The Open Access Journal of Science and Technology
vol. 7 (2019), Article ID 101264, 10 pages
doi:10.11131/2019/101258

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Research Article

Technology in Forensic Science

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Abstract. Forensic technologies have improved in recent years improving the sensitivity and strength of the investigative potential of forensic scientists. Further, the rules and guidelines for conducting digital forensic investigations have evolved over time. This article examined the different technologies applied in the field. Five technologies were assessed namely: scanning electron microscopy, DNA fingerprinting, alternative light photography, facial reconstruction and LA-ICP-MS. The study found a significant application of technology in forensic investigations, which has aided in improving the field substantially. The study recommends a collaboration of scholars to aid in converging the existing and the emergent knowledge for beneficial application in the field since different stakeholders are involved in the field. Also, it recommends the application of forensic genetics in more areas that are not necessarily linked to human genetic material.

Keywords: Alternative light photography, digital forensics, DNA fingerprinting, facial reconstruction, LA-ICP-MS, scanning electron microscopy

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Dates

Received 11 January 2019
Accepted 20 January 2019

1. Introduction

Forensic technologies have improved in recent years improving the sensitivity and strength of the investigative potential of forensic scientists [1]. Forensic science is a broad field and incorporates many technologies ranging from pattern recognition to chemical composition to DNA analysis [2]. Numerous fields within forensic science have improved considerably over the years, and new technologies have enabled new applications of forensic science [1]. There have been multiple advances in DNA technology over the past two decades that in turn have led to the development of very accurate forensic identification techniques [3]. The techniques include short tandem repeat (STR), rapid DNA testing, next-generation sequencing, and familial DNA searching [1]. The advancement in digital forensics and the increased usage of digital evidence in courts requires consistent education to judges and forensic scientists [4]. This will ensure that they are conversant with both the existing and emergent technologies applicable in forensic investigations. Also, there exist stringent guidelines concerning the use of DNA tests during forensic investigations. This requires a mandatory adherence to the legal system by the forensic scientists [5]. Hence, understanding the operation of different forensic technologies is crucial in aiding the effectiveness of the systems. In view the various developments in digital forensics and the strict rules governing the field, this study focused on exploring the multiple technologies used in forensic science.

2. Methodology

The development of this article was based on secondary data. It involved an assessment of past studies and views from different scholars. This approach was efficient in time and cost as the researcher obtained a massive range of professionally gathered data within a short period and with minimal resources [6]. Data was collected from journal articles and books that were obtained from two hubs: Google Scholar and Sci-Hub. The following keywords and phrases were used to isolate the relevant journal articles to the study: technology in forensic science, forensic technologies, digital forensics, and evolving trends in digital forensics. The articles used were selected based on their appropriateness in the study in exemplifying the technological application in forensic science [7]. Content analysis [8] was applied to analyze the articles and to derive conclusions.

3. Results and Discussion

3.1 Digital Forensic Science

Digital forensic science refers to "the process of obtaining, analyzing, and using digital evidence in investigations or criminal proceedings." Digital evidence includes a range of things such as the location of a mobile phone and images of exploited children [9]. Digital forensics emerged after the proliferation of digital devices in the populace and has attracted the attention of law enforcement practitioners and experts, and computer professionals [10]. It arose as a competing alternative to the traditional laboratory-based tests and practices due to its robustness and flexibility in examining the investigations at hand. The first phase of digital forensic science was from 1985-1995. This stage involved using program codes to view data in the internal operating systems and hardware of computers. The second phase was from 1995-2005. It evolved the development of sophisticated algorithms and codes in digital investigations. During this epoch, there was a tremendous growth in the use of computers to conduct investigations. The technology eruption catapulted the growth as the use of the internet gained popularity across the globe. Also, there was an outburst of children pornography cases, where computers were used in transferring the files. Hence, an undercover operation was launched online to investigate the incident. This led to the development of measures to combat the illegal trafficking of the files. The third factor that led to the advancement was the Y2K problem after the occurrence of the events on September 11, 2001. Although there was a minute role played by computers in the hijackings, computers were used to plan the ordeal. Thus, this gave rise to the need to invest sufficient resources in combating the crimes that were being instigated, planned and executed through the help of digital devices [11].

The third phase was from 2005-2010. In this period, the field had experienced robust growth and interest from different parties. This led to the acknowledgment of the digital forensics as an essential area in crime investigations. For instance, in 2006, the US implemented Rules for Civil Procedure that governed the application of digital information in evidencing cases [11]. Over time, the field has continued to grow tremendously in tandem with the advancement in technology. Currently, forensic scientists are required to understand time analysis and concepts such as Real-Time Clock (RTC) and local time on the computer operating systems [12]. The importance of developing methodologies that will be used by different parties in the legal system when using digital evidence in courtrooms has also increased [13]. This demonstrates the importance of digital forensic in gathering and examining the evidence.

Digital forensic investigations are conducted using different models. One of the models is the Generic Computer Forensic Investigation Model (GCFIM). The model was proposed in 2011 by Yusoff, Ismail and Hassan. It has five phases; pre-process, acquisition & preservation, analysis, presentation, and post-process. The pre-process entails undertaking all the activities required before commencing the data collection and investigation process. This entails activities such as assembling the necessary tools and obtaining the relevant approvals. The acquisition & preservation process entails capturing, storing and preparing data for the next stages. The analysis stage is the heart of digital forensics. It entails examining the data collected to isolate the root of the crime and the responsible parties in initiating and executing the criminal activities. Presentation relates to the documentation of the findings from the analysis phase. The post-process involves concluding the exercise [14]. The GCFIM is applicable in guiding the examination of digital evidence despite the technology or device used. Thus, it is a crucial model in understanding the operation of technology in forensic science.

3.2 Technology in Forensic Science

Several technologies are used in different fields of forensic science to conduct investigations and examine the evidence. Among them include: scanning electron microscopy, DNA fingerprinting, alternative light photography, facial reconstruction and LA-ICP-MS.

Scanning electron microscopy. Optical microscopes are used for many imaging tasks. This is because they are easy to use and are affordable [15]. However, optical microscopes only have a resolution up to the micron level and have limited contrast and depth. Scanning Electron Microscopes are an improvement to the optical microscopes. They have resolutions that enable the forensic scientists to view features and distinguish details at the sub-micron level. The property of Scanning Electron Microscopy that makes it invaluable to forensic scientists is the fact that this method enables the creation of precise images at very high magnifications in combination with accurate elemental analysis. Scanning Electron Microscopy is used in cases that require distinguishing between small heterogenic particles that have a complex composition [15]. Hence, Scanning Electron Microscopy can be used in situations that involve gunshot residue and pyrotechnical post-explosion residue. In other areas that require microscopic imaging but do not require high magnification elemental analysis and imaging, or that do not need information that can only be provided through Scanning Electron Microscopy imaging is acquired using optical microscopes [15].

The most common application of Scanning Electron Microscopy is the detection and classification of Gun Shot Residue (GSR). GSR is composed of a mixture of burnt and unburnt particles from the bullet, cartridge case, and weapon used in the shooting. Most of the primers used in firearms contain antimony, barium, and lead and thus samples collected from the suspected shooters are typically searched for these elements. There is a gradual shift, and most primers will be free from lead and other heavy metals that are easily identifiable during Scanning Electron Microscope imaging. This offers fresh challenges for forensic scientists on how they can identify shooters based on a Scanning Electron Microscope imagery of samples from suspects [15]. There is a need for standardized tests and standards for the various methods that are used for the detection and classification of GSR from shooter's hands. A new proficiency validation test is carried out every two years within the framework provided by ENSFI Expert Working Group "Firearms." This test sets the standards that forensic scientists will use when carrying out Scanning Electron Microscope imagery of GSR [15].

There have been cases of explosives that are composed of pyrotechnic mixtures. Therefore, when these improvised explosives are used, they create unique explosive residues that can be distinguished through Scanning Electron Microscope imaging and this can be used to provide clues about the attack. This method was used to offer clues after the Bali Bombings. Production, sampling, and final analysis of Post Explosion Residue (PER) are closely analogous to that of GSR. However, Scanning Electron Microscope imaging is not applicable in the analysis of PER from organic explosives [15].

DNA fingerprinting. Roewer defines forensic genetic fingerprinting as the comparison of the DNA in the nucleated cells of an individual with the biological traces that had been collected at a crime scene or from an individual to identify culpable individuals and exclude innocent people. The discovery of DNA fingerprinting in the 20th century evoked a paradigm shift in forensic investigations. DNA analysis in forensic science is currently based on lineage markers (mitochondrial DNA, Y chromosome) and short tandem repeats (STRs) [16]. Mitochondrial DNA (mtDNA) and non-recombining part of the Y chromosome are passed down to offspring matrilineally and patrilineally respectively and do not recombine. Together, mtDNA and the non-recombining part of the Y chromosome are referred to as 'lineage markers' [16]. Lineage markers are used by forensic scientists to compare the DNA of biological samples collected from a crime scene. Some of these biological samples include hair and blood droplets [16].

Nuclear DNA can also act as another lineage marker. The lineage marker that is used by many forensic investigations on rootless shaft hairs has been mtDNA [17]. mtDNA has been used because rootless shaft hairs have nuclear material that is easily destructible and also available in meager amounts. This justifies the choice of forensic scientists to use mtDNA because it is abundant even though nuclear DNA gives more reliable results during tests. Hair is one of the most common biological samples in a crime scene and thus affords one of the best ways of apprehending culpable suspects. Therefore, there is a need to use DNA test systems that will provide reliable results despite the low availability of nuclear material in rootless hair shafts [17].

Some scholars suggest that it is possible to extract nuclear material from rootless hair shafts and conducts DNA tests on the obtained sample with a relatively low margin of statistical error that can be used by forensic scientists. In this method, the scholars recommend a combination of an advanced DNA extraction methodology and a newly released nuclear DNA typing assay, the InnoTyper®. In their study, the scholars conducted DNA tests on samples of rootless hair shafts and had a 40% success rate. The scholars further suggest that there should be more experiments to improve the accuracy of DNA tests that use nuclear material [17].

Alternative light photography. It is imperative for the forensic scientist to gather data from the crime scene that will be helpful in solving the case. Therefore, identification of biological samples such as urine, saliva, semen, and blood is essential in investigating crime scenes [18]. In these cases, forensic scientists use alternative sources of lighting to detect and identify biological samples. Using alternative light sources to classify biological samples is preferred because it is simple, non-destructive, and presumptive and can be used to detect a wide array of biological samples. It is possible to identify biological samples using forensic light because of the natural characteristics that make them distinguishable from their surroundings. For instance, blood is identified using this method because of its light absorption properties while urine, saliva, and semen can be identified because of their fluorescence effect [18].

Untreated dry blood lacks the fluorescence effect but has a high absorption across a wide range of light wavelengths, being capable of absorbing light of wavelengths between 300 and 900 nm.

doi:10.11131/2017/101258

This range encompasses the entire light wavelength including visible, ultraviolet, and infrared light. When any bloodspot is exposed to any form of light, it will create a dark spot [18]. It is important to note that the bloodspot appears brighter when they are found in dark backgrounds. Therefore, the forensic scientist should take note of the color of the background before looking for bloodstains using alternative light sources. One alternative light source that is used in the detection of blood samples in crime scenes is the Rofin PL-10 Polilight, a xenon lamp of high intensity with selectable narrow bandpass filters [18].

Untreated dry semen is a photoluminescence substance in that it absorbs lower wavelengths of light (excitation spectrum) and emits higher wavelengths of light (emission spectrum). The average excitation spectrum of semen ranges between 300 and 480 nm. Polilight® can easily provide this. The emission spectrum of semen ranges between 400 and 700 nm [18]. As long as the forensic scientist provides the required excitation light, it is effortless to observe semen stains in the background because of the photoluminescence effect of these samples. Appropriate goggles are generally used to filter out the intense excitation light and that only allow the emission wavelength to be visible to the person wearing the glasses. The Table 1 summarizes the appropriate type of filters and/or goggles as well as the color of the observed stain depending on the excitation light [18].

Another biological substance that can be detected using alternative sources of lighting is saliva [18]. A dried saliva stain is colorless and therefore cannot be detected by an unaided eye. Saliva stains also have fluorescent properties though that of semen exceeds this fluorescence. A saliva stain is detectable using UV light, but this would not distinguish it from other stains because most of the stains appear as bluish-white under UV light. The Table 2 summarizes the types of goggles/filters and the color of the observed stain when saliva is exposed to different wavelengths of light [18].

The other biological sample that is detectable using forensic light sources is urine. However, urine is hard to detect because it is easily diluted when it is attached on surfaces. Also, the color of urine stains varies depending on the substances that are present in the urine. It has been noted that the color of urine stains from glycosuria patients was different from that of urine stains from ordinary people. Urine stains are more intense than those of saliva. The Table 3 below summarizes the color of urine stains and appropriate goggles and filters that can be used under different wavelengths of light [8].

There are various types of Forensic Light Sources (FLS) that can be used in the identification and detection of biological samples (Table 4). The FLS is chosen based on its features because different stains behave differently when exposed to the various light wavelengths. Therefore, each FLS is determined based on the facts on the ground.

Table 1: Excitation wavelength with suitable goggles or filters for detection of saliva.

Excitation light	Goggles/Filters	Color of the observed stain
UV	No goggles needed	Blue
Violet	Yellow goggles	Yellow
Blue	Yellow goggles	Yellow
Green	Orange goggles	Orange
Green-Yellow	Red goggles	Red
Green-Yellow	Violet filters	Black

doi:10.11131/2017/101258

There are various types of Forensic Light Sources (FLS) that can be used in the identification and detection of biological samples (Table 4). The FLS is chosen based on its features because different stains behave differently when exposed to the various light wavelengths. Therefore, each FLS is determined based on the facts on the ground.

For instance, since it has been proven that infra-red light can be used in the detection of blood samples on black fabrics, forensic scientists will choose FLS that have the capability of detecting IR light. There are also some FLS that can reveal stains that have been buried under the paint. Table 4 above summarizes the different alternative sources of light that a forensic scientist can use, along with the alternative wavelengths that it emits, and the types of stains that the source can detect [18].

It is also possible to detect tooth and bone with alternative light sources during forensic investigations. Tooth and bone have different fluorescence intensity when exposed to an

Table 2: Excitation wavelength with suitable goggles or filters for detection of semen.

Excitation light	Goggles/Filters	Color of the Observed Stain
Long UV	No goggles needed, but recommended to wear UV safety goggles	White-bluish
415 nm	Yellow goggles/555 nm interference filters	Not stated in literature
450 nm	Orange goggles/555 nm interference filters	White (Orange goggles)
470 nm	530 nm/550 nm interference filters	Not stated in literature
490 nm	555 nm interference filters	Not stated in literature
505 nm	555 nm interference filters	Not stated in literature
532 nm	Goggles that block 532 nm light	Yellow-Orange

Table 3: Excitation wavelength with suitable goggles or filters for detection of urine.

Excitation light	Goggles/Filters	Color of the observed stain
UV	No goggles needed, but recommended to wear safety goggles	Depends on abnormal substance pressure
415 nm	Yellow goggles	Not stated in literature
450 nm	Orange goggles	White
505 nm	Red goggles	Not stated in literature
532 nm	Goggles that block 532 nm light	Yellow-Orange

Table 4: Comparison of the tested FLS in recent literature regarding wavelength and detectable stains reported.

FLS	Wavelength (nm)	Detectable stains reported
TracER (Laser)	532 (Green laser beam)	Semen, Saliva, Urine
Spectra-Physics® Reveal ™(Laser)	532 (Green laser beam)	Semen, Saliva, Urine
Poliray™	415-610 (mounting interference filters)	Blood, Semen, Urine
Polilight® PL500	Adjustable from UV, 415-650 nm, and white light	Blood, Semen, Saliva, Urine
Lumatec Superlite 400	Adjustable from 320-700	Blood, Semen, Saliva, Urine
Wood's Lamp	320-400 (Long UV)	Semen (doubtful)
BlueMaxx BM500	450 (Blue)	Semen, Saliva, Urine
BlueMaxx Mini	450 (Blue)	Semen
Evident Product	365 (Long UV)	Semen, Saliva, Urine
Mineralight®	254 (Short UV)	Semen, Saliva, Urine
High Intensity LED	Variety of wavelength depends on the LED used	Blood, Semen (Urine was detectable by Luxeon™ Star V LED

doi:10.11131/2017/101258

alternative light source. Some scholars carried out experiments to determine the effect of alternative light sources on bone and tooth samples. In the study, tooth and bone samples were lit with forensic light sources and photographed after which ImageJ™ and Adobe Photoshop™ were used to analyze the images. The study revealed that the best wavelength for detecting bone and tooth is 455 nm in the presence of an orange filter. The experiment also established that bone and tooth have higher fluorescence than inert objects [19].

There are also scholars that seek to use alternative sources of lighting to detect bruises on the skin to determine the use of violence in forensic investigations. Bruises are easily overlooked as long as they are not visible to an unaided eye. These scholars sought to reveal the presence of bruising using infrared, narrowband, and ultraviolet light wavelengths. Some regions that had not also been bruised reacted in the same way as the bruised regions under red and blue light [20]. Hence, forensic scientists should exercise caution and wait for further research on the use of alternative light sources to identify bruises on skins.

Facial reconstruction. Forensic anthropology is applied in determining the age, sex, race and ancestry, dental formula, skeleton and bone structures, soft tissues, and face of decomposed and disfigured bodies of victims [21]. Facial reconstruction is a technology used in defining the facial appearance of the victims for visual identification. The process of facial reconstruction is conducted in three phases: anatomic modeling, morphology determination, and depiction of the resultant face for identification [22].

The anatomic modeling phase entails gathering the significant muscles and structures based on the provided anatomic guidelines. The proportions, outline and virtual position of the muscles and structures guide the process. The second stage, morphology determination, involves assessing the bony detail of the collected tissues and structures to determine the facial features. The process follows set anatomic principles [22].

In determining the eye morphology, a forensic scientist examines the internal and external location of the canthi and where the eyeball is located in the orbit. The identification of the positions is guided by the symmetrical analysis of the eyelids, the angular orientation of the canthi, the distance from the nose, and the distance from the lacrimal crest and malar tubercle. The nose morphology is guided by the width of the soft nose and the bony aperture, the angular position of the nasal base, and the location of the crista conchalis. The mouth morphology is usually guided by the constriction of the teeth, the dental arrangement, and the shape of the face. The ear morphology is directed by the angular position of the ear based on the location of the jawline, and the direction of the mastoid processes in identifying the attachment of the earlobe. The facial skin morphology is guided by the level of the tissue depth pegs [22].

The depiction of the resultant face involves applying various surface details such as skin textures and colors, hairstyles and individual effects. The details usually have a significant impact in influencing the level of recognition. This is because, without the details, it becomes tough to recognize the face. While at times it is difficult to identify the right skeletal material to use, there are times when the scenes provide clues. However, it is still an uphill task given the different variations of the surface details across different races and origins [22].

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). LA-ICP-MS is a technology applied in putting things together such as glass. The machine has a high and sensitive isotopic recognition ability that breaks down the glass samples of whichever size into their atomic structure. This guides in matching the particles found on the victim's body

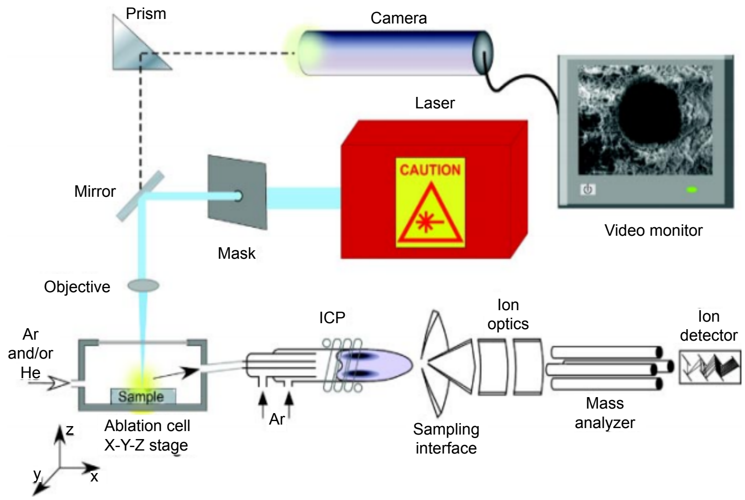

Figure 1: Representation set-up of a usual LA-ICP-MS.

or clothes with the sample obtained from the location of the crime. Further, the technology is used in identifying the course of bullets, the potency of impact and even the weapon used in executing the crime. Figure 1 below shows a representation set-up of a usual LA-ICP-MS [23].

The first step in the operation of the LA-ICP-MS involves removing a regulated volume of the sample. This entails placing the sample in a sealed ablation chamber, and a laser beam is directed to its surface. The placement is usually enhanced by monitoring it using a video camera or a microscope. The contact between the laser pulse and the surface area of the sample leads to the ablation of a proportion of the material, which may be in different forms. The next step involves transporting the ablated material to the ICP through a polymer tubing. The particles are then vaporized, atomized and ionized. Afterward, the ions obtained are then taken into a mass analyzer. They are detached from each other based on their mass-to-charge ratio. Lastly, they undergo through the process of high selective detection and quantification for use in the forensic investigation.

4. Conclusion

There is a wide variety of digital devices that can be used such as wearables, Internets of Things (IoT) devices, smartphones, tablets, laptops, desktops, and proliferation of cloud-based services. Therefore, there is a likelihood that the number of cases that involve digital evidence shall increase significantly in the future. The digital forensic technologies are advancing at an alarming rate coupled by changing regulations and guidelines in applying technologies for forensic investigations to keep up with the nature of the crimes and their identification in the digital arena. The study thus focused on examining different applications of technology in forensic science to provide a comprehensive assessment in the field. It centered on five technologies as follows: scanning electron microscopy, DNA fingerprinting, alternative light photography, facial reconstruction, and LA-ICP-MS. The study found a significant application of technology in forensic investigations, which has aided in improving the field substantially. Since digital forensics involves different stakeholders, more collaboration among scholars in this field is recommended to aid in converging the existing and the emergent knowledge for useful application in the field. Also, it suggests the application of forensic genetics in more areas that are not necessarily linked to human genetic material. Possible areas include cases involving animal attacks, bio-crimes, bioterrorism, and animal trafficking.

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