samples were sent to labs, the results were confusing. Even police, at prima facie, did not seize the crime scene and allowed the media to take photographs, which contaminated the crime scene. The clothes the suspect wore were also not taken into custody at the initial point; they were confiscated after months. Victims sexual assault was not included in the post-mortem report, but Doctor later mentioned an open vaginal cavity and white discharge in his testimony. Due to various loopholes in the investigation and prosecution, the trial was not conducted effectively and largely relied on circumstantial evidence. This led to multiple outcomes and prolonged the judicial process. The crime, which was

committed in 2008, concluded only in 2017 . This case serves as a clear example of how the deterioration of crime scenes and the lack of technological resources and expertise in utilizing them can not only delay justice but also result in its denial.

Secondly, in Nirbhaya Gang Rape and Murder Case the crime scene was properly seized by police initially and no intervention was allowed by any outsider and media till the collection of all evidence. Forensic experts played a crucial role by giving a strong evidence of presence of accused at crime scene through the call records, the combination of digital and physical evidence through proper crime scene management in case has led to conviction of the accused, all accused were sentenced to death. This case highlighted how advancements in forensic technology are crucial to resolving complex and difficult criminal investigations .

When comparing two scenarios of crime scenes, the factor that cannot be ignored is that with the application of advanced technology, crime scene management has become more efficient and reliable. It helped to deliver justice in time.

IV. CHALLENGES IN CURRENT CRIME SCENE INVESTIGATION

The crime scene is prone to manipulation through human intervention if not assisted carefully; the lack of advanced technology poses serious challenges to the accuracy and effectiveness of it. The issue arises with the inadequate facility for the documentation of the crime scene. The backbone of any investigation is ensuring the preservation of the evidence, it helps to analyze the crime scene at later stage without the loss of any evidence, however in many cases investigators still uses the outdated method such as hand-drawn sketches which are usually based on the muscle memory of the victims which often leads to confusion, or CCTV footage that lacks clarity, high-resolution picture which fails to capture all the relevant information.

Another limitation is the lack of on-site chemical analyzers, which leads to the transport of samples over long distances to forensic labs, resulting in delays and evidence degradation. These labs are burdened with heavy backlogs, which slow the investigation process. The recent Delhi government report shows that FSL is facing staggering backlogs in serious criminal cases, with more than 7,000 cases pending in cyber forensic unit, over 5000 in chemistry division, and approximately 4000 cases in

biology department . According to a study by the personnel and administrative reforms department in Kozhikode, Ernakulam, and Thiruvananthapuram forensic labs are facing a significant backlog with 62,558 cases pending as of 31st March 2024. The report indicates the pending cases have doubled from 2012-13, showing a serious concern in a growing number of unresolved cases. As per the report, due to a lack of delay in analysis of the evidence, they are forced to store it in a forensic lab, and due to inadequate storage facilities, it often leads to degradation of samples such as DNA, compromising the evidence's integrity and admissibility in court. While examining the reason behind backlogs, the report identifies that the lack of human resources contributes, but notes that simply increasing manpower will not solve the problem. The lack of modern equipment hampers the timely processing of the evidence, which further affects the progress of the investigation .

Moreover, concern arises with frequent loss of micro-evidence such as blood, semen, hair due to the non-availability of ALS(Alternative Light Source), thermal imaging, and chemical sprays luminol, this type of technology can be found helpful while investigating Rape cases or murder cases, looking for examples of Badaun and Kathua rape case showed serious gaps in evidence collection due to the lack of such technologies. The Badaun rape case raised a concern as due to absence of luminol spray and absence of ALS the police investigation at initial stage could not trace biological material at crime scene which was crucial for confirming sexual assault. Later, when the bodies were sent to post-mortem, the initial examination was conducted by a person lacking experience in specific cases, which questioned the reliability of the reports. Subsequently, when the forensic test was conducted by the Centre for DNA Fingerprinting and Diagnostics (CDFD), no male DNA was found on the victim's clothes, raising doubts about the initial allegations of sexual assault . This case indicates that if the crime scene had been properly investigated with all evidence preserved and appropriate technical tools used, the DNA traces might not have been lost.

The absence of a digital tracking system undermines the chain of custody. The maintenance of the chain of custody forms a critical process of evidence documentation, it is necessary to ensure the authenticity of the evidence seized at the crime scene . Therefore, maintaining the chain of custody must be done professionally, and people in charge need to

maintain ethical principles also Advanced solutions like blockchain for securing Logging AR/VR to recreate crime scenes are currently not found in traditional crime scene investigations, which leads to courts deciding on verbal testimonies. Supreme Court in Malaichamy and Another. Vs. The State of Tamil Nadu declined the consideration of the evidence (offending article) as it was not kept under seal by the Investigating Officer . This case shows how vital evidence can be compromised or lost. Had there been a digitally integrated evidence management system, the offending article could have been analyzed at the crime scene, securely logged, and the report should have been submitted on time.

The problems are even more pronounced in Tier 2 and Tier 3 cities, where technological infrastructure is limited compared to Tier 1 cities. For example, the Nirbhaya case (Delhi, 2012) benefited from better access to forensic tools and urban infrastructure, whereas in the Hathras case in Uttar Pradesh, 2020, critical investigative resources were lacking, impacting the quality and credibility of the investigation. In Kathua Rape case as well due to lack of forensic lab in local areas the critical samples were sent to Delhi Forensic lab. Initially, the special investigation team could not prove charges against accused due to lack of timely forensic analysis, but later when DGP Jammu and Kashmir sought help from Ministry of Home Affairs regarding assistance from Delhi forensic Lab, then the samples were sent to Delhi forensic lab, whose report formed solid evidence against the accused. If a local forensic facility had been available, the SIT could have gathered and analyzed the evidence in the initial stage itself .

Investigators face numerous institutional challenges, one of the most critical yet overlooked factors in crime scene investigation that is often neglected is the efficiency of investigators in conducting crime scene investigation. The critical aspect ignored is that Police training programs often do not provide experience with modern crime scene technology, and during their training, they are not equipped with this knowledge. The only toolbox they are provided with is for collecting fingerprints and footprints, etc. Additionally, a lack of logistical support to the police station from the administration also affects the investigation .

As we acknowledge the mentioned factors, we find that the lack of technology poses challenges in crime scene investigation. In the next section of this paper, we will understand how

technology is transforming the current situation.

V. TRANSFORMING CRIME SCENE INVESTIGATION USING ADVANCED TECHNOLOGIES

Traditionally, the detection of crime scene evidence, such as weapons, footprints, and bloodstains, has relied on manual analysis conducted by forensic experts. This approach is not only time-consuming and labor-intensive but also prone to errors. Therefore, there is a clear and urgent need for more efficient and reliable evidence detection methods in criminal investigations. The integration of new technologies into crime scene evidence detection stands out as a powerful solution poised to effectively address these challenges.

A. 3D Scanning Technology

Three-dimensional scanning technology has changed the way crimes scenes are documented and analyzed. This technology uses laser pulses emitted from a scanner, which bounce back upon encountering surfaces, enabling the measurement of distances and the creation of a detailed 3D point cloud of the scene. Specialized software then processes this data to generate highly accurate 3D models, which can be visualised, analysed, and measured with exceptional precision.

There are multiple benefits of making use of 3D scanning in CSI. It helps in more precise and comprehensive documentation. It captures every detail of a crime scene with millimeter accuracy. This level of detail exceeds traditional methods like photography and manual measurements. The digital nature of these models enables investigators and experts to virtually revisit the crime scene for re-evaluation and detailed analysis months or even years after the incident. Furthermore, 3D scanning enhances crime scene reconstruction by facilitating the creation of accurate virtual representations for various analyses, such as bullet trajectory studies, bloodstain pattern analysis, and accident reconstruction. In the courtroom, these immersive and interactive 3D models provide judges and court officers with a clear understanding of the evidence and spatial relationship, improving the substantiation of forensic expert conclusions. Contrasting older methods, the 3D laser scanning is non-destructive, which ensures the originality of the crime scene and evidence remains intact while capturing all relevant data. Additionally, the speed of data capture with the 3D scanner is also

fast, saving valuable time during the investigation process.

The problem with this 3D scanning technology is the high initial costs associated with equipment, software, and specialized training. Also, Effective utilization of this technology requires skilled personnel for operation, data processing, and analysis, necessitating specialized training and expertise. The concerns of accuracy and potential for manipulation of 3D scan data in court can not be ignored, highlighting the need for proper explanation and context for juries. Due to its optical nature, 3D laser scanning faces limitations in measuring surfaces that are not in the scanner's direct line of sight, making it difficult to capture concealed or obstructed areas. Additionally, varying environmental circumstances, such as ambient temperature and lighting, can pose challenges in obtaining excellent scans, particularly in outdoor settings.

B. The role of Drones in Aerial Forensics and Mapping

Drones emerged as valuable tools in transforming crime scene investigation, especially in the realm of aerial forensics and site mapping. Drones offer a unique bird's-eye view. It allows officers to capture aerial surveillance and detailed images of large and complex crime scenes that might be difficult to document effectively from ground level. It is equipped with high-resolution cameras and advanced sensors. Drones can collect evidence and map crime scenes by capturing images and videos from multiple angles, which can then be used to create accurate 2D and 3D models of the scene using techniques like photogrammetry and LiDAR.

In accident reconstruction, drones provide a fast and comprehensive method for documenting crash scenes, aiding in the analysis of vehicle dynamics, and identifying potential contributing factors. Additionally, drones equipped with thermal imaging and multispectral cameras which is very invaluable in search and rescue operations. It enables the location of missing persons or human remains, especially in challenging terrains. Their versatility includes bomb detection and investigation, enabling assessment of potentially hazardous areas from a safe distance, as well as suspect tracking and apprehension by monitoring movements and identifying potential escape routes. As it provides a remote vantage point, drones enhance the safety of investigators by reducing the risk of contamination and exposure to hazardous environments.

The use of drones in CSI presents some challenges. The operating drones in low-light conditions cannot produce results effectively. It often requires supplemental lighting to capture detailed images at night. Operational capabilities of drones are also affected by weather and environmental conditions, such as strong winds or heavy rain. If an investigator wants to use video footage captured by drones as evidence in court, they must ensure its stability, quality, and admissibility. Technical issues such as damage to storage media, lack of GPS data in certain situations, and inconsistencies across different drone manufacturers can also pose challenges.

C. Robotics Systems for Evidence Collection and Analysis

Robots can play important roles in CSI. From evidence collection to laboratory analysis, it can be utilized to explore hazardous environments such as bomb threats or collapsed structures, to assess the scene and gather preliminary data. They can also be utilized for remote evidence handling in contaminated or inaccessible locations, minimizing the risk to human investigators. MABMAT, a Specialized robotic system designed to capture detailed photographic and video documentation of crime scenes in a 360-degree format. In forensic laboratories, robots can automate repetitive tasks such as DNA extraction and processing, which increases efficiency and reduces human error. The use of robots in CSI will enhance the safety of investigators by reducing their exposure to dangerous environments and potentially harmful substances. Robots can also increase efficiency and speed by automating time-consuming tasks both in the field as well as in the laboratories.

The use of robotics in CSI faces some challenges. The high costs associated with the development and deployment, operating these complex systems require skilled operators, raise ethical and legal concerns regarding the potential use of force, algorithmic bias, and accountability. Robots lack human judgment and understanding, which prevents them from making complex ethical decisions or comprehending the nuances of a situation. Furthermore, integrating robotic systems from various manufacturers can be difficult due to issues with standardization and interoperability.

D. AI-Driven Enhancement of Digital Evidence

Artificial intelligence can prove a potent means of improving the review and assessment of digital evidence in investigations. It can apply its algorithms over vast swathes of digital

information from images and videos, network traffic, audio recordings, and large datasets surface relevant knowledge and insights. In image and video analysis, AI can sharpen image quality; perform facial recognition; identify not only some specific objects but also the identities of people within footage; and help in reconstructing incidents captured by surveillance cameras. During cybercrime investigations, AI may analyze network traffic patterns for malicious activity to recognize malware on the network, trace imaginary financial transactions, or bring to light other indicators of cyber threats. Some other applications involve speaker identification using AI-powered audio analysis tools as well as transcription of recorded conversations.

The advantages that artificial intelligence has in the field of digital forensics are profound. It could actually save time on all the boring tasks and allow human analysts to pay more attention to the complex and critical aspects of the investigation. AI algorithms can perform data analysis at a speed that is not humanly possible; therefore, increasing expedition and efficiency in investigations. Also, since AI would minimize human error and bias in data analysis, overall accuracy and objectivity would be transferred to forensic findings. More importantly, better detection capabilities resulting from improved pattern anomaly recognition may reveal critical evidence otherwise considered trivial.

There are challenges and limitations, though. It must be noted that the performance of AI algorithms is highly contingent upon the quality and representativeness of training data. Any bias in the data used for training the models will perpetuate those same biases, if not magnify them, in analysis. There is little or no explainability in some AI algorithms that operate as a "black box," reducing concern towards explainability and transparency. The ever-evolving nature of cybercrime requires continuous updates and retraining of AI models to keep their performance at par with new threats and techniques. There also exist legal and admissibility challenges to forensic evidence from AI-driven analysis to meet established legal standards for admissibility in court.

E. Applications of AI in Biological and Physical Evidence Analysis

Beyond digital evidence, the other significant contribution of artificial intelligence is in the realm of biological and physical evidence within forensic investigations. DNA analysis not only involves traditional DNA profiling through AI,

but also the construction of a suspect's physical characteristics from those same DNA samples (DNA phenotyping) and complex kinship analysis provision. While automated fingerprint matching through AI algorithms will help improve latent print visibility as well as some unique features that human examiners are not able to notice, this is not an application area where humans are better than machines. In forensic pathology, AI will be used to speed up autopsy result analyses that might eventually lead to better accuracy in determining the cause and time of death. Another area where artificial intelligence is making inroads into forensics is ballistics analysis, which would include automating firearm identification as well as bullet comparison. Forensic toxicology can now take advantage of AI in the identification of drugs and chemicals from complex toxicological data on their concentrations in biological samples. Further, considerations of AI applications are now coming up for assisting in deception detection based on verbal and nonverbal cues during interviews with suspects or witnesses. In other application area within forensics, that is biomechanics, AI can help anatomically reconstruct body motions along with external forces associated with any event or accident. Nanomaterials serve as another area where analysis through AI helps in identifying molecular-level toxic gases, explosives, and drugs via data obtained from nanosensors. Raman spectroscopy is another field where drug detection and material identification are being improved by applying AI. Finally, geospatial analysis incorporates several applications where drone imagery and crime scene mapping data are being processed using AI algorithms.

AI is changing how different types of physical and biological evidence are seen by making difficult steps easier, adding accuracy, and allowing scientists to get more detailed information from samples. Old ways of doing forensic tests could take a long time and make mistakes. Now, big data can be looked at in new ways using AI so that patterns show up fast and right, giving good results. Adding new biological methods called "Omics" (like genomics, transcriptomics, proteomics, metabolomics, and microbiome analysis) with AI helps in a strong way to look at bio samples for forensic studies. These methods give huge amounts of tricky info; AI helps check this data for better understanding of the bio proof, like figuring out food history from proteomics or finding microbial signs for small piece evidence checks.

F. Using Virtual Reality in Crime Scene Investigation

Traditional methods like photographs, sketches, and written notes for documenting crime scenes have limitations in relation to accuracy, completeness, accessibility, and the potential loss of crucial evidence. To address these issues, we can use LiDAR scanning and virtual reality (VR) to enhance crime scene documentation. The system uses a LiDAR scanner to take 3D information of the crime scene; this data is worked on and turned into a virtual space using Unity. This lets officers look around the scene in a detailed and interactive way, find evidence, and see the spatial links between things more clearly. The VR system helps talk and work together with law enforcement professionals, helping to recreate crime scenes for courtrooms. There are three different ways of getting ready with data. The best way had to do with looking at the crime scene using a LiDAR scanner and next making it in Unity. The things in the scene are detected and labeled, and a mobile app is used to let investigators, forensic experts, and police officers see the virtual crime scene. Each officer can get their own virtual copy of the scene, which allows them to look into the matter on their own without compromising evidence.

G. Using Local Interpretable Model-Agnostic Explanations (LIME) to enhance object recognition in crime scenes

LIME (Local Interpretable Model-Agnostic Explanations) is one of the powerful tools for enhancing the transparency and effectiveness of machine learning models. The integration of LIME greatly improves the accuracy and reliability of automated recognition systems.

Object recognition in crime scene images often involves complex backgrounds, varied lighting, occlusions, and irregular object appearances. Traditional deep learning models such as Convolutional Neural Networks (CNNs) are highly effective at detecting and classifying objects. But these models are often seen as “black boxes” because their decision-making processes are not easily interpretable. Investigators and forensic analysts need not only results, but also a clear rationale behind model decisions, especially in legal contexts where evidentiary scrutiny is substantial. LIME solves this issue by generating visual and textual explanations for individual predictions made by any black-box model. It does so by perturbing the input data and observing the resulting output changes. LIME highlights specific regions in an image that importantly contributed to the model's recognition of an object. This allows analysts to understand whether the model is focusing on the correct features, such as the shape of a weapon or the

outline of a footprint, rather than irrelevant background noise.

By using LIME, investigators can validate the reliability of object detection systems. For instance, if a model identifies in an image a gun, LIME can visually show which pixels are most influential in that classification. If those pixels align with the contours and metallic texture of the weapon, the result can be relied on. And if not, the prediction can be flagged for review. This helps prevent false positives and guarantees that the recognition is based on evidence. Additionally, LIME allows for the creation of more robust models by incorporating feedback loops. Insights from LIME explanations can guide data labeling, model retraining, or feature engineering efforts. Over time, this iterative process enhances the object recognition pipeline, making it better suited for the complex environments typically found at crime scenes.

H. Use of Technology in evidence collection and preservation in Investigation

The sensor-equipped smart devices and artificial intelligence contribute to generating an abundant data pool for forensic investigations. This data comes from very significant devices such as smart appliances and wearable technology that play an essential role in event reconstruction and timelines. Having IoT devices, it can be simplified to extract information and analyze it while maintaining evidence integrity and protocol. The real-time data capture added by the IoT technology boosts accuracy, with securely stored digital information. The tampering or data loss risks are minimized; therefore, a more secure base is provided for any legal action to be taken. In addition, IoT devices support real-time surveillance and warnings; hence, investigators can follow actions, identify irregularities, or quickly react when there is a potential threat. An important functionality not only in terms of evidence preservation but also in chain of custody maintenance as well. Tools such as IoTScout are engineered for aiding in acquiring and storing network traces, which is important in legal cases involving digital evidence from IoT devices.

The varied nature of IoT technologies, as well as the lack of standardized forensic procedures, poses complexities in identifying, collecting, and analyzing digital evidence. Problems like varying protocols, data duplication, limited device memory, and heterogeneity are required to be addressed. To overcome these challenges, the development of standardized IoT forensic investigation frameworks is crucial.

Additionally, legal and ethical considerations related to privacy, data security, and the admissibility of IoT-generated evidence in court must be carefully considered.

I. Use of Blockchain and cloud computing in the preservation of crime scene evidence

The blockchain technology can be used to enhance the authenticity and safety of evidence by making improvements in collection, preservation, and analysis methods. Blockchain and cloud computing technologies align with the United Nations' Sustainable Development Goals (SDGs), especially Goal 16, i.e., which talks about "Peace, Justice and Strong Institutions" and Goal 9, which talks about "Industry, Innovation and Infrastructure."

Blockchain technology arranges data by storing it in chronological order within interconnected blocks, preventing modification or alteration. This ensures the genuineness and integrity of the data, maintaining a reliable chain of custody. Utilizing blockchain technology enhances accountability, transparency, and effectiveness in investigations. It is helpful in the systematic and secure management of data, which is essential for upholding national security and supporting investigations.

Cloud computing also plays a significant role in the acquisition and analysis of evidence. It provides a platform for online computing, facilitating evidence collection and storage. Cloud computing, by offering ready-to-use IT infrastructure over a network, reduces the need for costly hardware and software.

J. Alternative light sources/UV light

The fundamental principle in Forensic Science is Principle of Analysis, "The analysis can be no better than the sample analyzed". With the advent of technical tool such as ALS the crime scene investigation can become robust without undermining this fundamental principle. The use of ALS is crucial when the evidence cannot be detected through the naked eye, especially in cases of sexual assault, violent crime, or trace evidence collection. These are portable forensic devices that emit specific wavelengths of light, such as UV rays. ALS is non-destructive and non-evasive, which allows the evidence to be located without damaging it, and rapid scanning of a large area is possible. This technology also helps in revealing subdermal bruises or bite marks, especially when they are not visible to the naked eye. Bodily fluids like semen, saliva, urine, and sweat can be detected when placed under these light conditions. This becomes crucial in injury documentation in assault cases. The ALS improves the visualization of certain evidence, which can be viewed with the help of

a barrier filter, such as goggles, or colored filters, and can be later documented for court purposes with a standard digital camera equipped with an appropriate filter.

VI. CASE STUDIES

A. Kerala Police Solve Murder Through Forensic Phone Reconstruction:

In 2019, the body of a woman named Rekha Mol, after she had gone missing, was found. Her phone was deliberately dismantled and scattered by the accused as it contained the crucial evidence. Kerala police tried to recover and reassemble the shattered phone. It recovered all the pieces of the phone from the woods, river, and canal and sent them to the state police digital forensics lab. With the help of technical skills, Assistant Director A.S DEEPA put back together the broken smartphone. Deepa began by examining the motherboard, which appeared to be intact. She then purchased a replacement display unit for the Xiaomi Mi Max 2 and connected it to the motherboard to test whether the device would power on. She then used Cellebrite UFED (Universal Forensic Extraction Device) software, which is a digital extraction tool, to bypass phone security and extract inaccessible data, leading to the discovery of the crucial evidence- WhatsApp Messages, voice recording, photos, and videos. The evidence linked the victim to key suspects and confirmed the murder location and crime.

B. AI solved a triple murder case in Kerala:

This case showcases how technology helped the police in solving the murder case. In 2006, in the town of Anchal in Kollam district, a 19-year-old woman and her 17-day-old twin daughters were brutally murdered. The case was eventually registered in the police station, with an investigation spanning two decades, with little or no progress at all. As the development in the field of computer science went on, the forensic departments saw a merger with the developing artificial intelligence. About this, Kerala Police's technical intelligence wing re-investigated the case in 2023 using AI tools. It used AI-aided Facial Aging to create the aged versions of the old photographs of the suspects. Social media cross-referencing was done to match the AI-generated images. The police found a matching photo from a social media post made by one of the suspects. It successfully traced both the suspects who were found living in Puducherry with new identities. This case stands as a testament to the transformative potential of AI and Digital tools and their

invaluable contribution to the criminal justice system.

VII. CONCLUSION

The Crime Scene Investigation (CSI) field is being substantially redefined with new technologies not just updating old methods but also changing the previous ways of investigating crimes, analyzing evidence, and delivering justice. The inadequacies of traditional methods and lengthy crime scene investigations that are prone to human error have started displaying themselves more vividly when challenged by the increasingly sophisticated criminal activities in this digital age. There has been a demand for adequate unchallengeable evidence, which can only be produced through the use of advanced tools that will make investigations more accurate, as well as faster and better. The paper discussed several such technologies that have served to transform CSI. One example has been 3D scanning, which has brought within reach unprecedented levels of accuracy and completeness in crime scene documentation. This technology helps investigators and experts to revisit evidence long after the initial investigation to analyze it in detail. Drones give a unique aerial view, which allows effective mapping of large and complex crime scenes and assists in search and rescue operations. The robotics systems are proving invaluable in hazardous environments, reducing risks to human investigators and automating labor-intensive laboratory tasks. AI tools are improving the analysis of digital, biological, and physical evidence. It is improving images and video analysis. AI is also automating DNA profiling and fingerprint matching. Virtual reality also emerged as a powerful tool for crime reconstruction. Furthermore, the application of LIME enhances the object recognition system as well as addresses the issue of “black box” nature of some models. The Internet of Things (IoT), blockchain, and cloud computing are also playing an increasingly important role in CSI. The case studies in this paper demonstrate the transformative potential of these technologies. The way Kerala Police successfully reconstructed the murder case using forensic phone analysis and the application of AI in solving the triple murder case shows the effectiveness of technology in conducting investigations and bringing perpetrators to justice. However, the incorporation of advanced technology into CSI presents several challenges. The issue of high cost in acquiring and

implementing these technologies, specialized training required, and concerns regarding privacy, must be addressed within time. The problems related to data security, admissibility of AI-generated evidence in court, and algorithm bias necessitate careful consideration and establishment of appropriate safety measures. Despite facing various challenges, the benefits of technology in enhancing CSI are immense and undeniable. The advanced technology enhances the accuracy, speed, and efficiency of investigations. These tools help solve crimes and ensure fair justice. It is very important that, with the advancement of technology, law enforcement agencies embrace these innovations while keeping associated challenges in check. The future of CSI depends on the ethical and effective use of technology. This will create a more efficient, reliable, and prepared justice system for the future.