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Deploying Artificial Intelligence (AI) to support law enforcement agencies in crime scene analysis and management.

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Abstract

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"A crime scene" is pivotal in solving a crime as it holds info about the suspect (s), method (s) used to execute the crime, wound (s) inflicted on the victim, and related evidence.

Artificial intelligence (AI) can simulate human intelligence in machines, and with the state-of-the-art technology available today can play a considerable role in solving crimes. AI has the functionality to maintain visual perception information, object identification algorithms and spatial information related to objects of crime. This information could be utilized to analyse blood spatter patterns and perform wound analysis which could match it to objects of crime discovered at the place of the crime.

This paper will examine how using AI at a crime scene would reduce the probability of technicians not documenting evidence or overlooking evidence, as information documented via AI would preserve it. Reducing the quantity of technicians at the place of the crime will reduce the risk of crime site contamination and improve evidence safeguarding. It will eliminate the inevitability of revisitation of the site of the crime. Robots could be deployed to collect tangible evidence which could be linked to the AI system deployed at the crime site, again to reduce the number of technicians on site. Information on evidence that might have been overlooked during the primary investigation would be retrieved by reviewing electronic evidence.

AI and robotics will support the crime scene technician and not take over his role, as robotics are not that autonomous yet.

Deploying AI to analyse a crime site implies that crime site processing could be expedited, that the crime site could be released sooner, and the criminal be brought to justice more rapidly.

Key words: crime scene, robotics, AI

Introduction

Evidence being overlooked, contaminated crime sites, and contaminated evidence often lead to suspects going free, or innocent people going to prison. Contaminated evidence might not be identified immediately, and only uncovered later when a case goes to trial which could mean that copious amounts of money would have been wasted, should the case be thrown out, or a mistrial declared.

Likewise, wrongful accusations and convictions can place a strain on society and discredit the criminal justice system and be a huge embarrassment to a state or country.

The scope of this paper correlates to serious crimes where the deployment of robotics and Artificial Intelligence will add value to closing a criminal case rapidly and augment the safeguarding of evidence. Less serious crimes for example burglary, where there is no serious injury or loss of life is excluded from this document.

We shall examine briefly the various functionalities proposed which will assist law enforcement with the management and processing of a crime scene. Crime and crime scenes will be examined, and we will highlight the challenges that law enforcement personnel experience around this topic.

Evidence, and how it is collected, will be discussed, and how we propose to apply these technologies.

Technology Proposed

Robotics

"Robotics focuses on the study of robots, defined as machines that can be programmed to perform manual duties". (Encyclopedia.com, 2018) In our environment, a humanoid robot would be meaningless without its associated Artificial Intelligence software.

History of Robotics

Isaac Asimov, an American writer, who created the word "robotics", close on forty years ago, specified the "three laws of Robotics" or Asimov's Laws, which are:

1. A "robot may not harm a human or, through inaction, allow a human being to come to harm". (Salge, 2017)
2. A "robot must obey the orders given it by human beings except where such orders would conflict with the First Law". (Salge, 2017)
3. A "robot must protect its own existence as long as such protection does not conflict with the First or Second Law". (Salge, 2017)

These rules were published in his short story, "Runaround" during 1942.

The first modern robots

"An inventor from Louisville, George C. Devol, Kentucky, USA, invented a reprogrammable manipulator called *Unimate*" (Stanford, n.d.) and never had any success in selling it. "In the late

1960's a businessman by the name of Joseph Engleberger acquired it and turned it into an industrial robot. He is known as the Father of robotics". (Stanford, n.d.)

Almost ten years later, Charles Rosen from Stanford developed a robot called *Shakey*, a mobile service robot, which was more advanced then "*Unimate*". Shakey could move around "unfamiliar surroundings and respond to his environment". (Stanford, n.d.)

Rodney Brooks and Andrea Stein formed the COG humanoid robot project. They had the common goal of producing an android that could behave like a human.

The Honda Motor Company in 1986 completed work on the 'P-1' which was meant to coexist with humans.

Almost a decade later P-3, which resembled a suited astronaut saw the light. An Ethernet modem was utilized to facilitate communication. P-3 could through its visual system identify and walk up a set of stairs and restabilize itself when pushed over. (Nocks, 2019)

Humanoid Robot

The researcher proposes that "a humanoid robot" *similar* to Surena IV be utilized to perform the activities at the crime site. A team of more than 50 researchers under the supervision of Dr. Aghil Yousefi-Koma, Professor of Mechanical Engineering at the University of Tehran, developed Surena IV. (Wikiwand, n.d.)

Surena IV is able to walk (turn/side/backward), even on "uneven surfaces", is equipped with "face detection and face follow" functionality, "object detection and recognition" and can follow objects. Utilized "limitless words and sentences in smart scenarios using Text to Speech" (TTS) It is supported by ROS (Robot Operating System) which is "used for interaction between software and hardware". Gazebo software is used for manipulating tasks. (Wikiwand, n.d.)

Surena IV's soles are coated with custom force sensors and helps it step over uneven surfaces by adjusting the position and angle of each foot individually, which would make it ideal for use at a crime scene, as it will not contaminate latent prints or other forms of evidence. (Brad Bergen, 2021)

Drone Technology

"A drone is the most commonly used name that refers to any unmanned aerial vehicle (UAV). Technically, a drone can refer to any vehicle – even those that travel in water or land – that can travel autonomously". (pilotinstitute, 2020)

To 3D scan the place of the crime, the researcher proposes a drone from Exyn Technologies, a drone company, who developed a drone which is powered by ExynAI, and is capable of exploring a 3D volume (space), without a pilot in the loop, and capable of Level 4 Autonomy. One would only indicate the vicinity to be explored and ExynAI will fly itself without human intervention. It can fly visual-line-of-sight, wireless communications, or GPS. It is able to illuminate the smallest areas, can map up to 16 million cubic meters or 9 football stadiums in a single flight (exyn technologies , 2021). The drone needs to be Internet of Robotic Things compatible as it would be required to communicate with the humanoid robot.

Forensic Robotic Evidence Trailer

The researcher proposes that a trailer be converted to house all the equipment proposed and as such can be easily managed.

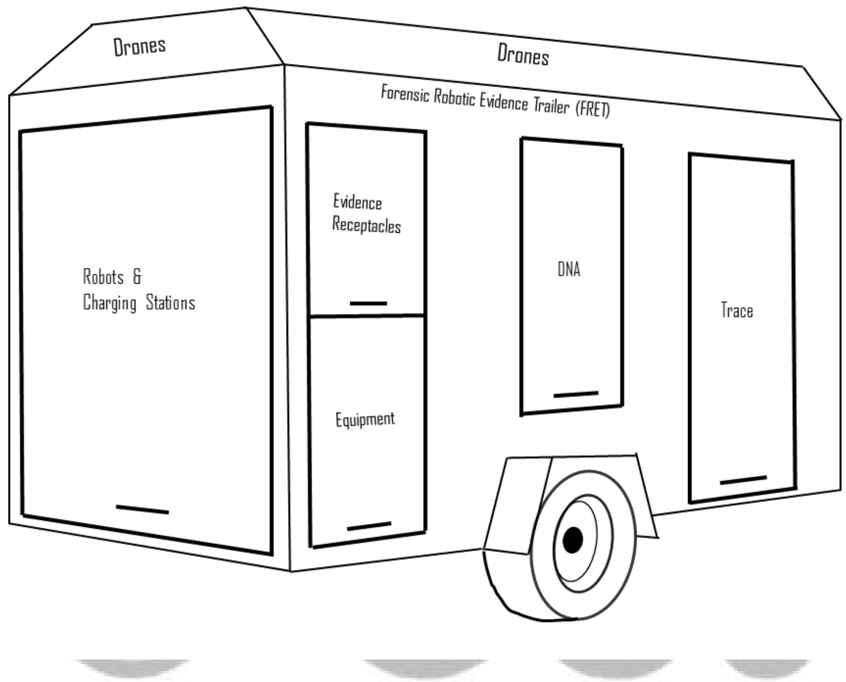

Figure 1 Forensic Robotic Evidence Trailer (FRET)

Artificial intelligence

How do we define Artificial Intelligence? Where better to get the information than first hand from the "founder of artificial intelligence", John McCarthy, who defined it as: "the science and engineering of making intelligent machines, especially intelligent computer programs. (McCarthy, 2004)

Coupled with the corresponding task of utilizing computers to comprehend human intelligence, Artificial Intelligence does not have to restrict itself to methods that are biologically observable. "During the Dartmouth College AI conference (1956) it was mentioned that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it". (McCarthy, 2004)

We will attempt to "make machines use language, form abstractions and concepts, solve kinds of problems now reserved for humans, and improve" themselves. (McCarthy, 2004)

Artificial Intelligent computer programs contain two basic mechanisms, a "knowledge base and inferencing capability", which means that it can draw "conclusions based on" prior knowledge and logic. "A knowledge base" stores information as answers to questions or "solutions to problems", and "programs are written" to enable "the computer to manipulate this information to make" judgements and reach conclusions. (Encyclopedia.com, 2018)

Pattern recognition

A division of Artificial Intelligence that is of particular interest to the researcher, and for this chapter is pattern recognition, which means that when "a program makes an observation it is often coded to compare what it sees with a pattern, for example, a vision program may try to match a pair of eyes and nose to find a face". (McCarthy, 2004) This functionality is especially relevant to our study as we would require forensic robotics to recognize and analyse blood spatter patterns, and DNA evidence, and decide to how process it.

Computer Vision

Computer Vision is another critical element which will be required to ensure the successful operation of the forensic robot as it analyses and evaluates visual information.

The onboard camera (J) will collect visual data which will be transmitted to the computer who will process the images, analyse it, and present the results on the selected output device. In the field of robotics, and to satisfy the designed goal of the robot, visual analysis is critically important (McCarthy, 2004). The on board camera should have 360 degrees field of view for spatial observation.

Internet of Robotic Things

"The Internet of Robotic Things (IoRT)" is the effective communication between automated devices and convey data over the existing internet. (Gabbi, 2015)

The robot that will be deployed at the scene of the crime will be at the centre of IoRT as it will manage the devices deployed at the scene, i.e. the drone(s), forensic storage receptacle etc.

Secure Cloud Services

All videos, photographs and related matter will be uploaded to the designated secure cloud for further processing by forensic staff. The case number will be utilized to create the cloud repository. Forensic team members would be granted access to the specific folder set.

Forensics as a service

"Anything as a service (XaaS) defines a broad category of services associated with cloud computing and remote access. Cloud computing technologies, offers vendor companies different types of services over the Internet or similar networks" (Techopedia, 2021).

Forensics as a Service (FaaS) is an existing service but limited to digital forensics as the researcher could find no evidence of it including any other branches of forensics, and therefore proposes that FaaS be further explored in order to include the non-digital branches like Forensic Podiatry, and Forensic Odontology.

The "Federal Bureau of Investigation" (FBI) owns and operates the "Violent Criminal Apprehension Program (VICAP)", a computer-system that collects "descriptions of crime scenes, victim, and offender data, including name and other personal identification related information, "criminal history records, crime scene photographs and statements. The data consists of cases involving homicides, missing persons, unidentified dead, sexual assaults, and other criminal" cases. (FBI, 2003)

The information collected by VICAP is used to "identify and match violent crime cases based upon certain characteristics, modus operandi and other criteria and will be utilized to examine, track, and detain serial offenders". (FBI, 2003)

Some serial killers leave behind a signature, and we could utilize information scanned at the crime scene to populate the relevant databases of law enforcement authorities in real time, and flag them to the effect, so that immediate action could be taken.

Management of the Crime Scene

What defines is a crime

No “universally accepted definition” of crime exists, however, in simple language we can define a crime as an act against the law, which is harmful “to an individual” or society. These acts are “punishable by law and the state”. “What constitutes a criminal act” is determined by the law of the country. In legal terms, an act will be “classified as a criminal offence” if “*actus reus*” (guilty act) is followed by “*mens rea*” (guilty mind)” (Excellence, 2021).

History of the crime scene

During the 19th century, crime site investigation was done in a haphazard way. Police were summoned to a scene once a suspicious death was discovered, followed by the doctor. The matter was then handed over to the coroner who arranged for a post mortem.

“Preservation of the crime site” was not thought of at the time and people trampled all over the scene. Potential evidence was removed and kept. The “body of the victim often remained at the crime scene” for extended periods of time until the coroner could arrange for the removal. It was common practice for the body to be cleansed so it was more palatable for the jury to view during the court case (Buckley, 2019).

William Augustus Guy, a professor of forensic medicine at Kings College in London published in 1844, an article in the first edition of “*Principles of Forensic Science”*, aimed at medical experts where he “trained doctors to observe the location of a body, its position, soil on which the body was laying, and nearby objects” (Buckley, 2019).

Sir Howard Vincent who was the "head of Criminal Investigation Department (CID) at Scotland Yard" (1881) published a set of specific instructions on "dead bodies" in the *Police Code and Manual of Criminal Law*. He emphasised that no one should touch the body before the police arrived, and not be moved until a senior official gave the go ahead. He also advised on footprint processing and photographing the body before burial (Buckley, 2019).

Hans Gross, "Austrian professor of criminal law", in 1893 published the "*Criminal Investigation: A Practical Handbook* which was translated into English in 1906". He and Edmund Locard laid "the foundations for modern crime scene" investigation. (Buckley, 2019) The handbook transformed "the location where a crime took place into a crime scene" and included "advice on the importance of evidence collection and preservation". Gross also introduced the crime scene sketch to plot location of items of evidence" (Buckley, 2019).

August Vollmer (USA) served as "Berkeley's Chief of Police from 1909-1931" and during those years was credited for:

- Insisting that fiber, soil, and blood samples be analysed to aid in the solving of a crime (1907),
- Opening the world's first police school where officers would learn "about the laws of evidence" (1907),
- Started using fingerprints to identify suspects,
- Suggested that "the role of police" should be "to prevent crime rather than solve it" (Dinkelspiel, 2010).

The first training courses for detectives was established in 1935 in the UK.

USLegal.com defines forensic evidence as: "*evidence obtained by scientific methods such as ballistics, blood test, and DNA test, and used in court, and can often help to prove the guilt or innocence of possible suspects"* (USLegal.com, 2021).

The implication of mishandled Forensic Evidence

How can forensic scientists make up for mishandled, contaminated, or unrecovered evidence? They cannot. If evidence is destroyed, it is destroyed, which could result in someone committing a horrible crime go free, or a jury sending an innocent person to jail.

Defining contaminated evidence

It is the unwanted "transfer of evidentiary material" from another source to a "piece of physical" evidence (NFSTC, 2013).

Biggest problems that crime scene technicians face at the workplace

Ask crime scene technicians to name the biggest problem that they encounter on the job, and you will consistently hear the same response—"crime scene contamination by curious officers, detectives, and supervisors" (Schiro, n.d.).

The major problem faced at "crime scene investigations" is extra non-essential personnel at the scene. Unfortunately, the "bulk of these non-essential personnel are often police" officers. (Schiro, n.d.).

“The first problem and the root cause of many other problems encountered in crime scene investigations, is the lack of administrative policies dealing with a specialized operation like crime scene preservation and investigation. Another major problem is the lack of communication at crime scenes” (Schiro, n.d.).

The manner in which mistakes are handled at a crime scene is a problem and this can lead to bigger problems, including perceptions of cover-ups and conspiracy. Mistakes at a crime scene are inevitable (Schiro, n.d.).

Not enough photographs taken at a crime scene is a problem that is also still encountered. The crime scene photographer has only one chance to thoroughly document it and should capture that scene and all evidence from as many angles as possible (Schiro, n.d.).

Realizing the impact and consequences that these actions might have, the researcher proposes that a robot and drone be deployed to undertake the majority of these tasks, including photography and videography. The photographic technology available today can take incredibly detailed photographs and will therefore mitigate the risk that insufficient photographs be taken. The drone that is proposed can record both video and still photographs, and as such will complement the degree of accuracy required to assist with the investigation.

Perhaps the manner in which crime sites are managed should be reviewed, and revised to accommodate modern day technology, for example, allowing a drone to access the crime site first and photo-, video graph as soon as the victim has been lifted from the scene.

Forensic Evidence in Court

Forensic evidence is important for resolving non-violent cases as well as the most violent and brutal cases.

The importance of forensic evidence in court is that science is objective and does not lie. A judge or jury is more likely to find favor with the side that presents compelling forensic evidence to prove a party's guilt or innocence (Bangerter, 2021).

Deoxyribonucleic Acid (DNA) evidence could be obtained from a decomposing body found in a forest, which could identify the person. Trace evidence could connect a possible suspect to the victim. Forensic evidence could convict a suspect after a "sexual assault case" (Bangerter, 2021).

You could find yourself in a situation where forensic evidence could absolve you from a crime, your life depends on it, and you would want to be sure that that piece of evidence has not been tampered with and will stand its ground during a trial, and not be thrown out as inadmissible in court as a result of contamination.

The crime site

A crime site is defined as a "physical location where a crime has been committed", which "may provide potential evidence to crime scene investigators". It could refer to a building, a vehicle, a person's body or anywhere else "where a crime has been committed" (Robertson, 2004).

In addition, entry or exit paths, areas nearby where evidence may have been discarded is also included in this definition. The crime scene can either be primary, or secondary, which refers to the "scene related to a crime, but not where the crime itself occurred". If a person is killed in one location then dumped at another, that dump site is a secondary scene (Study.com, 2021). In the next section we will discuss the importance behind protecting the scene of the crime.

The gravity of conserving the crime site

The primary reason for documenting the site of the crime first is that the search phase is extremely destructive. Once a crime scene is processed it will not be the same as items will be collected, and disturbed (Miller & Massey, 2016).

The “Locard Exchange Principle” forms the basis for the use of “physical evidence” in a criminal investigation, and it is of utmost importance that the “crime scene” be made secure, and access to it is restricted to prevent entry for nonessential people (Miller & Massey, 2016).

According to (Chiro, 2018), the most crucial phase of the “collection of evidence” and its preservation is the protection of the crime scene, in order to keep pertinent evidence uncontaminated until such time it can be recorded and collected. The effective prosecution of a case can pivot on the state of the physical evidence at the time it is collected (Chiro, 2018).

Baldwin mentioned that potential contamination “of physical evidence can” occur at the crime site, during the packaging, collection, and transportation of evidence to a secured facility or laboratory, and during evidence analysis and storage” (Baldwin & Puskarich, 2017).

“Lack of protective measures can result in the destruction of important evidence, and thus misdirect investigators and adversely influence the final result of the investigation. In the worst situation it may prevent the solution of the case or result in a wrong conclusion” (Crime, 2009).

Although there are a number of cases documented worldwide, the one that comes to mind is the murder case of six year old JonBenet Ramsey, where the former police chief of Boulder, Colorado admitted that there was insufficient evidence, and confirmed that the crime scene was mismanaged, which prevented the murder of JonBenet Ramsey from going to trial (Strom, 2020).

As we have established the criticality of crime site management, it is only logical that we examine the method of securing it, investigate and propose possible technologies that could aid law enforcement in accomplishing this critical phase of the crime site investigation.

Safeguarding the crime site

One can conclude from the earlier section that stabilizing "the crime site" is extremely important, (Pennfoster, 2014), which is normally undertaken by the First Responder or First Officer once they arrive at "the crime scene". Initially, he or she must call for backup, help the victim, and secure "the crime scene". (Armenta, 2018) However, if the victim is still alive, an "attempt should be made to take a dying declaration. Every effort should be made not to disturb the crime scene and to preserve it in as original a condition as possible" (Pennfoster, 2014).

Processing of the place of the crime is performed by the "crime scene" technicians or investigators, and *not* the First Responder, neither the First Officer on "scene". The First Responder has the responsibility to bring control to a chaotic situation, "the crime scene" (Gardner, 2012).

The crime scene should be cordoned off, implying that both the inner and the outer perimeter should be clearly demarcated (Chiro, 2018). Crime-scene tape, barriers, or officers could be used for this purpose (Donofrio, 2000).

A common approach path, which narrows down the area where crime site technicians could freely roam, should be established, and marked by the crime scene personnel in order to prevent contamination of the scene (Chiro, 2018).

Perimeter Security

Perimeter security, which is critical to the preservation of the crime scene, could be managed by using an UAV (Unmanned Aerial Vehicles) with video streaming to a control centre where law enforcement personnel could monitor people movement and immediate take action against perpetrators.

Unmanned Arial Vehicles (UAVs) equipped with motion sensors, and/or infra-red camera functionality that can intelligently detect objects or people in areas of limited visibility, for example forests, which would again reduce the burden of law enforcement, and reduce the risk of harm to law enforcement staff during search operations, especially when a suspect is on the loose (Lorenz Technology, 2021).

"Drone-in-a-box", which is a cost-effective and fully autonomous UAV that may well be deployed to manage perimeter security and will augment the operations at the crime scene as it deploys easily and is completely mobile (Easy Aerial, 2021).

By deploying this technology, one could reduce the number of law enforcement personnel at the crime scene and reassign them to more critical tasks and thus decrease the number of individuals that could potentially contaminate evidence. UAV's will be Internet of Robotic Things compatible and thus be able to communicate with the other IoRT robots deployed at the crime scene.

Entrance to Crime Site

Only authorized personnel should be allowed to enter the inner crime scene, and law enforcement officers on the scene should maintain a log of movement of crime scene personnel entering and exiting the scene (Pennfoster, 2014).

Artificial Intelligence and robotics technology should be deployed at the crime site by crime scene technicians, which can facilitate in the monitoring of people moving about the crime site.

The researcher proposes that robotic technology be deployed to undertake this task, in the form of ‘Pepper’, the robot. He will control access to the crime scene as he is equipped with facial recognition and can raise the alarm when unauthorized people accesses the scene. Having been equipped with Facial Recognition, he will be able to recognize authorized personnel and issue them with Personal Protective Equipment (PPE), and if anyone accesses the scene that does not wear Personal Protective Equipment (PPE) will raise the alarm. (GÉNÉRATION ROBOTS, 2021) He is configured with a touch screen tablet on the breast which could interact with law enforcement staff. The crime scene technical lead will configure Pepper accordingly and indicate who will be allowed to enter the crime scene.

Once the crime site has been stabilized and secured, crime site technicians can proceed to process the scene which is the subject of the next section.

Crime Site Processing

Before exploring crime site processing protocol, one needs to understand why a crime site is processed, and in summary, it is to understand what has taken place, to gather evidence and to ensure that justice is done eventually. (Ziets, 2013)

Crime site processing consists of the "examination and evaluation of the site for the sole purpose of recovering evidence and documenting the scene's condition *in situ*, or as found", ensuring as little as possible disturbance to the scene at the end. (Gardner, 2012)

Evidence Collection

Evidence collection is critical to the case as no matter which action a crime scene investigator takes, he or she has to defend that action in court, often two to four years later. (Oklahoma, 2015)

Recognizing the characteristics of the item will aid the investigator later when he or she begins looking at relationships and decides whether the item is foreign to the scene. The first consideration then is to recognize the item, if possible, and consider its use, function, or purpose at the scene (Gardner, 2012) and as most investigators are familiar with the forensic evidence linkage triangle, it will remind the investigator "that each item discovered must be considered a mechanism for linking the scene, the victim, or the suspect in some form or fashion". (Gardner, 2012)

"Each piece of evidence" must be considered against this triangle to determine whether that "piece of evidence" has evidentiary value. (Gardner, 2012) Deploying robotic technology which will be discussed below will relieve the crime scene technician from this duty and focus on other tasks.

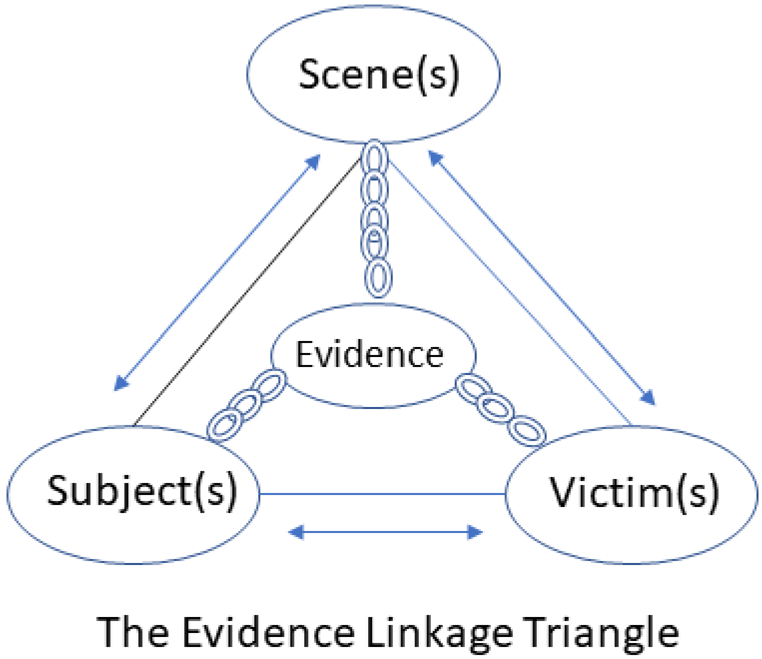

Figure 2 Evidence Linkage Triangle

Crimes are not instantaneous events as normally a criminal must approach the scene, commit the crime, and then leave the scene. (Gardner, 2012)

The Process

Various crime site investigation protocols have been documented but for the purpose of this chapter we will focus on the one as described in the book by Miller and Massey, "The Crime Scene, A Visual Guide" (Miller & Massey, 2016) which covers the following steps:

Establishment of the crime site security

Preliminary scene survey

The preliminary survey or walk-through of the place of the crime along with the detective or officer in charge should take place after the exchange of information, where relevant details pertaining to the case is shared, including but not limited to the case number, type of investigation and name of victim(s) and personal information. (Indiana State Police, 2020)

Once this step has been completed the crime scene investigator will formulate a plan to process the crime scene, which includes the actions to collect and preserve evidence, (Indiana State Police, 2020) and will decide on the search pattern that will be used, which is dependent upon whether it is an indoor or outdoor crime scene, and type, nature, and size of crime. (Boopesh, 2020)

The crime scene investigator will via his slate computer or tablet instruct the robot to use the appropriate search pattern (zonal, grid, spiral, wheel) and deploy the drone to scan and photograph the crime scene.

“The crime scene investigator” will proceed to take notes of the place “of the crime”, document evidence and the condition of it. (Indiana State Police, 2020) This task should not be seconded to a robot as they would not possess the necessary intelligence and knowledge that comes with years of experience in the field.

The robot will utilize its built in navigation system to navigate the crime scene. This functionality has been successfully tested using a “neural framework for robot navigation in a cluttered environment based on “sensorimotor” map learning”. It was tested in real time and navigation to different targets were achieved successfully in a home-like laboratory. (Yan, Weber, & Wermter, 2013)

The “sensorimotor map consists of”:

- a spatial memory "that learns the environment through" visual perception (Yan, Weber, & Wermter, 2013)
- an action memory for "learning actions associated with state transitions" in the spatial memory (Yan, Weber, & Wermter, 2013) and
- "an action layer that controls the robot's behavior based on the associated action input". (Yan, Weber, & Wermter, 2013)

The camera (J) installed in the robot will be utilized to extract the visual features from the environment around it and be processed for navigation purposes.

Normally at this time, the crime site investigator will make the call whether to deploy additional crime site personnel, or to call for additional crime site processing personnel, which could include blood spatter analysts and alternate light sources which would be used to identify trace evidence (Indiana State Police, 2020).

The researcher proposes that these tasks be undertaken by the robot deployed at the crime site and will be further elaborated on in the specific sections.

Evidence collection – transient evidence

Transient evidence, for example, shoe- and tire prints in melting snow, due to its temporary nature, should be processed first (Miller & Massey, 2016), followed by "trace evidence such as hairs, fibers, glass, soil, and plant material" as it may be used to associate an individual with a crime scene or another individual. (Indiana State Police, 2020)

Traditionally Dental Stone (a casting material) has been used to preserve transient evidence, or impression evidence as it is alternatively called, which could also include tool -, and bite marks. (Gardner, 2012)

Forensic sources recommend that Dental Stone should be allowed to dry for at least 30 minutes, (Latent Technical Leader, 2019) while another source has stated that drying time could be as much as 45 minutes in less favorable environments, like cold and wet weather, and ultimately 24 hours for moisture to evaporate from the casting. (McCutcheon, 2016) Both of these curing times leave the evidence in a vulnerable state and open to contamination as it is exposed to the elements.

To circumvent this lengthy drying process, and to guarantee that no harm is affected to the transient evidence, the researcher proposes that robotics equipment be used to perform a 3 dimensional (3D) scan of the shoe or tire print which can later be printed in a forensic laboratory and used as admissible evidence. (A) We will utilize a compatible Faro Technologies' 3D Laser Scanning Integration tool which has been successfully implemented on 'Spot', the robot, and as it is a handheld model it will work via the robot. (FARO®, 2021)

The camera unit of the 3D Scanner on the robotic should be equipped with a stabilized gimbal platform (C) which is vibration free as it is pointless to deploy robotic technology which introduces additional contamination which we tried to eliminate in the first place.

The robot should have a small footprint (B) so as not to contribute to evidence or crime scene contamination and should be equipped sufficiently to work alongside humans, and hence the researcher proposes the use of a robot which has been specifically designed for this purpose.

The robot should position and align the scale ruler onto the surrounding area of the print so that it reflects the actual dimensions of the print before the 3D scan commences. Evidence marker numbers should be selected by the robot from the forensics kit and placed next to the print that will be scanned, and then proceed to scan the print.

Once the scan has been completed, chain of custody[1] information will be generated by the robot and included in the electronic file that will be sent to the crime lab for processing.

The scanned image(s) should be sent instantaneously to one or all of the following:

- The SoleMate® database (UK) which "contains details of more than 42,000 items of footwear including sample shoe prints". (FPX, SoleMate, 2021)
- The Federal Bureau of Investigation (FBI's) footwear database that is a "computerized reference collection of more than 14,000 shoe outsoles from hundreds of different footwear manufacturers". (FBI, Forensic Science Communications, 2009) The researcher could not obtain more recent data; however, one can assume that this number would have increased significantly over the last decade.
- The SICAR® database, which is a shoeprint and tire tracks database could be interrogated to obtain information regarding prints found at the crime site. (Bureau of Criminal Apprehension, 2021)

The robot, which is equipped with networking capabilities (D) would assist the crime scene technician by obtaining rapid results from database queries enabling a head start in identifying these scanned prints, as they would already know which type of tire or shoe print they would be looking for, which can be communicated to the tablet or slate computer carried by the crime scene technician, who can take further action.

[1] The chain of custody is the most critical process of evidence documentation. It is a must to assure the court of law that the evidence is authentic, i.e., it is the same evidence seized at the crime scene. The chain of custody proves the integrity of a piece of evidence. (Badiye, Kapoor, & Menezes, 2021)

Complete or partial foot prints should be scanned, and the ratio (fraction or percentage of foot length is of height) can be applied by the robot to determine height of the person (Giles & Vallandigham, 1991) Research done by Giles and Vallandigham suggested that there is a biological correlation between foot length and height, with minor exceptions between different races.

To further assist the crime scene technicians on site, the robot should also determine whether the shoe print (full or partial) belongs to male or female. Research has proven that footprint measurements could be used as a determinant of sex (Kanchan & Krishan, 2014), and share this information electronically with the crime site technician.

The Artificial Intelligence module of the robot should be capable of analysing the data obtained from the scans and estimate the stature of a person from measurements obtained from a footprint and communicated to the crime scene technician. (Asadujjaman, Rashid, & Hossain, 2020)

Once all the scanned images of the transient evidence has been gathered and processed, it will be uploaded into the secure cloud so that the relevant forensic team has immediate access to the data.

Value of 3D Printed Evidence

3D printed evidence has already been used successfully in court during an English homicide trial. (Baier & Warnett, 2018)

Furthermore, 3D printing allows for a "juror to actually see or even hold a piece of evidence, which can have an extremely powerful impact on their understanding of an expert's testimony and ultimately on the outcome of the case". (Rahman, 2020)

An additional benefit to 3D printing is that no evidence bag is required at the crime scene, as the object of evidence will be printed off site and can therefore not be subject to finger print/shoeprint contamination.

As the robot will be sterilized and not contain any human DNA it is a contributing factor to the reduction of contamination. The footprint of the robot would not contaminate or superimpose its own shoe prints on those left by a possible suspect or victim, as it would not be compatible with human prints.

Assigning these tasks to robots should free up officers and crime scene technicians to tend to higher priority crime scene work, for example victim and eyewitness interviews, and thereby contribute to the quicker release of the crime scene.

Evidence collection – DNA

DNA could be found anywhere at a crime site, including those from law enforcement personnel, first responders, and the public illegally entering the crime site.

Possible sources of DNA should be identified during this phase of crime site processing, and any item that may contain or have been in contact with bodily fluids should be collected and preserved.

Care should be taken as DNA evidence could be “contaminated when someone sneezes or coughs over evidence or touches a part of their face and then touches the area of evidence containing DNA”. (Annapolis Police Dept, 2007)

Using a robot for DNA evidence collections purposes would reduce the risk of DNA contamination as they do not sneeze or cough.

Wet and dry DNA (blood, semen, and saliva) evidence is normally present at the crime scene. DNA evidence that is already in a dry state is very stable and can easily be processed. Should any DNA evidence be found that it not in a dry state it should be collected, and air dried, as Ultra-Violet light, extreme heat and high humidity might destruct the DNA molecule. (Genetic Technologies, Inc, 2015)

Bodily fluids are naturally fluorescent and by using a selected light source will easily identify DNA evidence. Technology exists that can be incorporated into the torso of the robot that will perform this task, for instance, the Mini-CrimeScope Advance. (SpexForensics, 2021) Alternatively, it could be carried in a backpack, and the light source could be configured so that the light emitting head could be easily reached by the robot. (E)

Once the DNA evidence has been located and identified, the robot will proceed to the specific location to determine whether the DNA is wet or dry and will utilize YOLOv3 ("You only look once" version 3) technology, which is a "real-time object detection algorithm that identifies specific objects in videos, live feeds, or images". YOLOv3 is a CNN (Convolutional Neural Network) (visio.ai, 2021) which is fast and accurate and can be trained to distinguish between wet and dry DNA, and it will complement the functionality of the light source. (F)

Based on the input received from the light source and object detection modules (YOLO), it will now select the correct disposable DNA collection swabs from its forensic kit (G) attached to the 'frontal pelvic area' and proceed to collect the evidence. The robot will package the dry DNA evidence in porous paper bags and wet DNA will be allowed to airdry before being packaged in the allocated container (H) which will be discussed below. Biohazard stickers will be affixed to bodily fluid evidence bags.

The robot will be equipped with a “BionicSoftHand Pneumatic robot hand with Artificial Intelligence”, and it will enable it to handle delicate equipment. (Festo.com, n.d.) It controls its movements via the pneumatic bellows structures in its gripper fingers. The thumb and index finger are additionally equipped with a swivel module, which allows these two gripper fingers to be moved laterally. This gives the bionic robot hand a total of twelve degrees of freedom (Festo.com, n.d.) which would be especially useful when tweezers are used to collect minute samples of forensic evidence. Once the evidence has been collected we would require a secure DNA evidence storage facility, and this is where our modified food delivery robot would come to good use.

The robot must be capable of discarding single-use equipment for collecting biological samples (hair/tissue/bones/teeth/body/other bodily fluids), for example tweezers and the resultant benefit is that there will be no cross contamination or transfer of DNA.

The allocated container mentioned above (H) in the form of a Food delivery robot, has been on the market for a number of years. It can easily be reconfigured to keep its contents cool and dry, instead of hot and humid, and be utilized as a DNA repository at the crime site. One such an example is the Starship Robots delivery robot. (Starship, 2018)

The cargo bay of the food delivery robot can be mechanically locked and opened only by the recipient with a smartphone application for example, and as the technology exists through The Internet of Robotic Things (IoRT), the robot is able to command and control the Starship robot (IoT Times, 2019) and would by implication be able to open it to receive evidence and afterwards close it, thus, securing the DNA evidence, and reducing the risk of evidence being contaminated, damaged, or removed.

The researcher suggests that the evidence repository is equipped with a Quick Response (QR) code reader linked to the locking mechanism, which will open the lid once it reads the QR code, receiving the envelopes that contain the evidence. All these measures will contribute to the safeguarding of evidentiary material.

The evidence cardboard box located inside the receptacle will be sealed by the robot once the crime scene is released, or the box is full. A tamper proof QR code label will seal the evidence box.

When the evidence receptacle senses that it has been loaded to capacity, it will signal the robot accordingly, and return to the forensics trailer and dispatch an empty one to the crime scene. All this communication would be possible as a result of the Internet of Robotic Things modules.

Information which should appear in the evidence log, will be electronically updated by the robot. All relevant information that is required by law to maintain chain of custody shall be converted into digital format and embedded in a QR code, which the robot will print via its QR code printer (K) and affix it to the evidence envelope.

Evidence collection – Trace evidence

Macroscopic evidence (Trace evidence) "should be collected from an area prior to being dusted for fingerprints otherwise it might cause damage to potential evidence". (Robertson, 2004)

Trace evidence is described as "any small piece of evidence that can be collected at a crime site" by the crime site technician, and normally includes, but is not limited to hair, fibers, glass, soil, blood flecks and skin. (Claridge, 2021)

Trace evidence (hairs/fibers) should not be removed from an object, but sent to the lab as is, where possible. The fact that the trace evidence is on the object is important especially when it comes to the evidence linkage triangle.

As trace evidence could be vital in solving a case, it is essential that utmost care is taken when processing it, by wearing protective head gear, shoes, and gloves. To minimize the risk of destroying or contaminating evidence the researcher recommends that robotic technology is deployed to execute this task.

We have already mentioned that the robot is equipped with Mini-CrimeScope Advance (SpexForensics, 2021) and this is the tried and tested method to reveal trace evidence as it has multiple light illumination sources to detect fibers. Oblique or parallel lighting of a surface will reveal small particles. If this source does not highlight any evidence, the fluorescing light source will be used.

Trace evidence will be collected using disposable tweezers, then packaged using evidence bags and sealed with evidence tape and a tamper proof QR code label, which contains the chain of custody information.

Trace evidence too large for an evidence bag will be boxed by the robot, sealed with evidence tape and tamper proof QR code label, and photographed. Evidence which the robot distinguishes to be too large to handle, will be flagged and details transmitted to the crime scene technician for further processing.

Robots are already so advanced that they can draw blood from a patient and applying this precision (Universal Robots, 2017), would be able to collect nail clippings and nail scrapings from the victim. This evidence will be collected using the prescribed protocol (Fingernail Clippings Evidence

Collection Kit) (TriTechForensics, 2021), packaged and sealed in the appropriate evidence bag using evidence tape and a tamper proof QR code label and photographed.

Once all the trace evidence has been processed, the robot will proceed to vacuum the crime scene using a 3M Trace Evidence Vacuuming unit to collect particulate evidence that meets law enforcement needs. (Forensics, 2021)

Evidence collection – photography

We have already mentioned comments by (Schiro, n.d.) that the collection of photographic and video evidence seems to be problematic as it is a contributor to evidence contamination and that too few photographs are taken of a scene.

The crime scene photographer has only one chance to be successful at this. The researcher proposes that the drone equipped with a 3D scanner be deployed to photograph the whole crime scene even before evidence collection is started, as a drone will not contaminate or cross contaminate the crime site.

Evidence collection – Latent Prints

“A latent fingerprint is a fingerprint that is not apparent to the eye but can be made sufficiently visible, as by dusting or fuming, for use in identification”. (SpexForensics, 2021)

Finger-, palm-, and bare foot prints are some of the best kinds of evidence that can place an individual at the site of a crime.

Forensic Standard Operating Procedures specify that non-movable items that contain prints should be processed using either black-, grey- , or magnetic powder.

Small transportable items that could contain latent prints should be packaged by the robot in paper evidence bags. (Robertson, 2004) We will apply the same processing protocol, by sealing the envelope or box with evidence tape and seal with printed tamper proof QR code label, and deposit in the forensic evidence receptacle.

Fingerprint powders could contaminate the print and ruin the opportunity to lift it or leave it intact for the processing of other techniques.

Difficulties that exist with dusting and lifting of prints from plastic bags, foil, wood, concrete walls, and magazines, using traditional methods can now be overcome by using a forensic light source with multiple wavelengths.

The researcher proposes to making use of the Mini-CrimeScope (SpexForensics, 2021) which has the functionality to emit alternate light sources, and along with fluorescent powder, ensuring that this method of detection greatly increases the probability that the print will be detected. Once the fingerprint has been illuminated, the robot will photograph and upload the image to the cloud and made available for further analysis and processing.

Simultaneously, it could interrogate "The Integrated Automated Fingerprint Identification System (IAFIS)" which is a "computerized system maintained by the Federal Bureau of Investigation (FBI) since 1999", which is a national automated fingerprint identification and criminal history system. (FBI, 2003)

The INTERPOL Secrétariat Général (IPSG) runs an International Fingerprint data-base known as the AFIS Gateway.

The FBI launched their national "Palm Print System (NPPS)" during May 2013. This system dramatically improved law enforcement as it provides access to prints previously stored on local, state, and federal law enforcement databases. It provides 29 million unique palm prints and could be queried by the robot on site. (FBI, National Palm Print System, 2019) Considerable time could be saved by processing prints in this manner compared to the time taken for prints to be taken to a lab and processed.

These fingerprint repositories could immediately be interrogated via the Internet to determine whether the prints found at the scene are related to a possible suspect. The results will be communicated to the crime scene technician via tablet or slate computer.

Issues around latent prints

Forty eight percent (48%) of 131 participants in a worldwide survey acknowledged that they have damaged or destroyed latent prints. (German eForensics GmbH, 2021) A total of 44% of the participants responded that they 'slightly often' damage or destroy latent prints.

These results clearly indicate the existence of unfortunate damage and destruction of traces in some cases which could have helped to identify a suspect. (German eForensics GmbH, 2021)

Using robotic technology minimized the risk of fingerprint damage or contamination, as there is only one chance to successfully process a print.

Evidence collection - Blood Spatter Analysis

Blood is one of the "most significant and frequently encountered kinds of physical evidence associated with the forensic investigation of death and violent crime". (James & Eckert, 1999)

History

Historically, “bloodstain interpretation has suffered through a long period of neglect, and as a result, investigators in death cases frequently have not appreciated the very information available from this source”. The earliest known “significant study of bloodstain interpretation that has been documented and preserved”, was done by Dr. Eduard Piotrowski in 1894 at the Institute for Forensic Medicine in Krakow, Poland. (James & Eckert, 1999)

In 1939, Balthazard was the first to analyse the meaning of the spatter pattern. (James & Eckert, 1999)

In 1971, Dr. Herbert MacDonnell used blood spatter as a tool in modern forensic examination. (Copley-Fairlawn City Schools, 2021)

Value of blood spatter to investigation

The “circumstances and nature of violent crimes frequently produce a variety of bloodstains” that, when “carefully studied and evaluated with respect to their geometry and distribution”, may “provide information of considerable value to assist an investigator with the reconstruction of a crime scene”. (James & Eckert, 1999)

Performance of Blood

“Blood can leave the body in many different ways, depending on the type of injury inflicted. It can flow, drip, spray, spurt, gush or just ooze from wounds”. (Forensic Science Simplified, 2013)

Several types of blood stains can be found at a crime scene:

- **"passive stains"** (drops, flows and pools resulting from gravity acting on an injured body),
- **"transfer stains"** (object coming into contact with existing blood stains and leaving wipes, swipes, or pattern transfer such as bloody shoe, or smear), and
- **"projected" or impact stains** (blood projecting through the air and are usually seen as spatter, but may also include gushes, splashes, and arterial spurts). (Forensic Science Simplified, 2013)

Bloodstains have traditionally been classified into three major categories based on the extent of external force required to produce them as well as their relative size.

These categories are:

- **Low-velocity impact** – external force applied to blood source of up to 5 ft/second, which includes normal gravitational force. Typical size of bloodstain produced is 3mm or greater in diameter. Varied directionalities may be produced. Splashed, swipes, running.
- **Medium-velocity impact** – external force of between 5 and 25ft/second but could reach 100ft/second with golf clubs or martial arts weapons. Typical bloodstain is 1 to 3 mm in diameter, varied directionalities. Blunt force trauma, cutting or stabbing.
- **High-velocity impact** – external force greater than 100ft/second is applied. Typical size of bloodstain is less than 1mm but may vary in size. Stains produced are less then 1mm in diameter. Gunshot, explosions.

Behaviour of blood

When blood is exposed to the external environment as the result of trauma, and subjected to various forces, it will behave in a **predictable** manner according to the principles of physics. The application of the physical properties of blood and the principles of fluids in motion form the basis for the study and interpretation of the location, shape, size, and directionality of bloodstains relative to the force or forces that produced them. (James & Eckert, 1999)

Two characteristics of blood that are worth mentioning is the viscosity and surface tension of blood. These play a significant role in the analysis of blood spatter.

- Viscosity is the "resistance to change form due to mutual attraction of molecules to each other" and increases greatly as a result of clotting. Blood is six times more viscous than water.
- "Surface tension is the force that pulls the surface molecules towards the interior of a fluid and decreases the surface area and cause the liquid to resist penetration". Surface tension is measured in force per unit length, or dynes per centimeter. (James & Eckert, 1999)

Blood is a solid, suspended in a liquid and certain variables like temperature/humidity, volume of blood and target surface characterizes affect the drying times. (Wilson, 2019)

Bloodstain pattern analysis may establish:

- Type of activity that created the bloodstain pattern(s)
- Point of origin
- Positions during bloodshed
- Movements during bloodshed
- Movements after bloodshed
- Number of hits or shots
- Identity and/or activities of individuals present during the event
- Bloodstain patterns on subject's body and garments

- Bloody latent prints and shoe prints
- Weapon identification
- Chronological sequence of events during and after bloodshed. (Wilson, 2019)

Bloodstain Pattern Reconstruction

The purpose of a reconstruction is to show the approximate location of the blood source that created those patterns. The focus of this chapter will be on impact pattens, which is the effect of blood that splashed as a result of something hitting it, and the secondary spatter (satellite spatter) that splashes out from the pool of blood frequently leaves behind distinctive patterns that can be interpreted, and one can discern how much force was involved and shows approximate location of the blood source for that pattern. (Wilson, 2019)

In order to solve such a related crime, we need to create a reconstruction of the event to determine where (in 3D space) the incident occurred, by:

1) <u>Determining the area of convergence.</u> Convergence is when a blood source is subjected to a force or impact, the resultant blood droplets may strike a target surface at various impact angles and direction. The point of convergence is a point to which blood stain patterns could be projected as shown in Figure. (James & Eckert, 1999)

   The tried and tested historical way to calculate the convergence and point of origin was applying the string method, (Bevel & Gardner, 2008) as indicated in Figure .

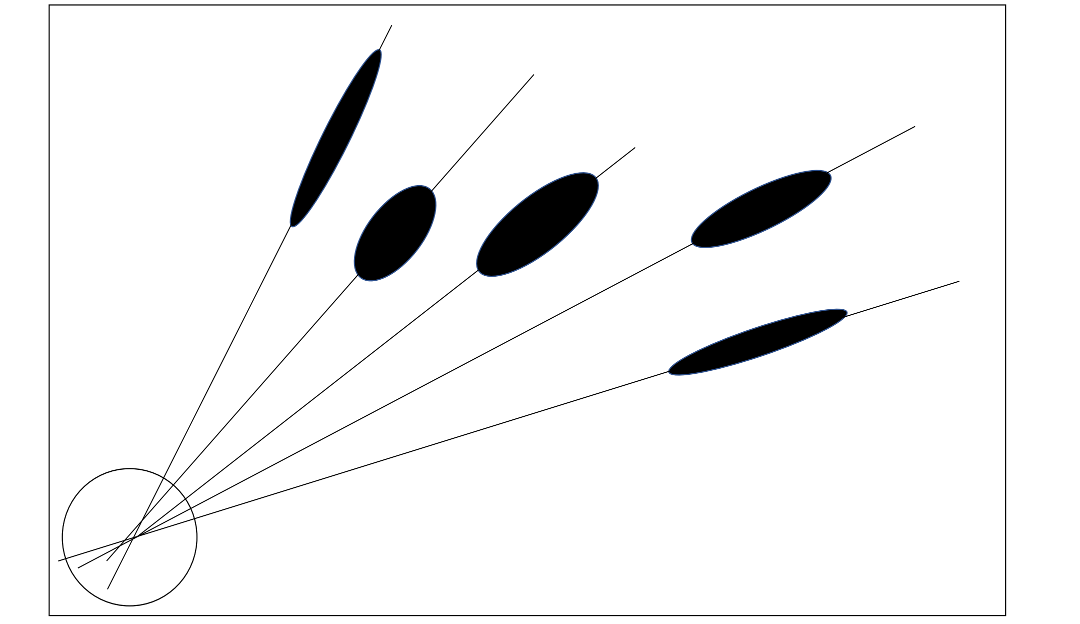

Figure 3 Area of Convergence

2) Calculating the angle of impact.

The *Angle of Impact* is calculated as: $\sin^{-1}$ (R) where R equals the width of blood drop / length of blood drop. Result reflects the angle at which the bloodstain hit the surface. Example, R = 5.1 / 10.6 = 0.4811 and the arcsin of 0.4811 ($\sin^{-1}$ 0.4811) = 29° (rounded) which tells us that the blood drop hit the floor from a 29 degree angle.

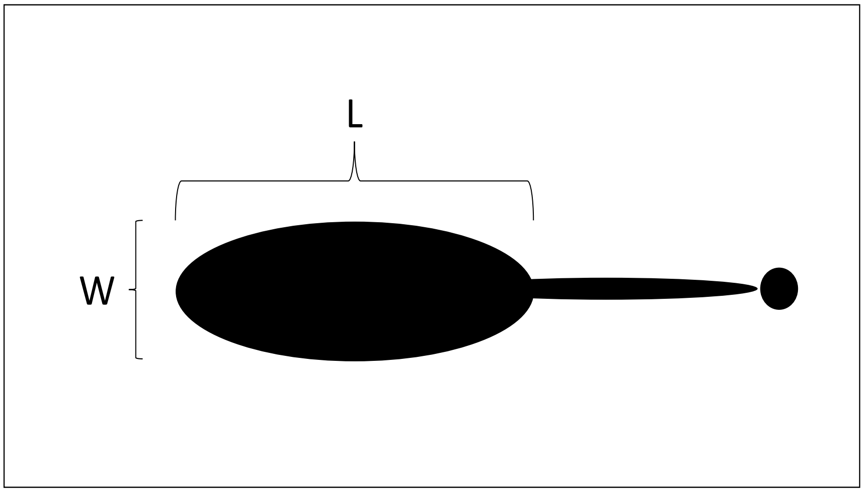

Figure 4 Blood spatter measurement

3) Calculate tangent of angle of impact.

   Use tangent function on scientific calculator and input tangent (29) which is 0.55430905.

4) Measure the distance and determine the height. Using a ruler or measuring tape, measure the distance from the bloodstain to the point of convergence, for example, 10.2 feet.

   To determine the height of the source (impact), get the tangent of the angle (0.5543) and multiply it by the distance, 10.2 x 0.5543 = 5.6ft.

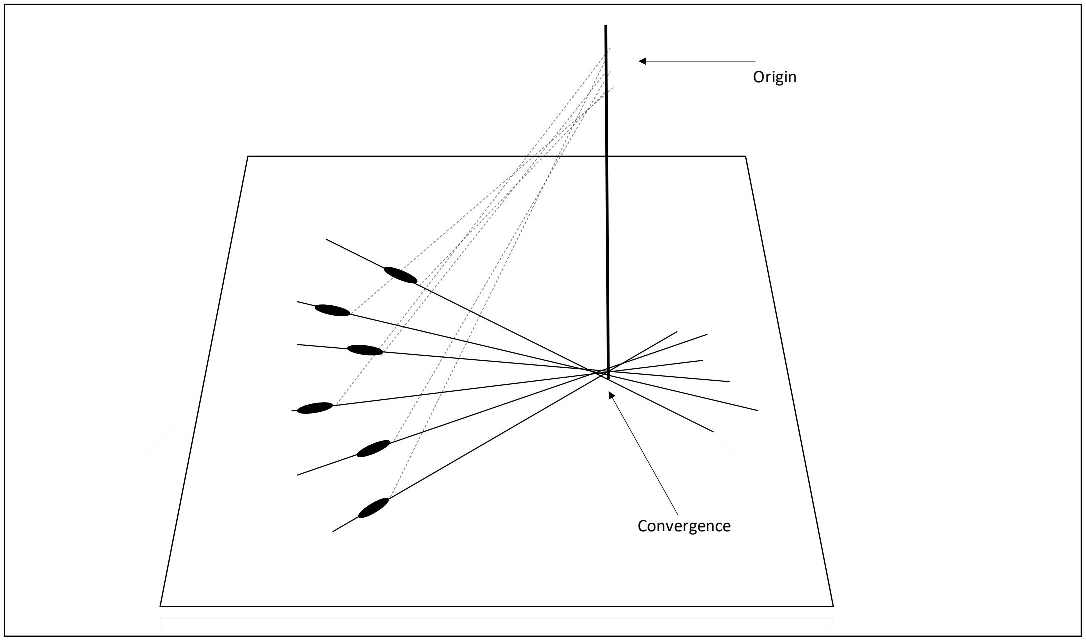

Figure 5 Point of origin

It is now evident from how high (5.6ft), and how far away (10.2ft) from the spatter and at what angle (29°) that injury occurred, and the spatter moved forwards (directionality), and to achieve this result using a ruler, protractor, and strings and scientific calculator.

Spatter related

Bloodstain spatter is one component of Bloodstain Spatter Analysis. Depending on the crime committed, transfer blood patterns, drip stains, gunshot spatter, wipes and swipes are also found at a crime scene, including voids ("empty places in the spatters that indicate that something or someone") caught the spatter instead of the surrounding surfaces. In the case of a high-density spatter, this may mean that the assailant got some of the victim's blood on himself or herself. (Crime Scene Forensics, LLC, 2018)

The bloodstain pattern analysis may be performed on scene, in a laboratory setting, or in an office by reviewing case materials, such as photographs and reports, i.e., offline, which means that days can go past before investigators could reach a conclusion. (Crime Scene Forensics, LLC, 2018)

One needs to be cognizant of the fact that the results produced by the analysis is just an approximation, which can narrow down the location of the source to about the size of a basket or soccer ball in a room which is 10ft x 10ft x 10ft. (Wilson, 2019)

Often there is too much blood spatter at a crime scene, and it might not be possible to determine a pattern to apply this method of bloodstain spatter analysis.

The researcher has discovered that some members of the Police have bypassed bloodstains at a crime scene as they did not know what the blood stains meant. (Sommer, Edde, 2016) Unfortunately, the researcher could not find additional statistics that could corroborate the statement made by (Sommer, Edde, 2016), or whether the situation has since improved. Suffice it to say, if one law enforcement official is the cause of an innocent person going to prison or receiving the death sentence, it is one to many.

Research done on Bloodstain Spatter Analysis

Research has been done on the subject of bloodstain spatter analysis, by example, an automatic algorithm was developed by (Shen, Brostow, & Cipolla, Unknown) to analyse bloodstain spatter at a crime scene which is an alternative solution to the 2D string method mentioned elsewhere. This innovation could bypass the labor intensive process performed by investigators at the crime site.

Additionally, software programmes are available which can assist an investigator in analysing bloodstain spatter. HemoSpat (HemoSpat, 2021), and BackTrack are two familiar ones.

FORident Software performed tests on BackTrack to validate the accuracy of it and produced results that were acceptable to the bloodstain analysis community. (Maloney, 2009)

Although the researchers used paint instead of blood (biohazard), they reported that their algorithm matches the accuracy expected from a forensic investigator, and that it could roughly estimate the 3D origin (height of impact) assuming that the trajectory was straight. They suggested that further research on this be done as the gravitational forces need to be accounted for in the algorithm, which will ensure more accurate results.

(Joris, Develter, & Jenar, 2015) suggested to use fiducial markers and computer vision algorithms to analyse bloodstain pattens. This subject would need additional research to prove the technology proposed.

Next Steps

The researcher has already cited YOLOv3 (visio.ai, 2021), a clever “convolutional neural network” (CNN). It is a “real-time object detection algorithm that identifies specific objects in videos, live feeds, or images”. It has a proven itself to be successful and could be taught effectively to recognise the various blood spatter patterns at a “crime scene” and should be integrated with the robot on site.

YOLO3 is cloud based, plus freeware tutorials are available to get it up and running in the cloud. (github, 2020) Additionally, (Attinger, Liu, Bybee, & Brabanter, 2018) have already built datasets of bloodstain spatter patterns which could be utilized by YOLO3’s learning modules.

Further research could be done to expand this dataset to include all types of bloodstain spatter, and furthermore to indicate which pattern was caused by what kind of weapon.

Every endeavor should be made to ensure that this dataset cloud based and accessible to the wide law enforcement community, possibly managed in a similar way as the shoe and tire tracks databases.

The rationale behind implementing drone assisted blood stain spatter pattern analysis is to keep crime scene technicians from contaminating blood evidence as it is quite evident from the manner in which calculations are done, that they need to be on the ground to take measurements or move around. Even if computer programs are used, the technician still needs to roam around the crime scene. A drone is able to effect high density scans, be able to zoom in and record these splatter patterns so that it could be analysed off site.

Conclusion.

The purpose of this chapter was to determine how robotics and Artificial Intelligence could assist law enforcement with the management and processing of a “crime scene”, and with the collection and preservation of evidence.

The researcher has discovered that there are still irregularities in this area of law enforcement, although not much information is readily available to report it statistically. It is assumed that these statistics would be kept hidden from the public to prevent civic protest.

This work by no means represents an exhaustive analysis of the subject as time and space does not permit.

Possible workarounds have been proposed under the different topics, however, although the robotic solutions have proven to be successful in their own environment, they would have to be tested as an integrated solution, before deployed in the field.

Aside from what was mentioned above, money could be saved as the robot would not need Protective Equipment.

Of the benefits that could be realised are time savings, in that finger prints could be sent for analysis while the crime scene is being processed.

Implementing a totally integrated solution such as this might be costly but will never equate the cost of a human life, or the repercussions of someone being sent to prison innocently or letting a perpetrator go free to commit more murders.

Recommendations

The researcher recommends that further research be done to complement the current blood spatter pattern datasets available.

It seems like there is no conclusive database representative of the total law enforcement forensic environment and on the contrary seems fragmented, therefore the researcher recommends that Forensics as a Service be further explored as this service could be hugely beneficial to the wider law enforcement community.

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Appendix 12

List of Figures