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Forensic Analysis
From Death to Justice

Edited by B. Suresh Kumar Shetty and Jagadish Rao Padubidri

FORENSIC ANALYSIS - FROM DEATH TO JUSTICE

Edited by **B. Suresh Kumar Shetty**
and **Jagadish Rao PP**

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Notice

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Meet the editors

Editor, Dr. B. Suresh Kumar Shetty is presently appointed as Honorary State Medico-Legal Consultant for three districts in the Government of Karnataka. He received his master's degree at KMC, Manipal, and joined as faculty at KMC, Mangalore, where he has been teaching since 2005. He is awarded a certificate in "Analytical Toxicology & Forensic DNA Typing" in 2006, PG certificate in Torture Medicine in 2011, and completed his MBA [Hospital Administration] in the year 2016. Perusing FAIMER fellowship from Manipal University. He has co-authored chapters in 3 books and peer-reviewed articles in 15 reputed national and international journals, as well as contributed over 70 articles in scientific journals. He guided postgraduates in Forensic Medicine and undergraduates in ICMR student projects. He has been an author of "Atlas book on Forensic pathology ' published by Jayeepe Publishers. He was Nominated by the International Bibliographical Centre, Cambridge, England, Selection Committee and earned a position of TOP 100 Health Professionals in the year 2009, for making a significant contribution in his field to engender influence on a local, national and international issue.

Co-Editor, Dr P P Jagadish Rao has attained his title Doctor of Medicine from KMC, Manipal in 2006. He was awarded the title of the Diplomate of National Board [DNB] in 2007. Dr Rao subsequently completed PG diploma in Criminology and Forensic Sciences in 2005, Diploma in Cyber Law in 2008, PG certificate in Torture Medicine in 2011 and MBA(Hospital Administration) from Sikkim Manipal University, Sikkim, India in 2016. He has been enrolled as Member of National Academy of Medical Sciences by National Board of Examinations, New Delhi, India. As a distinguished academician Dr Rao has contributed more than 60 scientific papers in various National and International index, high impact journals. He has authored a book titled " Atlas of Forensic Pathology" by Jaypee publishers in the year 2013. He has presented scientific research papers in various State, National and International professional gatherings held in many countires of thw world.

Contents

Preface

It is my pleasure to place before you the book *"Forensic Analysis – From Death to Justice"* which presents one of the major portions of the broad specialty of Forensic Science comprising mainly of Thanatology and Criminalistics. This book has been designed to incorporate a wide range of new ideas and unique works from all authors from topics like Forensic Engineering, Forensic Entomology and Crime Scene Investigation.

The book covers the following topics:

Geomatics and Forensic: Progress and Challenges - Forensic Engineering

In this chapter photographs hold prime information about complex crime scenes. They form a basic key in developing hypothesis during police investigations and also prove these hypothesis in court. Forensic analysis involves crime scene information as well as its reconstruction in order to extract elements for an explanatory police test or to show forensic evidence in legal proceedings. An amalgamation of data from different sensors whose final purpose is a 3D accurate modelling is explained and it moves into a highly active research area, where there are still many doubts to be resolved. The final section focuses on these tests and outlines future views.

Forensic Analysis of the Wakayama Arsenic Murder Case - Forensic Engineering

This chapter highlights one incident, its influence on scientific research and how it was carried as well as its conclusions.

Forensic Hydrology - Forensic Engineering

The chapter describes the useful tools to determine the real causes, naturally or human induced, that made a natural phenomenon into a disaster. This branch of forensic analysis, and particularly of engineering forensics, can be applied directly in the context of climate change, which will increase the magnitude and frequency of extremes. The application of these concepts to the case of floods and droughts but other applications such as drought analysis can be addressed too, especially to prevent future disasters.

Parasitic Hymenoptera as Forensic Indicator Species- Forensic Entomology

This chapter presents features of parasitic wasps. Necrophagous insects are the most important environmental evidence associated with a decomposing corpse. They reveal information for estimating the post mortem interval and determination of whether the body had been moved. They are used in toxicological analyses and in surveillance, as well as biosensors, which is some of their usefulness in forensic applications.

Molecular Genetics and its Applications in Forensic Sciences – Crime Scene Investigation

This piece helps us to understand a framework of modern forensic medicine, a new field of forensic genetics, that mostly involves working with investigations which have as a goal human genotype identification. This is thanks to their unique characteristics, which are non-recurring and inherent for each individual application of molecular genetics in medico-legal and criminalistics identification.

Usage of Infrared-Based Technologies in Forensic Sciences – Crime Scene Investigation

This chapter presents a IR-based Technologies and forensic photography techniques and how they emerged in a new era of crime scene investigations. The chapter describes how they helps in the identification of evidence obtained from crime scenes. It also highlights the importance and the advantages of Infrared Thermal Imaging among these techniques, as well as describe the operating principles of Infrared Thermal Imaging technologies that may be generated in the future.

I hope that the book *"Forensic Analysis – From Death to Justice"* will be useful to the practitioners of forensic medicine, experts, pathologists, law makers, investigating authorities, undergraduate and postgraduate medical school graduates of medicine.

Lastly, I wish to express our solemn sentiments and sincere thanks to all my colleagues. First and foremost, to the co-editor of this book Dr Jagadish Rao PP, Associate Professor, Department of Forensic Medicine. Furthermore, my thanks goes to: Dr Archit Boloor, Associate Professor, Department of Medicine; Dr Aditi S Shetty, Associate Professor, Department of Obstetrics and Gynecology, Kasturba Medical College, Mangalore, Manipal University, for their valuable feedback and suggestions while editing this book.

I wholeheartedly give thanks to Ms. Sandra Bakic, Senior Commissioning Editor, for her constant support and suggestions during the process of editing, and thank the entire InTech team for giving me a unique opportunity in this process.

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Section 1

Forensic Engineering

Chapter 1

Geomatics and Forensic: Progress and Challenges

Pablo Rodríguez-Gonzálvez,
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Additional information is available at the end of the chapter

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Abstract

Since graphics hold qualitative and quantitative information of complex crime scenes, it becomes a basic key to develop hypothesis in police investigations and also to prove these hypotheses in court. Forensic analysis involves tasks of scene information mining as well as its reconstruction in order to extract elements for explanatory police test or to show forensic evidence in legal proceedings. Currently, the combination of sensors and technologies allows the integration of spatial data and the generation of virtual infographic products (orthoimages, solid images, point clouds, cross-sections, etc.) which are extremely attractive. These products, which successfully retain accurate 3D metric information, are revolutionizing dimensional reconstruction of objects and crime scenes. Thus, it can be said that the reconstruction and 3D visualization of complex scenes are one of the main challenges for the international scientific community. To overcome this challenge, techniques related with computer vision, computer graphics and geomatics work closely. This chapter reviews a set of geomatic techniques, applied to improve infographic forensic products, and its evolution. The integration of data from different sensors whose final purpose is 3D accurate modelling is also described. As we move into a highly active research area, where there are still many uncertainties to be resolved, the final section addresses these challenges and outlines future perspectives.

Keywords: forensic engineering, photogrammetry, laser scanning, indoor mapping, gaming sensors

1. Introduction

The set of techniques which could be included in geomatics has always been helpful in forensic investigation. Not having the purpose of making an exhaustive list, the main areas of interest in which of geomatics and forensic engineering are especially linked are described below.

- **Interactive 3D reconstruction**. Using different techniques such as panoramic photography or terrestrial laser scanner (TLS) point clouds can virtually recreate crime scenes. 3D recreations facilitate researching tasks because investigators can take measurements whenever they want or interactively recreate the facts through simulation methods. All this become a key, not only as a support in criminal investigations, but it can be used by lawyers, judges and experts to observe the reactions of defendants [1].
- **Biometric studies**. Biometry is a researching area whose purpose is the automation of the identification and the recognition of human beings based on their morphological characteristics [2]. Facial recognition by means of computer vision is a proven method to verify human identity. The development of 3D facial models overcomes the limitations of traditional 2D images derived from differences in lighting, depth and perspective, yielding more reliable and robust information [3].
- **Anthropological studies**. Skulls and bones 3D modelling has been one of the fields in which geomatics has contributed more efficiently with forensic analysis [4]. Thanks to the possibilities offered by computer vision, it is possible overlapping portrait pictures taken before the death of an individual, with the rendering skull and to establish different levels of matching between them.
- **Footprint studies**. These studies are used to recognize prints in general, specifically footprints, shoeprints or those left by vehicle tires [5]. The main contribution of geomatics in this area is to provide an accurate geometric graphic documentation that allows the automation of the process of comparison with data stored in database. High-density 3D models are needed to provide an accurate level of detail for this purpose.
- **Ballistic:** The use of sensors such as TLS opens the door to new possibilities to analyse bullet trajectories, improving the quality on the determination of angles and directions regarding with rest of the scene and evidences. At this point, the employment of special ballistic rods, invariants to deformations [6], allows extrapolate the inner gunshot trajectory in a rigorous way.
- **Forensic GIS.** Geographic information system (GIS) and the current spatial data infrastructure (SDI) are the most suitable technologies to combine spatial data coming from different geomatic sensors, as GNSS (global navigating satellite system) or satellite imagery, with database and cartography. Therefore, GIS becomes a powerful tool to map, manage and analyse any kind of spatial data in forensic and criminology. Controlling suspicious movements in GIS from the data on their mobile phones could be a good example. Another example is the elaboration of crime maps that allow build patterns in crime commission and relate them with other geographical, social or economic variables, which it is necessary in police planning tasks, promoting the understanding and prevention of crime [7].

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Figure 1 shows the suitability of the most common instruments and techniques used in forensic crime scene investigations. They are ranked according to a qualitative score of the following parameter: sensor precision and resolution, portability, autonomy, distance range and among others.

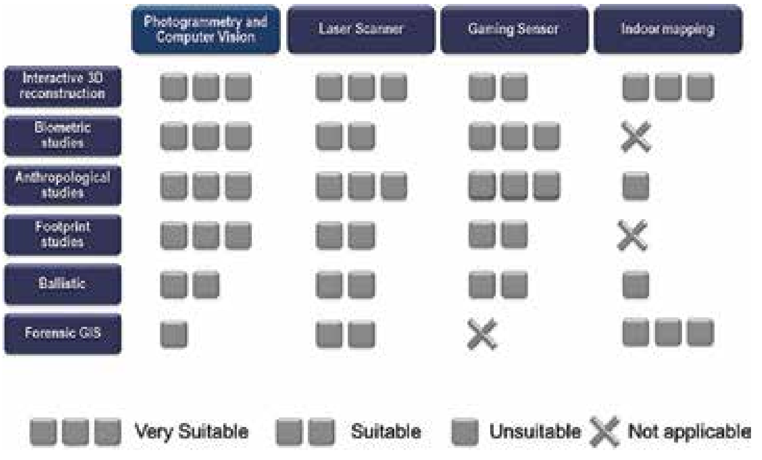

Figure 1. Suitability of different instruments in forensic analysis.

Crime scene documentation tasks (indoors and outdoors) imply firstly an ocular inspection. In these tasks, the police must carry out a meticulous work of observation and documentation of direct evidences, whose purpose is to collect any data to discover, document and demonstrate the facts and their circumstances.

Photography, video and infographic design can be considered as classical techniques able to integrate and complement the ocular inspection phase. Through these techniques, crime scene information is exhaustively gathered in a non-invasive way. While general data set collected are on the basis to propose broad hypothesis about the events, detailed data from specific areas become extremely important because they permit to link individual evidences.

Although the use of photographic documentation in crime scenes is a constant in police investigation, it is the hybridization of sensors, caused by the rise of digital photography, electronics, computers and telecommunications, which has led to the extension of geomatic methods to technical documentation in forensic analysis.

After this introduction, this chapter shows, in Section 2, the main requirements for graphic information. Geometric accuracy is shown as the key question since provides not only relevant data about the object in the scene, but allows to establish relationships between different elements in order to determine distances, heights, surfaces or volumes. The aim of Section 3 was to make a review of the current geomatic techniques that are being applied in 3D crime scene reconstruction and their interrelation. Section 4 will be focused in three new approaches into geomatic applications in forensic analysis. Finally, Section 5 outlines the concluding remarks of the different methods and techniques.

2. Spatial information in Forensics: attributes and requirements

As already noted, crime scenes, on which forensic investigations are conducted, can be initially classified into two types: those that occurs in small areas, frequently indoors, and those that take place in large areas, outdoors. Thus, location and area size determine the methods to be used, creating some limitations that make it useful or useless the instrumentation according to its technical specifications. Any case, it can be said that evidences acquire particular geometric arrangement on a three-dimensional frame. The spatial relationships between evidences in a crime scene are described by the following basic geometric concepts: distances (measured on different planes), angles (defined both on a vertical plane and a horizontal plane), height differences (distances measured on a vertical plane) surfaces or volumes.

It is a well-known fact that the ability to image recognition in humans is an extraordinary attribute. That is the reason because images have traditionally become the main communication way for humans to grasp and transmit spatial relationships between objects in scenarios. Recognizing the importance of ocular inspection in police investigations, digital images constitute a lifelong testimony of an instant, through which the facts can be explained and reconstructed. Thus, images have taken a key role in criminal investigations and they are the basis for some forensic researching areas such as ballistics or calligraphic.

A crime scene is somewhat brittle over time. This is the reason because data acquisition should be performed before the evidences could be degraded, modified or disappeared. Later, when forensic analysis is in progress, it is often required coming back to the scenario. In that moment, a real and accurate 3D reconstruction is essential to reinforce stated hypothesis or establish new ones.

The main goals in forensic infographics are geometric accuracy, realism, flexibility, dynamism and completeness (**Figure 2**):

- **Accuracy** in spatial positioning implies planimetric and altimetric positioning. It would be possible in 3D reconstructions, an accurate measurement of angles, distances, heights, surfaces and volumes. This implies that data acquisition methods (photography, photogrammetry, terrestrial laser scanner, etc.) should ensure a reasonable uncertainty values to guarantee accuracy and reliability.

- **Realism** is understood as the ability that computer graphics has to evoke and reproduce crime scenes. 3D virtual models become really important in court to verify witness testimonies or to support lawyer's theories, enabling the reconstruction of facts and accidents.

- **Flexibility**. Understood as the set of graphic properties in 3D scenarios that allow us to change both the observer point of view and the scale. While traditional photography provides an image from a single point of view, the camera at the time of the shooting, the three-dimensional graphics let us change the point of view, placing virtually the investigator in the position of any person involved in the facts. Furthermore, changes in scale provide general and detailed information.

- **Dynamism.** A further step in 3D scenarios virtually reconstructed is to add movement. Infographic software tools enable the generation of animated sequences making more understandable the facts. The workflow in the infographic phase is based on the vectorization and generalization of geometries and the generation of avatars in movement.

- **Completeness.** Forensic analysis needs to deal with data set that offers full information of interest. When information is acquired investigators must be sure that the entire elements are recorded because the lack of data becomes a general weakness. In this sense, occlusion and information shadows must be avoided by planning appropriate strategies in data collection.

- **Non-invasiveness.** Nowadays, non-invasive measurement techniques avoid direct contact between the operator and the object to document, guarantying the preservation of all the original characteristics in the scene and therefore become essential in current crime scene management, overcoming traditional ones in which the risks of contamination were notably higher.

Figure 2. Example of the main goals in forensic infographics.

If these properties remain, it would be possible to give consistent and accurate answers in forensic analysis. Answers based on interactive simulations that allow elaborating more robust hypothesis about the events and to explain all their circumstances. Spatial data sets, coming from different sensors, provide a broad range of geomatic products that are necessary to describe in order to establish their properties and requirements.

3. Geomatics and Forensics: overview

This section will describe the main geomatic technologies currently applied in forensic analysis. Since the early 1960s, we are witnessing a quick evolution of sensors and algorithms in geomatic science. That evolution was supported by the electronic advances such as electromagnetic distance and angular measurement, computer miniaturization, increase of computer power or imaging semiconductor circuits. Nowadays, the drive is now reinforced by the telecommunications advances. **Figure 3** shows a quick summary of this evolution.

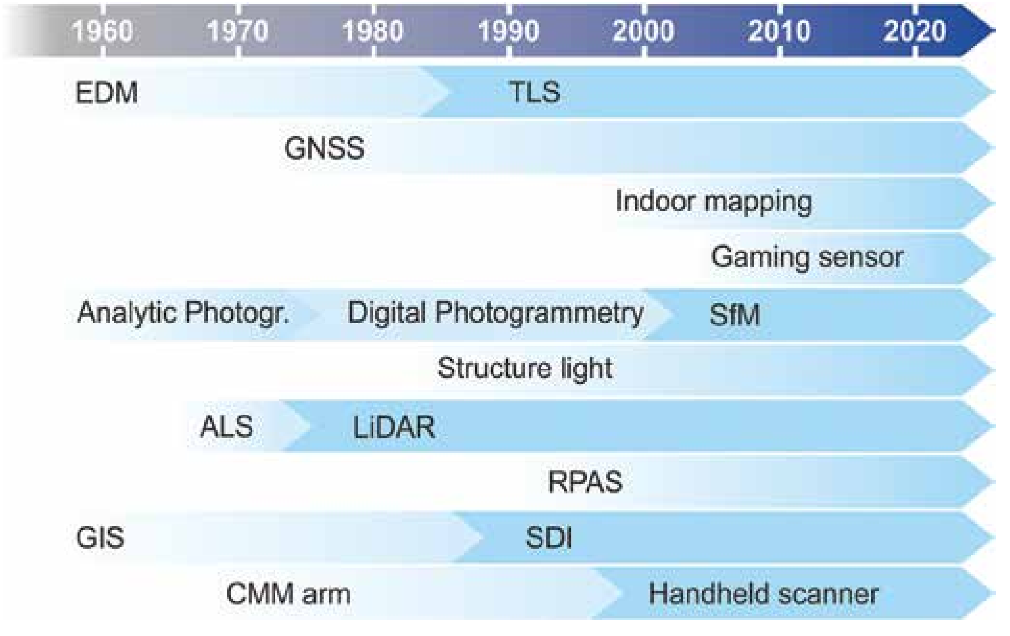

Figure 3. Chronological chart showing geomatic advances related to forensic science.

3.1. From photography to photogrammetry

By themselves, photographic images, whether analogue or digital, do not have metric properties. That is, we cannot infer direct measures of the objects displayed in it, or obtain the distances that lie between them. We can visualize, interpret, or analyse, but not exploit them metrically. This is because images are built on the base of the conical perspective, rather than an orthogonal projection. As a consequence scale in images is variable. Therefore, performing accurate measurements on images must be done by taking some precautions.

Photogrammetry deals with obtaining metric information (two-dimensional or three-dimensional) from photographic images, allowing crime scene 2D or 3D reconstruction while preserving strictly their geometric characteristics [8]. The basic principle for photogrammetry is the geometric relationship that takes place between the points of the object (3D element in space), the corresponding image points (2D), and the point of view (placed in the centre of the

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camera lens). In essence, it is noted that each point of the object, the photographic image, and the viewpoint verified the colinearity condition, that is, they define a straight line (**Figure 4**).

In the photogrammetric workflow, we can distinguish the acquisition phase and the phase of restitution. In the first one, from a three-dimensional real object, the image is built. The restitution process is just the opposite: from the image will attempt to reconstruct the object, that is the mapping or virtual representation.

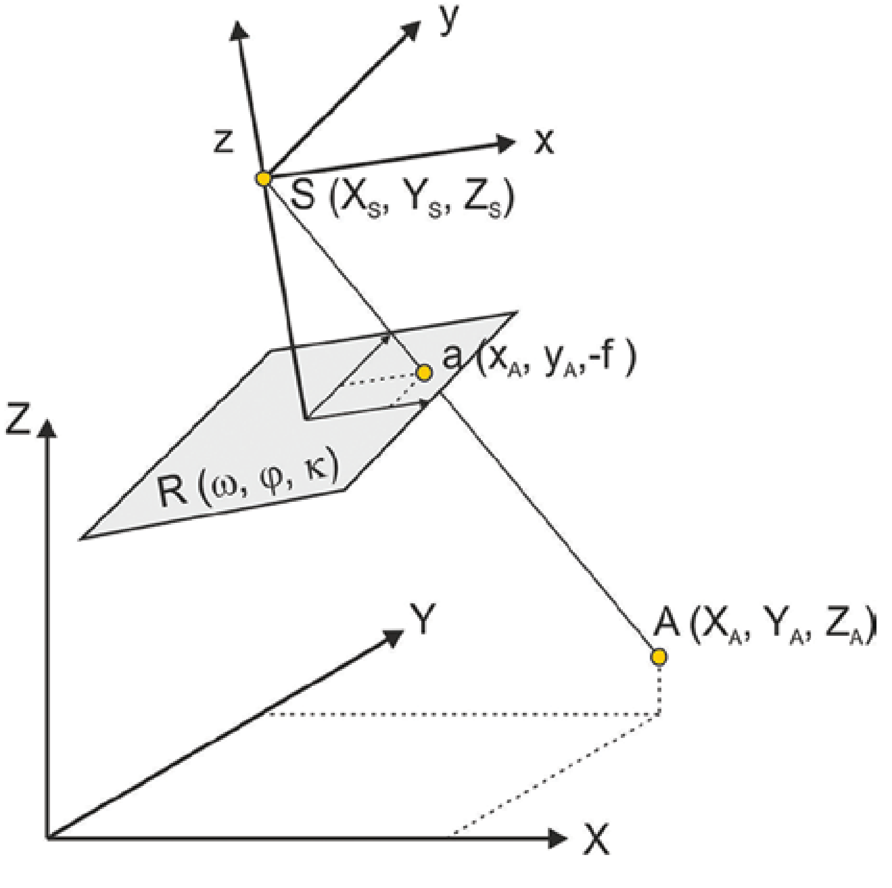

Figure 4. Basis of colinearity condition.

For the cartographic restitution of a photograph, it must be solved three problems of geometric nature. First, the position of the viewpoint with respect to the photograph (or digital image) must be identified. This implies that the internal geometric characteristics of the camera (essentially its focal length, distortions and deformations) should be known. This process is known as *internal orientation*.

Second, we must determine the location of the photograph viewpoint regarding the object. This process is called *external orientation* if the location of the object is referred to a ground coordinate system, or *relative orientation* when not working with a real reference system. When documentation of indoor scenes is done, the Cartesian reference system is characterized by the fact that the Z axis tends to coincide with the vertical direction and XZ (or YZ) plane usually matches to some of the façades or walls object (if there is possible, on the contrary it could be arbitrary). The positioning of each photograph in space is determined by the three spatial coordinates (X, Y, Z) and the three spatial angles (ϖ, ϕ, χ) of the viewpoint.

Finally, the reconstruction of the object is performed through the intersection between different correspondent and perspective lines (collinearity condition) by using at least two photographs. In geometric terms, this means a difficult task, especially in those cases where a full automation is required. To solve this problem, photogrammetry, without prior knowledge of the object, acts similar to the behaviour of human vision, in which images are obtained from two converging intersections.

3.2. Panoramic images and virtual tour

In this subsection, we want to focus on panoramic images and virtual tours. In spite of the difficulties to take measures in panoramas, they have an extraordinary capability to organize spatial information in qualitative terms, which is essential to describe hypothesis in forensic research.

Unlike conventional photography, in which a detail or a particular frame in the scene is shown, panoramic images have the property to collect the whole graphic information, covering a large angular field of view [9]. Thus, it is intended to get the feeling of being in the scene. The immersive experience can be achieved on a 360° field of view basis, greater than the human eye can see in an instant.

With the advent of digital age panoramic photography has boomed and multiplied its possible applications. Digital technology increases the flexibility of these documents to be altered, enhanced, rescaled, processed, resampled or fused in a ‘simple’ way. Computers are able to show the part of the panoramic picture corresponding to any direction and display it in real time. Thus, the feeling of a natural sweep through the panoramic image, which simulates plausibly turns to the viewer's head, is created.

Panoramic images can be projected on flat, spherical, cylindrical or cubic surfaces (**Figure 5**). To do this, it has to be solved the classic problem of mapping, which gives the optimal solution to represent on a flat support (either paper or digital) the surface of the Earth.

Panoramic images are on the basis to create virtual tours. This is an interactive non-metric product of that allows travelling through complex scenarios, making virtual check and supervision. They also permit the addition of extra information in a various formats (text, photos and multimedia resources) that are accessed interactively. Virtual tours are integrated into a compact interface in which an interactive map acts as a guide to explore and travel through the single panoramas.

One of the strengths of the panoramic photography and virtual tours is its portability. In the end, panoramas are standard digital images; virtual tours only need flash viewers or html5 support (built-in web browsers).

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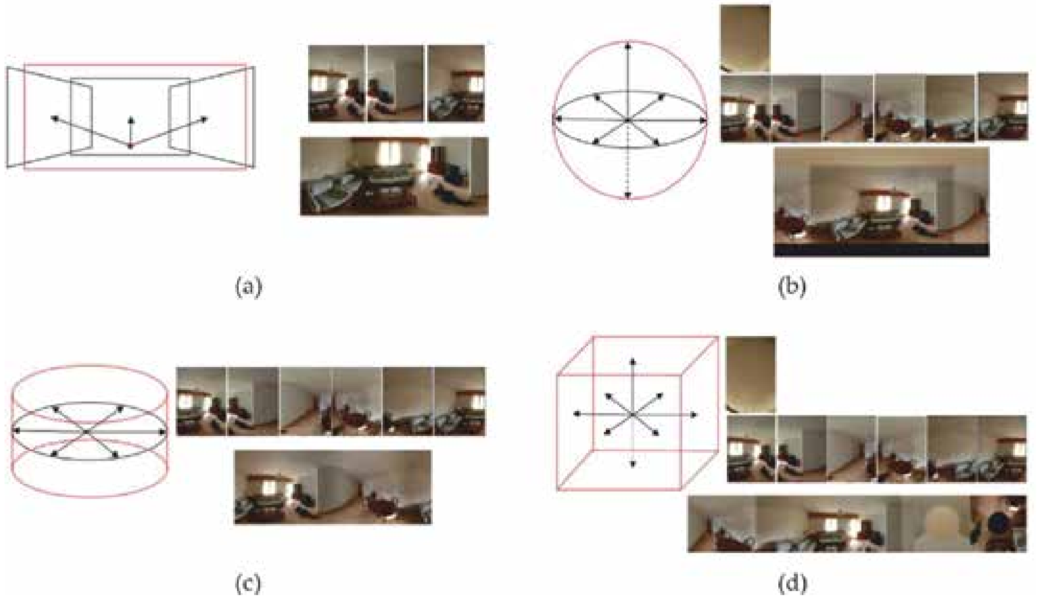

Figure 5. Different projections of panoramic imaging: flat (a), spherical (b), cylindrical (c) and cubic (d).

3.3. Terrestrial laser scanner

TLS is a non-invasive measuring instrument, whose use began to spread in the late 1980s. It produced many changes, not only in planning, but in the development and implementation of 3D projects [10]. It came as an adaptation of the previous aerial laser scanning (ALS) and LiDAR (light detection and ranging) systems. Using TLS in 3D reconstruction of small crime scene or large area disasters is a powerful line of work in forensic engineering. The simplicity and visual effectiveness of graphics obtained directly in data acquisition phase should not hide the complexity of further discrimination and categorization processes, absolutely necessary if we want to accomplish the forensics' requirements. The massive and automatic capture of 3D metric information is its main and advantageous feature. Unlike other technologies, in which operators only select the most significant points in order to geometrically define the scene, TLS is based on the concept of 'blind' and complete measurement by means of using an active sensor able to acquire millions of points in just a few seconds.

TLS acquires point clouds: a set of three-dimensional points on a Cartesian system. In addition to *X*, *Y*, *Z* coordinates, in every single point, it will be added some attributes (additional information), such as its radiometry (RGB values of colour), its intensity.

There are several physical principles on which this TLS technology is based, and there are also many different brands, models and built on solutions provided by manufacturers. That implies that there is not standard TLS equipment able to solve all the forensics' requirements (measurement accuracy, distance range, radiometry detection, angular capability, etc.). By contrast, forensic users have to assess the features and performance of the TLS so that they fit their requirements.

Given the physical basis underlying the measurement of distances TLS can be classified into three groups: flight time, phase shift and an optical triangulation (**Figure 6**).

- **Flight time.** This principle is based on the accurate measurement of the time invested by the laser pulse to travel between the emitting source and the object. Knowing the flight time, and being the speed of light a constant, distances can be deduced very simply. To complete the definition of the vector two angles have to be measured simultaneously: horizontal and vertical angles. Having the distance and angles referred is easy to deduce the three Cartesian coordinates, and it is a TLS work. The laser beam sweeps the area of study really quickly (from 1.000 to 100.000 point per second), taking the measure of the coordinates of every single point according to the density set up by the user. The scanning effect is achieved using oscillating mirrors that allow small and precise angular changes. Compared to other TLS, flight time allows larger measuring distances, even kilometres. However, they are less accurate than the optical triangulation ones. Its accuracy is between a few millimetres and two or three centimetres, since the laser beam divergence increases with the distance. Similarly, the accuracy will also be determined by the minimum possible angular value between two successive points. In forensic analysis, this kind of TLS fits the requirement of large scenarios in open areas, that is natural disasters or terrorist attacks.

- **Phase shift.** These TLS take the principle of electromagnetic distance measurement used by topographic devices, which is based on calculating the distance between the laser scanner and the object point by determining the phase shift between the transmitted and received wave. As the above method, two angles measured in perpendicular planes (horizontal and vertical) are also collected for the location of each point. Medium distances range (up to 100 m on average) and a reasonable accuracy (around a few millimetres) make that this type of TLS are the most suitable for general purposes, being broadly used in inside crime scene and also in small areas outside.

- **Optical triangulation.** Unlike the above, where the distance is calculated directly, this technique is based on a simple principle of triangulation. It is intended to solve a triangle from the known value of the baseline (one side) and the measurement of the adjacent angles. The baseline is defined by the distance between the laser emitter and the camera that receive the light reflected on the object while the adjacent angles are determined during the measuring operation. By a simple mathematical operation, the position of each point can be calculated. This type of laser scanner is very accurate, below the millimetre. However, its distance range is limited to a few meters. Thus, they are the most convenient equipment for short-range and high precision measurement, for example anthropologic studies or archaeological remains.

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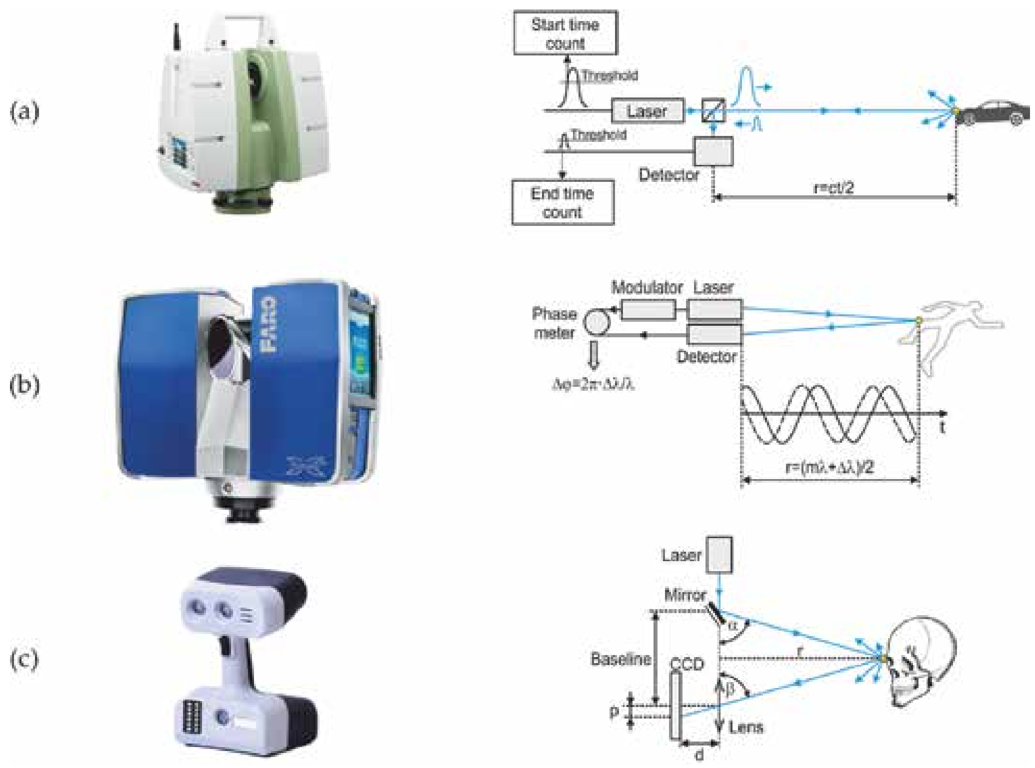

Figure 6. Measurement principles of TLS systems. Time of flight (a); phase shift (b) and optical triangulation (c). Images courtesy of Leica, Faro and Artec respectively.

In order to choose the appropriate equipment, it must be considered the best balance between accuracy, completeness, resolution, and timing in data capture and processing.

3.4. Unmanned vehicles in Forensic scene

In Forensic analysis, unmanned vehicles could be classified into two types: aerial or terrestrial. Basically, differences are related to the platforms but not to the payload. They share the common problems related to sensor hybridization, mission planning, electronics and telecommunications. Due to its versatility and its increasing popularization, this section is devoted mainly to the aerial ones.

Since the arrival of digital photogrammetry in the early 1990s is remarkable, the development of low-cost devices and procedures is available to all users [11]. Unmanned aerial vehicles (UAVs), also known as remotely piloted aircraft systems (RPAS), allow to obtain aerial imagery and mapping products whose applications extend to several scientific fields and therefore in forensic analysis. UAV can fly dangerous areas where forensic researchers can explore, document and reconstruct the scene safely and quickly.

Aerial imagery has the ability to display portions of the object from a different perspective. Oblique images, those that are not restricted by the verticality of the shot, open a wide range of applications in forensics, either as a supplement to the understanding of the scene, or for extracting added information to the terrestrial one. Aerial images can be integrated into more complex systems, such as GIS, by georeferencing. Surveying tools such as GNSS provide 3D information of significant points in the aerial images in order to link them to global coordinate reference systems.

There are basically two built-on types of UAV: rotary wing and fixed wing (**Figure 7b**). The most extended are the electrical multirotors, being the most common configurations those which have 4, 6 or 8 propellers (**Figure 7a**). Multirotors improve the performance of radio control helicopters increasing manoeuvrability and stability in the air. Electrical engines also are able to reduce vibrations, an extremely important matter to achieve high-quality images. On the other hand, the presence of multiple engines increases the security by diminishing the possibility of failure of any component.

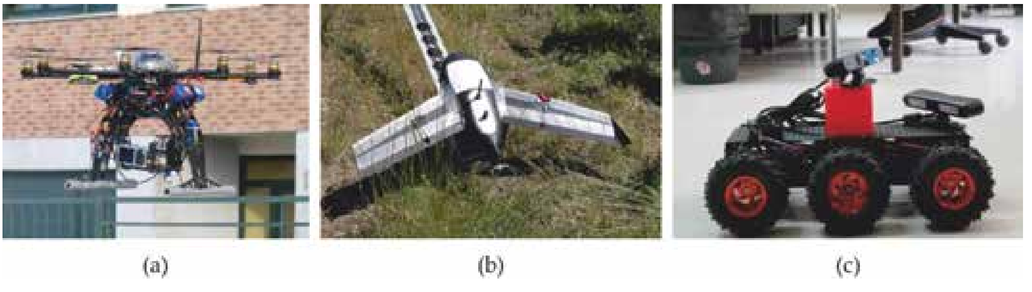

Figure 7. Unmanned vehicles employed in forensic science. Multirotor (a); fixed-wing (b) and ground vehicles (c).

Mission planning optimizes the process of data collection. Flying over complex scenarios, the operator can take advantage of the high manoeuvrability of multirotors turning off automated control of the route and turning on manual control. For this purpose, real-time display devices are available putting virtually the operator in the point of view of the camera in the air.

UAV platforms are composed of independent devices, being possible to customize the configuration of the payload. This makes possible to have on-board different types of cameras: SLR cameras, video, thermal, multispectral. The possibility of integrating the data coming from different sensors provides a new level of interpretation to complex and large scenarios in forensic analysis.

Regarding the terrestrial unmanned systems (**Figure 7c**), also known as unmanned ground vehicles (UGV), they can be used for inspection or target location in indoor areas or GNSS-denied environments. Their size can be easily scaled accordingl to the mission objectives and payload. They share the advances in the UAV field, such as the mission planner for outdoor environments. However, they take advantage of robotics, being possible add as payload a remote controlled manipulator arm, for inspection tasks. In all cases, the autonomous exploration of the scene requires a sensor hybridization of passive (photogrammetric) and active (laser) sensors for a real time mapping and localization.

3.5. Complementary techniques and their interrelation

Due to its transversal and multidisciplinary character, geomatic techniques are suitable and provide added value in forensic science, from crime scene reconstruction to post-mortem analysis. The main common feature of the individual techniques that could be grouped into the geomatic science, it is their non-invasive and non-destructive character. The taxonomy of the 3D measuring methods is structured according to the electromagnetic energy interaction, been mainly the analysis and processing of reflected or transmitted energy. However, each one has its own advantages in terms of achievable precision, data resolution, flexibility, portability or radiometric resolution. In order to summing up all and with the aim of providing a comprehensive classification, in **Figure 8**, a selection of the sensors and techniques currently

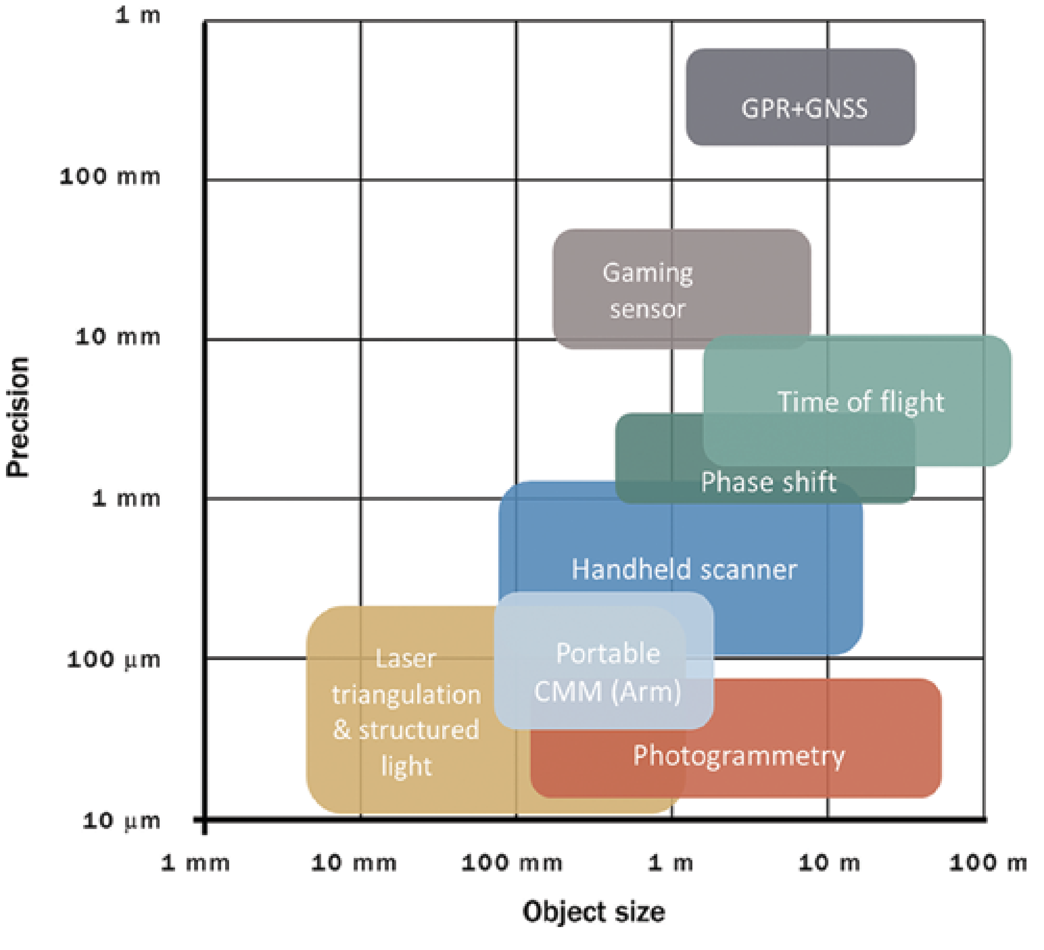

Figure 8. Relationship between different geomatics methods employed in forensic science.

used in forensic science are ranked according to their precision and the size of the studied object and/or scene. A more detailed description of the individual techniques and their variants can be found in [12].

The portability is a common relevant factor, due to the need of moving sensors around the object or scene to carry out a proper data acquisition. Although in some cases, the evidence could be moved to the forensic lab, geomatic sensors should provide a medium degree of mobility and portability.

Although some geomatic techniques have showed to complement a full spectrum of possibilities, some of them could provide added value in forensic analysis.

In order to surpass the limitations of precision and resolution of TLS, focused on the recording of medium or large scenes, sometimes more precision and resolution are required for the 3D modelling of small objects or evidences. In these cases, the coordinate measuring machine (CMM) or handheld scanner could offer an alternative. These systems allow tactile and discrete point measurement and massive point acquisition using a linear scanner. However, the main problem of CMM is its portability and its lack of radiometry.

CMM and handheld techniques are highly useful in soft and nonparametric surfaces where any contact will disturbance the previous measurements, or worse, affect the preservation of the evidence. The unique geometric counterpart is the limitation in depth acquisition, being unable to acquire data in holes of small diameter or deep holes.

On the other hand, sometimes the precision is not always a critical factor, being crucial the ability to discover hidden information in the scene. At this point, the ground penetrating radar (GPR) has been proved as useful technique for detection of underground structures, mainly clandestine graves [13] but not limited, being other alternatives the search for buried weapons, drugs, hazardous waste, etc.

The main advantages are the non-invasiveness property and the capability to cover wide areas (outdoors and/or indoors). However, its applicability is limited to the specialized training in data acquisition, processing and data interpretation [14], being also critical the data acquisition planning, since the bigger the suspicious area the lower efficiency in its detection. Moreover, this sensor should be combined with an alternative system to georeference it according to an external reference frame. Due to its simplicity, portability, and appropriate precision, the GNSS systems are chosen to connect the GPR data with a global frame.

For a more extensive review of geomatic/geoscience methods applied to forensic search, please refer to [15].

4. Progress and challenges

This section will be focus in three new approaches into geomatic applications in forensic analysis. Firstly, recent advances in computer vision and photogrammetry are described; secondly, highly portable active sensors, known as gaming sensor, as introduced as an low-

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cost alternative; and finally, the indoor mapping systems are presented, as a new way to acquire large amount of data in movement.

4.1. Computer vision and Forensic analysis

The recent advancements on flexibility, automation and quality due to the algorithmic evolution in photogrammetric and computer vision techniques will be the topics of this subsection.

Although for post-mortem examination, two-dimensional photography has been established as 'gold standard' [16], the possibility of getting 3D information overpasses the 2D photography. The main reason is that there is not any data projection, so it is possible to measure different invariant (e.g. distances, surfaces) without any deformation. Some authors have worked with the orthophoto as a metric support of the forensic analysis, but the lack of depth or Z coordinate limits its exploitation in forensic analysis. Other authors have tried to provide 3D metric capabilities directly to the image, generating the solid image, which encloses the RGB values together with *XYZ* coordinates. However, this approach requires other sensors such as laser scanners.

For these reason, the complete 3D documentation and modelling based on images are being employed in several forensic analysis of evidences, such as pattern injuries against injury-inflicting instrument in weapon analysis [17], bite mark identification [18], wound documentation and analysis [19], or forensic pathology [20].

Although image-based modelling methods have required a long learning curve, the recent advances in photogrammetry and computer vision algorithms and software tools have allowed the automation of workflows opening the use of these tools to non-experts users [21]. In [21], it is shown how the image approach for 3D reconstruction and dimensional analysis of crime scenes fulfil the forensic requirements in terms of automation, flexibility and quality (**Figure 9**).

The hybridization of both disciplines has made it possible advances on three milestone issues: (1) automation of features extraction, matching entities and image orientation under unfav-

Figure 9. Example of use of the photogrammetry in a crime scene.

ourable conditions; (2) the guarantying of quality in results by means of robust procedures providing greater accuracy and reliability; (3) flexibility, by making it possible to work with any type of image (visible, thermal, infrared, etc.) and any type of camera (calibrated and non-calibrated). However, the main milestones regarding image-based modelling currently are twofold: (i) cope with texture-less objects (ii) obtaining CAD models from point clouds, which are more useful in forensic analysis.

Since texture-less objects could appear in any kind of forensic scenario, in the first stage of 3D reconstruction (interest point detection), the matching results will be poor. That is because the local image features (through their descriptors) are unable to provide a robust correspondence among them. For this reason, they present a significant challenge in computer vision and photogrammetry, especially for the image detectors and descriptors. If high amounts of texture-less object are present in the scene, the number of wrong correspondences in the image orientation process (see Section 3.1) could surpass the efficiency of robust methods, and as a result, the camera orientation would be incorrectly determined.

The most novel automatic approaches to afford nonparametric forms are based on 2D and 3D triangulation strategies, which generate a surface model. Nonetheless, this falls far from what is expected of CAD models in forensic analysis, which must be shaped as solid models with topological relations and properties. Nowadays, there are only semi-automatic approaches to generate solid models based on three methodologies: (1) fitting of basic primitives for those simple objects which are represented by means of a parametric shape; (2) performing cross-sections that, accompanied by shape extrusion operations, enable the generation of the corresponding solid model; (3) fitting of more complex functions of B-spline type (NURBS-non-uniform rational B-spline) which, through cross-sections and sweeping operations all along a path make it possible to generate the solid model. However, all of these methods need manual interaction at the moment of point clouds segmentation and results refinement.

4.2. Gaming sensors and Forensic analysis

Gaming sensors were designed as motion sensors for the entertainment industry. Opposite to the active laser system, they do not generate directly a 3D point cloud. Instead, they create a range image, where every pixel of 2D image is linked to the distance or depth. Their potential for the 3D mapping of objects and indoor environments was recently discovered, opening new fields of applications in forensics (**Figure 10**). These sensors, also known as RGB-D cameras, are designed based on high frame-rate data acquisition. The main disadvantages are their low accuracy in distance measurement, and their low spatial resolution (understood as pixel size). Despite these drawbacks, these new RGB-D sensors are a low-cost alternative to other well-established active laser systems, such as the TLS or photonic mixer devices (PMD). Their autonomy, portability and high acquisition frame-rate have revolutionized the field of 3D documentation [22].

The first generation of gaming sensors had a quick diffusion, both in the entertainment industry and in scientific community [23], being especially analysed from a geometrical point of view, since different sources of noise could affect them. However, the second generation of gaming sensors, distributed in mid-2014, has been the subject of a limited number of study

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Figure 10. Gaming sensor employed for crime scene documentation. Image courtesy of Faro.

cases. In addition, they were released with severe changes in the measurement system, which is different from the former generation, based on the structured light principle. The new ones incorporate time-of-flight technology, increasing the spatial resolution and allowing the possibility of working outdoors.

Due to its recentness, their applicability in forensic science is being proved by recent studies such as crime scene modelling [24]; post-mortem analysis [25]; body measurements for anthropometric purposes [26]; and gait recognition [27], becoming a useful tool since does not require the collaboration of the subject. Alternative applications of gaming sensors are real-time surveillance and biometric studies, as face recognition and face analysis [28]. At these tasks, the active light source could cope with the illumination changes of RGB passive methods (which could disturb the final 3D model), making gaming sensor an inexpensive way for real-time analysis. However, the resulting range image could be affected by some geometrical problems such as the presence of holes in the image due to occlusions, the inaccurate depth computations, the measurement noise and the low spatial resolution.

Nowadays, these problems are overcoming by the second generation of gaming sensors and the new developments of kinect fusion libraries [29]. These libraries are focused in solving the position of the individual range images and merge them into a 3D scene by means of a volumetric integration.

Together with the advances in gaming sensors, some promising outcomes are being developed in forensic face analysis thorough local feature extraction methods [30]. Feature extraction can be driven in two ways: by means of the position and shape of facial features, known as geometric-based; or by means of a construction of global/local descriptor also known as appearance based. The last ones are widely used, being the local face descriptors those which have better performance in non-controlled environments.

In biometric forensic studies, a common disadvantage of gaming sensors and visible methods is their vulnerability to spoofing (synthetic forged version of the biometric original). This weakness is being overcome by thermographic cameras. The new challenges try to solve the integration of different electromagnetic range images, for example thermal with visible, dealing with a problem known as multimodal matching [31].

4.3. Indoor mobile mapping systems and Forensic

Indoor mobile mapping systems could be defined as a complex set of sensors that allows spatial data acquisition in movement. This is especially useful in forensic indoor scenarios when some environmental conditions become dangerous for humans (chemical risks, danger of collapse, etc.) or simply in those places really complex where a lot of laser or photographic stations would be required [32]. The set of sensors is composed by two groups of electronics devices working together on a self-moved vehicle [33]. On the one hand, navigation instruments are in charge of the guidance of the vehicle, providing an automatic motion through a planned route. On the other hand, the role of geomatic sensors, such a digital cameras or laser scanners, is the acquisition of spatial data (images and point clouds), as described in previous sections. Both geomatic and navigation sensors are controlled by a microprocessor, so that measurements are done simultaneously. Furthermore, each set of spatial data is associated to a time stamp which links it with the positioning settings of the mobile unit in every instant [34].

Navigation devices could integrate high-precision GNSS, advanced inertial technology (three axis accelerometers and gyroscopes), magnetometers and pressure sensors to calculate orientations and heights. The indoor georeferencing is done by using measures from GNSS outdoors. The inertial measurement unit provides uninterrupted data of the true position, roll, pitch and yaw of the system when moving indoors [35].

Data acquisition is performed when the vehicle is in motion following a planned route whose purpose is to cover all the parts of the scene. There are two possibilities in the route configuration: making a round trip, or a back and forth displacement. The strategy selected will come as a consequence of the ground characteristics in the area inspected, since obstacles should be avoided in order to have a continuous path. If the last option is not possible, data will have to be acquired in different sequences, and then a registration procedure will put all the sequences in the same coordinate system, considering that there are overlapping areas within consecutive sequences. When data acquisition is finished, the absolute position of each single point is calculated from the data of the trajectory of the navigation unit, making it possible to obtain a complete 3D point cloud of the inspection area.

The time needed for indoor mobile mapping systems during data acquisition is equal to the time that a person needs to walk through the area of interest; with the noticeable time reduction regarding other systems and an important cost decrease [36].

In forensic engineering, indoor mapping systems (**Figure 11**) stand out for their suitability for the acquisition of big and complex indoor scenes, as they perform automatically multiple processes such as dynamic scanning and self-determination of the autonomous trajectory of the vehicle. As a result, 3D metric information is obtained in real time as the vehicle completes its path.

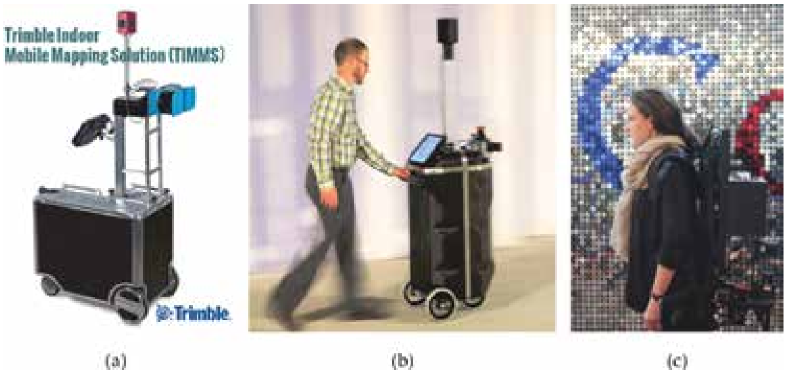

Figure 11. Indoor mapping systems: TIMMS (a), iMMS (b) and CARTOGRAPHER (c). Images courtesy of Trimble, SmartGeometrics and Google, respectively.

5. Concluding remarks

This chapter has described the close connection between geomatics and forensics. We analysed the main areas in which geomatics can be useful for forensic analysis, and detailed the main requirements that spatial information must fulfil to meet the needs of forensic studies. There has been a brief and understandable overview to the main geomatic technologies currently used, describing their fundamentals and emphasizing its usability in forensic analysis. Section 4 was devoted to the three most promising areas in which scientific community is working.

The new technological advances have yield an increase of data sources, each with their own technical specifications in terms of resolution, precision, quality, etc. At this point, data integration is a valuable tool in forensic engineering, since allows synergic combination of these diverse and heterogeneous sources into a reliable and accurate way, which contributes to a robust interpretation of the crime scene.

Moreover, there are new sensor advances which are still in a deployment phase. For this reason, their direct application in forensic science is not efficient. However, they have a great potential in forensic and only require a customization and algorithm adaptation in order to ease their use and maximize their performance. In a similar way, other sensors, that could fulfil these needs, have not yet been integrated in the common forensic workflows, due to their cost and/ or difficult to use (specialized training).

The wide variety of geomatic science solutions (hardware and software), their complexity and the difficulty of integration can divert the non-expert user from the real aim: to assist forensic researchers. In order to prevent this, a high degree of automation is desirable for an effortless implementation in the forensic daily routine. The automation is a key issue for the non-expert users of geomatic techniques, as well as, the provision of user interfaces focused on the forensic needs instead of the geomatic ones. In this regard, the developments of specifics tools for forensic tasks are aligned with this objective.

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Chapter 2

Forensic Analysis of the Wakayama Arsenic Murder Case

Jun Kawai

Additional information is available at the end of the chapter

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Abstract

This is a review paper of forensic analysis of a murder case of Wakayama arsenic poisoning incident. The influence of this case on scientific research was not small in such a way that papers related to PTSD, disaster medical, copycats, chemical analysis, unwanted chemicals in food, terrorism, and so on were published. The forensic analyses on Wakayama arsenic poisoning incidence have characteristic that SPring-8, a largest synchrotron radiation facility, was used, as well as many other analytical techniques, but now most of the forensic analyses submitted from the prosecutor have been revealed to be fabrication, hiding the truth by logarithmic calculations, and therefore not scientific. Most of the testimonies at the court by the analysts were also lies. Examples of such false analyses are explained.

Keywords: X-ray fluorescence (XRF), inductively coupled plasma (ICP), synchrotron radiation (SR), atomic absorption spectrometry (AAS), Wakayama arsenic poisoning case

1. Outline of the Wakayama arsenic murder case

Four people were killed by arsenic poisoned curry at a summer festival on July 25, 1998, and other 63 participants were heavily injured but survived though they ate the poisoned curry. It is still not well known whether some embryos or fetuses were included within 63 or not, because the personal data is not open. The arsenic intake was authorized by the arsenic analysis of urine. One of the two curry pots was poisoned during the cooking for the preparation of the festival in a small town in Wakayama city. Wakayama is a city near the Osaka Kansai International Airport. Although the outline was reported by Kimura [1], a brief chronologically ordered outline should be described here.

The curry was cooked in two pots in a garage of a festival organizer's house. The curry was cooked from noon till 3 pm there, and then moved to the festival venue. During the noon and 3 pm, the curry pots were kept boiling by housewives of the organizers in turn. One of the housewives there, Mrs. H, was arrested on October 4 and prosecuted as the murder on December 29. She was sentenced to death on December 11, 2001, at the Local Court of Wakayama. Then again she was sentenced to death at Osaka Court of Appeal. Finally, May 18, 2009, the death penalty has been fixed at the Supreme Court of Japan. She has denied from the first until now, but she is now in the death row.

The only evidence was a paper cup found near the cooking site. This paper cup might have been used to poison the curry pot bringing arsenic. Powder of about 35 mg arsenic oxide, As_2O_3, was left inside of the paper cup. Her husband had arsenic oxide powders as white ant pesticide, as his job was white ant exterminator. Therefore the key forensic analysis was the identification of arsenic oxide powders between her husband's and the powder adsorbed on the inner surface of the paper cup. "High concentration arsenic" was found on one of her hairs, which was one of the several hundreds of hairs cut on December 9, 1998, by the police. These two evidences are the main reasons of her death penalty. The hair was analyzed by synchrotron radiation X-ray fluorescence (SR-XRF) and also by atomic absorption spectrometry (AAS). Several impurity elements in the arsenic oxide powders were analyzed by the SR-XRF and inductively-coupled plasma atomic emission spectrometry (ICP-AES), as was reviewed by Kawai [2]. Infrared (IR), ion chromatography/inductively-coupled plasma mass spectrometry (IC/ICP-MS), X-ray diffraction (XRD), scanning electron microscope-energy dispersive X-ray analysis (SEM–EDX), and many other chemical analysis techniques were used.

Because the chemical poison was used by the Tokyo subway sarin attack in 1995, the Wakayama arsenic case attracted large attention by mass media, such as television, newspapers, and gossip magazines, at that time for about 1 year duration. The forensic analyses were performed mainly by the National Research Institute of Police Science, Tokyo University of Science, St. Marianna University School of Medicine, Osaka Electro-Communication University, and Hiroshima University. It was well known to the public at that time that SPring-8, one of the third generation synchrotron radiation facility, a 1.5 km circumference accelerator ring of 8 GeV, was used for the forensic analysis. The forensic analysis of SPring-8 was just 1 year after it became in use. Since 2012, Kawai, the author of the present paper, found many faults in the forensic analyses in this case, of which documents were submitted to the court from the prosecutor, and again this murder case becomes discussed in Japan.

2. Influence on the academic researches of Wakayama arsenic murder case

The sarin attack at Tokyo subway was just a few years before this arsenic murder case. Therefore, many academic research papers on Wakayama murder case were published, which discussed the relation of the subway sarin attack. Some examples of papers related to the Wakayama case are as follows.

From the point of view of medical treatment at disasters, such as Matsumoto sarin attack in 1994, Tokyo subway sarin attack in 1995, Wakayama arsenic murder case in 1998, and other bombing terrorism in Japan from 1990 to 2002, were compared and discussed a future risk of terrorism and emergency management [3]. However this kind of lessons were not used at the earthquake, tsunami, and nuclear disaster at March 11, 2011, Japan. Intoxication with arsenic curry was reported in the same journal [4]. Bioterrorism threats to food were discussed [5]. Related to the subway sarin attack, importance of information sharing systems among hospitals was discussed [6], because the victims were distributed to many hospitals in Wakayama city. The patients were first treated as taking rotten food, then organophosphorus pesticide or cyanide. Therefore the information sharing was important. "FACT-Graph", a data analysis method, was used to analyze keywords "cyanide" and "arsenic" as nodes of the graph analysis [7]. PTSD (posttraumatic stress disorder) was discussed [8]. Copycat poisoning cases, such as sodium azide (NaN_3) and cyanide incidents in 1998, were discussed from the view point of chemical disaster response system [9]. A vast number of copycats appeared just after the Wakayama incidence. The importance of quality assurance against incidents of unwanted chemicals in food such as arsenic, cadmium, mercury, and lead, including Wakayama case, were systematically discussed [10]. Case seen in clinical practice at intentional acts such as nicotine, arsenic (Wakayama), rat poison, and methamidophos were discussed [11]. Economic impact of arsenic contamination in Bangladesh was studied referring to the Wakayama incidence [12].

Concerning medical treatment, dermatology [13–16], neurology [17], and many other papers were published.

Between the Wakayama incident on July 25, 1998, and the accusation of the suspect on December 29, 1998, many copycats were appeared mimicking poisoning [18], as mentioned above, using different chemicals, such as sodium azide, pesticides, and cyanide. At the first stage of Wakayama case, cyanide was erroneously detected, and this point was studied from the view point of chemical analysis [19–21].

Related to analytical chemistry, ICP-AES analysis of impurity elements of arsenous oxide in order to identify the As_2O_3 in paper cup and that of Mrs. H's husband were reported by researchers of National Research Institute of Police Science, Japan [22–24]. Forensic analysis using SR-XRF analysis was reported [25–29]. The importance of SR-XRF for forensic analysis was also reported in an encyclopedia [30]. LC/MS [31] and HPLC/ICP-MS [32] were reported as arsenic chemical state analysis methods related to Wakayama case. A screening method of inorganic arsenic in urine was developed [33]. A large number of other papers can be found at Google Scholar by the key words, "Wakayama arsenic".

3. Identification of arsenic oxide powders

There were eight kinds of arsenic oxide evidences. Mr. M, who was a brother of Mrs. H, kept arsenic oxide powders, which were originally used as the white ant pesticide by H's husband, long before the incidence. The evidences were as follows: (1) Paper cup, (2) M's green 50-kg can, (3) M's milk can, (4) M's white can marked "Heavy", (5) M's brown Tupperware, (6) A milk can found at H's old house (This house was at that time Mr. T's house, and we call this "T's milk can"), (7) A plastic container found at H's kitchen, but a few particles of arsenic powders were attached on the inner surface of the container, and (8) arsenic oxide crystals found in curry pot. These are tabulated in **Tables 1** and **2**.

No.	Evidence meaning	As wt% [34, 35]	As_2O_3 wt% [36]
(1)	Paper cup	74.80	98.7
(2)	M's green 50-kg can	77.0±3.4	101.6
(3)	M's milk can	77.6±4.0	102.4
(4)	M's white can, "Heavy"	68.6±2.2	90.6
(5)	M's brown tupper	65.7±1.6	86.7
(6)	T's milk can	48.7±0.8	64.3
(7)	H's kitchen container	Not available	Not available
(8)	Curry pot crystal	Not available	Not available

Table 1. Arsenic oxide powder evidences.

No.	Evidence meaning	Na	Mg	Al	P	Ca	Fe	Zn	Ba	Starch
(1)	Paper cup	393	16	138	7	79	146	297	5	0
(2)	M's green 50-kg can	35	6	0	5	3	36	203	0	0
(3)	M's milk can	32	5	0	5	6	28	201	0	0
(4)	M's "Heavy"	59	105	308	85	3965	303	178	2	+
(5)	M's brown tupper	70	49	170	86	147	861	205	21	0(+)
(6)	T's milk can	87	203	2266	234	>1%	153	124	7	+(0)
(7)	H's kitchen container	NA	NA	NA	NA	NA	NA	NA	24–36	0
(8)	Curry pot crystal	NA	NA	NA	NA	NA	NA	NA	23	NA

NA: Not available.
NA: Not available.
+: Positive.
0(+): Three tests not detected, one test detected, out of 4-time tests.
+(0): Three tests detected, one test not detected.

Table 2. Light element concentrations of arsenic oxide powder evidences (ppm).

The elemental concentrations analyzed using ICP-AES by the National Research Institute of Police Science are shown in **Table 1**. The judge wrote the death sentence by describing that one of the arsenics powders from evidences (2)–(7) was brought by H using the paper cup and put into the curry pot. However it is strange that the arsenic oxide powder concentration of the paper cup was 98.7 wt%, but evidences (4)–(6) were significantly lower than the paper cup. Finger prints were not found on the paper cup. It was known from testimony that the H's

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husband bought the 50-kg green can (2) more than 10 years before, and distributed into several small cans, (3)–(6). The prosecutor guessed that H brought the arsenic powder from her old house (6) using the container (7) to her new house kitchen at house-moving. Then she brought the arsenic powder using the paper cup (1) to the curry pot.

The National Research Institute of Police Science also analyzed five impurity elements, Se, Sn, Sb, Pb, and Bi, in (1)–(6). The chemical properties of these elements were quite similar to that of As, that is to say, Se is neighbor to As in the periodic table, Sb and Bi are in the same column, Sn and Pb are neighbors of Sb and Bi respectively, and thus they co-existed from earth crust. The concentrations of these elements were plotted as "radar chart" as shown in **Figure 1**, by the National Research Institute of Police Science (NRIPS). Similar radar charts of arsenic oxide powders from different industries are shown in Refs. [22] and [23]. However I found that the concentration ratios of Se/As, Sn/As, Sb/As, Pb/As, and Bi/As were multiplied by 1,000,000, then the logarithms were calculated and the radar chart was plotted by NRIPS. The pentagon radar charts of six evidences well overlap each other and looks like the arsenic oxide powders were identical as shown in **Figure 1**. However, both the 1,000,000 times and the logarithm are unfolded, and the radar chart is replotted including As concentration [37], then the hexagon of the paper cup (1) is significantly different from those of H's arsenic powders (2)–(6), as is shown in **Figure 2**.

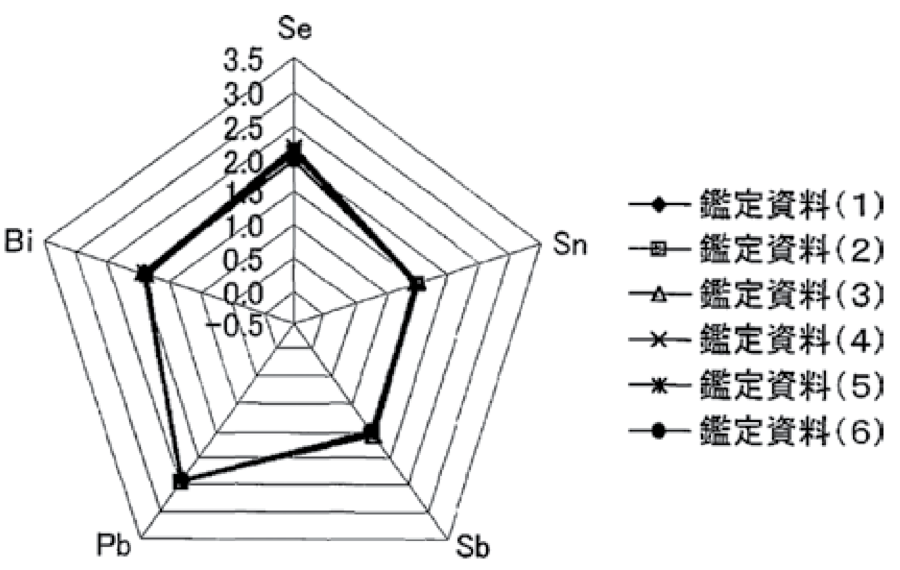

Figure 1. Radar chart of six evidences (1)–(6) taken from a document of the National Research Institute of Police Science, Japan. The document is a public document, not a copyrighted matter.

The hexagon radar chart is interpreted as follows.

1. The regular hexagons mean the same root as M's green 50-kg can (2).

2. Large regular hexagon means that the arsenic powder was more diluted. H's husband used diluted arsenic oxide powders for white ant pesticide.

3. A slight distortion from the regular hexagon means the error of quantitative analysis as well as inhomogeneity of arsenic oxide in a can. Evidences (2)–(6) were sampled five times and then analyzed five times. The As concentrations of evidences (2)–(6) in **Table 1** are displayed as averages ± standard deviations of five time analyses.

4. Significantly distorted hexagon means different roots, such as the paper cup (1). Once, one of the Bi concentration data of M's "Heavy" (4) had a small analytical error in its concentration out of five data of NRIPS, and the hexagon was distorted. Such one-time error in five measurements can be detected by the distortion: very sensitive to different root.

The root or origin of the paper cup (1) is significantly different from M's green can (2). The multiplication of 1,000,000 and logarithmic calculation was in order to hide this truth.

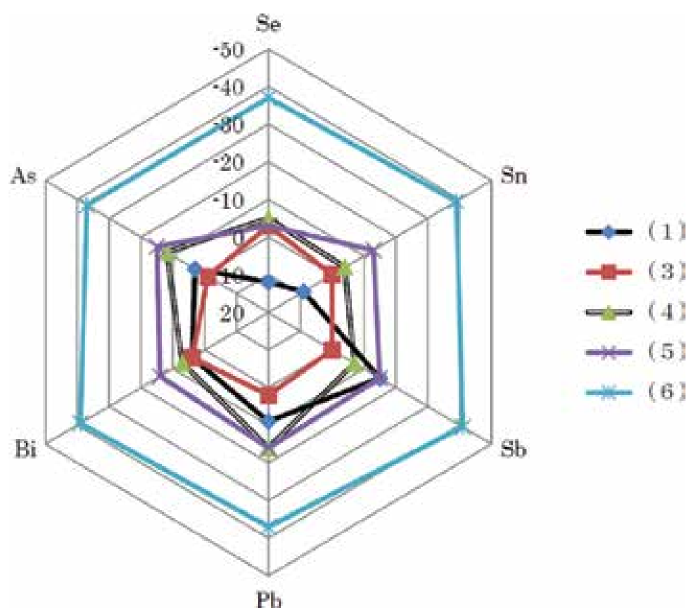

Figure 2. Unfolded radar chart taken from Ueba and Kawai [37] with permission.

The legal document of the National Research Institute of Police Science concluded that the arsenic oxide in the paper cup (1) and H's arsenic oxide powders were less than 50% identical [38]. The small difference between paper cup (1) and H's arsenic shown in **Figure 2** could not be recognized by the XRF spectra of SPring-8. Two representative SPring-8 XRF spectra measured by the Tokyo University of Science are shown in **Figures 3** and **4** [39], from which one cannot recognize the difference of the root. Though it has been revealed that spectra were measured only once for most of the evidences [40], the Tokyo University of Science concluded [39] that paper cup (1) was 100% identical to the H's arsenic oxide powders (2)–(7) in

Table 1. The details of the SR-XRF method at SPring-8 was reported in Refs. [27, 28], and it is found from these papers that the precision of the SR-XRF quantitative analysis was not high enough for the present forensic analysis, and thus the discrimination was not possible. The SR-XRF analysis conclusion was a false conclusion forced by the prosecutor [37].

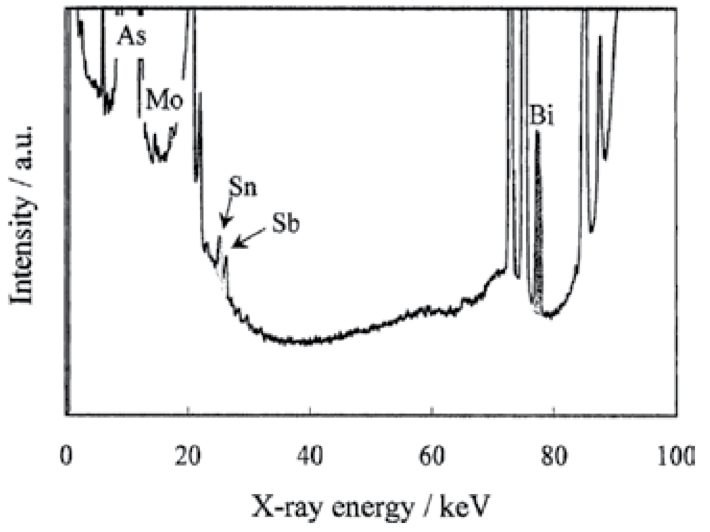

Figure 3. SR-XRF spectrum of paper cup (1), taken from the legal document of the Tokyo University of Science [39]. The document is a public document, not a copyrighted matter.

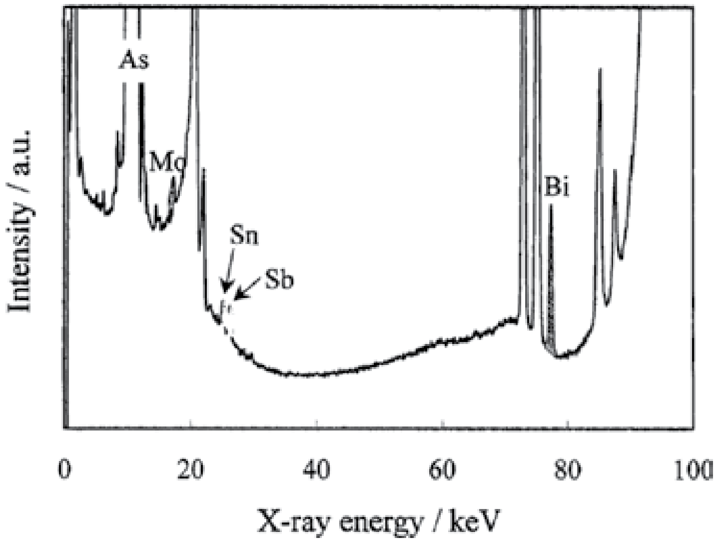

Figure 4. SR-XRF spectrum of M's green 50-kg can (2), taken from the legal document of the Tokyo University of Science [39]. The document is a public document, not a copyrighted matter.

4. Hair analysis

H's hair was analyzed by St. Marianna University School of Medicine, using AAS (atomic absorption spectrometry) after NaOH digestion and hydride generation technique. They found 90 ppb As^{3+} in her hair. The method was the same as reported in Ref. [41]. St. Marianna University knew that As^{3+} was not appropriately analyzed when using the method of Ref. [41], and thus they had not analyzed As^{3+} from 1984 to 1997 [42]. However they analyzed As^{3+} in 1998 in the forensic analysis of H's hairs and concluded that 90 ppb As^{3+} was exogenously attached to her hair. They used an old atomic absorption spectrometer, which was made in 1970s, i.e. too old, using paper and a pen-recorder, and measured the peak height with a rule. In early 1990s, the chemical state analysis of arsenic had been performed by an ion chromatography (IC)/ICP-MS or an HPLC/MS [43] and the analytical instruments had been computerized. The advancements of these analytical instruments were due to the zenith of the semiconductor industry [44]. Therefore St. Marianna University obtained As^{3+} concentration using an old non-computerized AAS machine, where chemical state of arsenic compounds changed depending on pH. Therefore the forensic analysis results on the chemical state of arsenic of H's hairs were quite doubtful.

Many of H's hairs were also measured at BL-4A of KEK-PF (Photon Factory at High Energy Accelerator Research Organization, a synchrotron radiation facility in Tsukuba), and found an arsenic particle on a hair. The synchrotron radiation beam size was 4 or 1 mm width along with the hair shaft. It is still not clear how many hair shafts were measured and how many particles were found. It is said that arsenic particle was found on only one or two hair shaft(s), using 100 h of the KEK-PF beam time for hundreds of hair shafts.

At SPring-8, the same hair was measured but arsenic signal was not detected and testified that the spectral data was deleted [44].

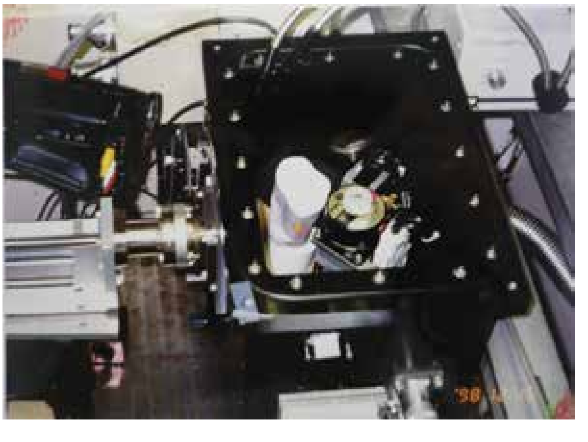

Figure 5. Photo of measuring the paper cup (1) at the beamline BL-4A of KEK-PF, taken from the legal document of the Tokyo University of Science [39]. The document is a public document, not a copyrighted matter.

At KEK-PF, the paper cup (1) was measured, where arsenic powder was adsorbed on the surface of the cup (**Figure 5**). The hair shafts were measured at the same measurement chamber at the same beam time using a holder shown in **Figure 6** [45]. The hair and the paper cup were handled carelessly and cross-contamination might have been happened. The detection limit of arsenic at KEK-PF was worse than 90 ppb, and thus the SR-XRF analysis results contradicted with the AAS results.

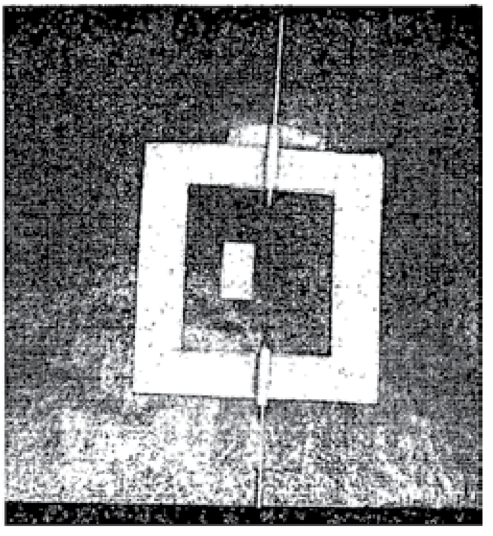

Figure 6. Photo of hair shaft holder used at BL-4A of KEK-PF, taken from the grant report document of the Tokyo University of Science [45]. The document is a public document, not a copyrighted matter.

It should be pointed out that scanning electron microscope energy dispersive X-ray analysis (SEM–EDX) was not used for the hair analysis. SEM–EDX was much easier and direct observation method compared with the SR-XRF line scan. Uranium particle attached to a hair shaft was clearly observed using an SEM–EDX rather than SR-XRF, which was reported in 2015 [46], but this type of SEM–EDX analysis was possible even in 1998. It is quite strange why such a direct observation using an SEM–EDX had not been performed in 1998.

5. Light elements analysis

The results of light elements analysis are summarized in **Table 2**. This table is the results of the National Research Institute of Police Science. M's green can (2) was pure arsenic oxide imported from China. M's milk can (3) was directly taken from the green can (2). If **Table 2** is compared with **Table 1**, the concentrations of the impurity light elements are mostly inversely related to the arsenic concentration. That is to say, when As wt% was less, then Al and/or Ca concentrations were higher, for e.g., M's "Heavy" (4), M's brown tupper (5), and T's milk can (6). However, paper cup (1) was different. Sodium and iron concentrations were higher, but arsenic concentration was also high. If saline water like the sea water about one litter was poured into another green 50-kg can, and then dried, sodium concentration could be explained, but the sea water should take the mass ratio Na:Mg:Ca=100:12:4, which was significantly different from the ratio in **Table 2**. Based on the discussion at Section 3 and the present section, the paper cup arsenic oxide powder (1) was taken out from another green can imported from the same industry, but this green can was once exposed to saline water containing Na, Mg, and Ca, when mining, smelted, shipping, or in use.

It is known that arsenic green 50-kg cans were imported from China twice in a year for total 10 years. The M's green can was one of the 60 cans imported at the same time by a ship, known by the shipping mark on the can. At the top, 10 or 15 cans were sold in Wakayama city in a month, and consequently at least more than one hundred cans were sold in Wakayama city before the arsenic curry incidence.

Starch was found for several arsenic oxide powder evidences using infrared (IR) analyses twice and iodine-starch tests twice. M's brown tupper (5) and T's milk can (6) results were contradicted as shown in **Table 2**. The paper cup (1) did not contain starch, and if the sentence was correct, starch powder mixed in the arsenic disappeared when taken by the paper cup.

Barium is not a light element but was found in several arsenic oxide evidences. Barium was an impurity element in SiO_2 for M's brown tupper (5), because barium was not water soluble. Barium was an impurity element of Ca for T's milk can (6), because it was water soluble; calcium was due to the cement. However, the barium in paper cup (1) has not been analyzed whether water soluble or not. Based on these fact, Osaka Electro-Communication University and Hiroshima University, who performed forensic analysis according to the order of judge in 2001, concluded that paper cup arsenic oxide (1) was identical to either M's brown tupper (5) or T's milk can with the probability of 80% [47]. But this was wrong, because the concentration of arsenic was higher for paper cup than those of (5) or (6); also because of the discussion related to the hexagon radar chart in Section 3.

6. Summary

I have published comments on the forensic analyses on Wakayama arsenic poisoned curry [2, 34, 35, 38, 40, 42, 44, 47–55], and revealed many false and truth-hiding reports step by step. Nakai of the Tokyo University of Science published papers in order to refute the above comments, but the refutations were not successful, and recently he has kept silence. The prosecutor sought some authoritative professors who could write documents against Kawai, but failed to find. The earlier discussion in the literature was cited by Chemistry Views [56], Spectroscopy Now [57], and Russian review paper [58].

The false forensic analyses were documents of National Research Institute of Police Science, of the Tokyo University of Science, of both Osaka Electro-Communication and Hiroshima Universities, and of the hair analysis of St. Marianna University School of Medicine. These four forensic reports had main role in the death penalty of Mrs. H. Forensic analysis reports of other cases have been checked by me, and it was found that many of them were also false [44, 55]. Neufeld and Scheck [59] launched "Innocence Project" early 1990's and many death row prisoners were released from jail. The innocence project in US was based on DNA analysis, but many other forensic analysis methods have been improved [60] due to the innocence project. Compared Japanese situation with US, the quality of forensic analysis is poor as discussed above. The National Research Institute for Police Science is not an independent research institute and they use forensic analysis in order to arrest a suspected person, but not for the proof of innocence. This is a big problem for the administration of justice in Japan.

False of four main forensic reports in Wakayama arsenic case means that all the important forensic reports submitted from prosecutor are false in Japan.

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Chapter 3

Forensic Hydrology

Aldo I. Ramirez and Alejandra Herrera

Additional information is available at the end of the chapter

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Abstract

This chapter is intended to call the attention towards a relatively new topic in engineering forensics: forensic analysis in hydrology. This type of analysis can be seen as a useful tool through which it is possible, in a fully objective way, to determine the real causes, natural or human induced that made a natural phenomenon a disaster. This branch of forensic analysis and particularly of engineering forensics can be applied directly to the case of floods and droughts but is not limited to those extremes phenomena. In particular, the application of these concepts to case of floods looks immediate, but other applications such as drought analysis can be addressed too. In the case of flooding events causing material damages and even loss of human lives, forensic analysis can provide results that help to clarify responsibilities but specially to prevent that future disasters happen again. This chapter will provide important information for the new forensic hydrologists, a discipline with great future, especially in the context of climate change, which will increase the magnitude, and frequency of extremes.

Keywords: flood, drought, methodological guide, forensic analysis, hydrology

1. Introduction

The term ‘engineering’ makes reference by definition, to the voice ‘to produce’. Engineering can be considered as part of the technical sciences that put together the general and abstract scientific knowledge and the technology, being that as human activity, it is present in the design, construction and testing; maintenance, conservation and operation of structures, machinery (fixed and mobile), installations and systems [1].

Forensic activities are primarily oriented to the establishment of the origin and causes of a fact; that is precisely the reason why engineering should be involved is such activities, giving birth by this to what it is known as forensic engineering.

It is true that we are used to hear about the application of forensic science in crimes and felonies. In fact, even the dictionary definition for forensic science leads us to the application of scientific practices within a legal process. This can be translated into the participation of highly specialized professional or criminologists, who do research, seek and locate evidence—many times laboratory based—that can provide conclusive proofs about a fact that needs to be clarified. Sometimes, the evidence cannot be seen at first glance and a much deeper exam is needed in order to determine the true causes of an event. Even engineering or hydrology in particular have not been mentioned so far, a lot of the concepts described seem to fit very well in these disciplines. At the end, any forensic investigation has the objective of establishing how an undesired event happened and eventually, what to do in order to prevent that it happened again.

Forensic engineering has evolved to an interdisciplinary approach, considering another specialty such as anthropology, sociology and economy among others. It can be state that the general purpose of forensic engineering is to determine or clarify the causes of failure of certain system with the objective of improve the designs or assist in the operation procedures.

Common losses or failures that forensic engineers usually address include among others, damages to structures caused by natural phenomena such as thunderstorms, hurricanes, storm surge, saline intrusion, fires, etc. In fact, the need of research in this field is associated to a combination of climate conditions, topographic and physiographic conditions and resilience of the population: for example, coastal zones in poverty and a high potential of hurricanes incidence are highly susceptible to suffer. Nevertheless, some of these fields have rarely been addressed by forensic analysis, missing out on the advantages it could provide investigations on this topic.

All of these lead to derive from the environmental and earth sciences and forensics, the so-called forensic hydrology. Even though the term is often associated to the different quantitative components of the water cycle, forensic hydrology also includes topics as water pollution and contamination, floods, droughts, other water-related resources and water infrastructure operation among others. There will be occasions in which forensic hydrology would help to prevent or at least reduce severe damages and in some others, it would lead to better water management, improve its use and allocation.

The adjective forensic applied to geosciences appeared around 1980s [2], but few investigations have been developed since then. Derived from cases associated to pollution of water or soil, researchers started to talk about forensic geochemistry or forensic geology, as a synonym of the process to describe the use of specific techniques to find the sources of the pollution.

Some 20 years later, the growing concern on nature protection we could see the beginning of environment sciences forensics. On the other hand, the so-called engineering forensics, do research on materials, products, structures or components that fail or do not work in the way they were designed, generating or contributing to the collapse or failure of a civil work.

It is in the intersection of environment science forensic and engineering forensics where we can locate forensic hydrology with the main objective of determine the probable cause of an event or the human sources that contribute to increase damages or even human losses. This type of analysis can be seen as a useful tool through which it is possible, in a full objective way, to determine the real causes, natural or human induced that made a natural phenomenon cause a disaster.

Forensic hydrology could be referred to the topics of water pollution, but also to floods, droughts or even water management, among others. In the case of floods, for example, forensic hydrology would help to identify responsibilities in a particular event and to plan for actions in order to prevent future damages. In the case of droughts, forensic hydrology allows to systematically address the effects caused by the phenomena, both immediate and in the mid-term, and also evaluate the measures that were taken in order to prevent future problems.

Precisely in the topic of extreme phenomena, forensic hydrology can be directly applied as we said to the case of flood or drought. In the case of flooding events causing material damages and even loss of human lives, forensic analysis can provide results that help to clarify responsibilities but specially to prevent that future disasters happen again. Even drought is a phenomenon much more complex to address, because its geographic scope is bigger and the impacts produced can extend a lot in time, forensic analysis can help to determine the main aspects and the locations that are more urgent to focus on.

Forensics hydrology procedures will give us the reconstruction of the event in order to determine what really happened, what factors contributed, what failed, who were the main actors that have something to blame about the damages, etc. In the case of floods, for example, forensic analysis should include principles for hydrometeorology, hydrology, hydraulics, social and political sciences, with the help of technology for modelling and simulating.

In this chapter, the topics of hydrological extremes, both floods and droughts are presented. In the first case, a methodological guide based on Ref. [3], is provided, while in the second a more general methodology is sketched. This investigation will provide important information for the new forensic hydrologists, a discipline with great future, especially in the context of climate change, which will increase the magnitude, and frequency of extremes.

2. Forensic analysis of floods

In the topic of extreme phenomena, forensic hydrology can be directly applied to the case of floods. Forensic analysis of floods consists on the application of a methodology immediately after the occurrence of the event. Its application will give us the reconstruction of the event in order to determine what really happened, what factors contributed, what failed, who were the main actors that have something to blame about the damages, etc. The analysis will then be directed towards performing an evaluation or study of the event after the points mentioned have become clear. The final objective of the analysis is to suggest what is needed to aid or improve the system and thereby prevent this type of disaster in the future, to whatever extent possible. Flood analyses need to integrate hydrometeorological, hydrological, hydraulic, social and political principles with the help of technological modelling and simulation tools. The likely causes of damages due to floods in a basin can thereby be determined and the key factors involved in causing the damage can be documented.

A methodological guide for flood forensics has been already developed by the authors of this chapter [3]. Particularly for the case of floods, the guide has been organized in five phases: (A) information gathering and integration, (B) hydrometeorological and hydrological analysis, (C) hydraulic analysis, (D) integrative analysis and (E) final diagnosis.

Each phase implies the development of several activities with the only objective of documenting and looking forward to clarify the actions that occurred. Some actions involve a detailed scientific analysis, while other needs the construction of a Geographical Information Systems (GISs) or even the implementation of a numeric simulation model. Some stages include field works in order to determine how the systems and action plans functioned and in what way the emergency was managed or even how the population lived the event.

Flood forensics looks for the integration of geographic, hydrologic, hydraulic, social, economic and political aspects in order to identify which of these factors intervened as main drivers to favour o diminish the impacts of the flood.

When commencing phase A, information gathering and integration, it has to recognize that this is not an easy step, since in many cases, information may not exist or if it does, it may be disperse and difficult to compile (**Table 1**).

Phase	Stage	Before	During	After
A. Information gathering and integration	1. Recopilation of geographic, hydrometerorological, hydrologic, hydraulic, socioeconomic and politic information			
	2. Status and quality of hydrometeorologic and hydrometric information			
	3. Geographical Information System			
	4. Geomorphological characterization of basins			

Table 1. Phase A of flood forensic analysis, based on Ref. [3].

The attention in this phase could be oriented towards the following:

- Geographic: Geographic and human aspects, theme maps, satellite imagery, aerial photographs, topographic surveys, photographic registers of the impacted zone of the streams and river, the basin and the urban environment.
- Hydrometeorologic: Records of daily basis climatologic stations, automatic stations and meteorological observatories. Such information will provide information of the rainfall event regarding its genesis, extension, magnitude, duration and intensity.
- Hydraulic: Records of flow gaging stations, physical conditions of hydraulic infrastructure as well as its design information; outflows from infrastructure and the official operation policy as well as the actual operation conditions during the flooding event. If it happens that the analyst can join the field inspections during the event, he can perhaps document or at least observe flood stages, depths, velocities and sediment transport rate in critical reaches.

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- Socioeconomic and political: Information of interest in this regard includes action and development plans and programs, damages caused, emergency management, personal testimonies, historical records of past flooding events. Additional information may include data for soil use change in the basins, floodplain occupancy and poverty conditions of the population in high-risk areas. This can help in the verification of the preventive measures and the preparation actions that were taken in the zone of impact, the actions that have been implemented to improve the living conditions of the affected people and those actions oriented to the emergency management preparedness and the post-disaster reconstruction in order to avoid major damages. Personal testimonies become high value information because these are not usually included in technical reports. Interviews to direct affected people, observers and authorities can add significant value to the analysis.

With this information, a Geographical Information System (GIS) should be integrated. A base map can be used as basic platform for consultation and processing in the forensic analysis. One of the first processes would be the determination of the geomorphologic characteristics of the hydrologic system of the case study in the extents of the integral model. The use of this GIS results in advantages that are evident. If a GIS of the region exists at the moment of the flooding event, the possibility of uploading specific real time information would be of high value, transforming the GIS in a full dynamic tool. This can contribute in the execution of operative actions and in the strategic decision making facilitating the problems comprehension and eventual resolution.

Phase	Stage	Before	During	After
B. Hydrometeorological and hydrological analysis	1. Storm génesis			■
	2. Spatio-temporal distributions	■		
	3. Time series analysis and statistical parameters estimation	■		
	4. Probabilistic frequency analysis	■		■
	5. Precipitation in excess (event runoff) estimation			■
	6. Establishment return period of the event (precipitation and discharge)			■
	7. Modelling and simulation of the rainfall – runoff process	■		■

Table 2. Phase B of flood forensic analysis, based on Ref. [3].

In this stage of phase A, an analysis regarding the quality of the information should be carried out. In the case of missing climatic data, for example, hydrometric information could be an alternative. It should be noted that the estimation of missing values or the use of transposition techniques from neighbour basins significantly affect the reliability of the analysis.

During phase B, hydrometeorological and hydrological analysis, the most critical steps of the methodology are addressed. The comprehension of these processes in the basin constitutes the base of the study, giving support to the full understanding of the event that generated the flooding (**Table 2**).

The comprehension of these hydrometeorological processes should include the analysis of the storms genesis. It is well known that a storm is the set of rains of well-defined characteristics that belong to a giving meteorological perturbation, but in this phase, the natural phenomena must be clearly identified and characterized in its relationship to the flood event. The fact that it was a single storm or a combination of events must be stated. The genesis of a storm that produces a flood event is a key to forensic flood analyses. Likewise, the temporal and spatial scales of the precipitations should be characterized, trying to represent their variability in the context of the basin or basins involved. For example, isohyet maps can be constructed in order to better visualize the distributions of the variables and be able to obtain information about the spatial evolution of the event. Graphs on the temporal evolution can also be obtained and further analyzed looking for tendencies, patterns of seasonal variations. The reconstruction of the rainfall field that occurred before and during the event is recommended. If the information is available, isohyet maps can be built with durations from 5 min (or even less) to up to 96 h, if this time window is relevant.

A basic but fundamental process is the determination of the descriptive statistical parameters of the event, since this could help to state in a few indicators, the whole set of observations of a single variable, making comparisons more precise and easier than those that can be done from graphs and plots. Monthly rainfall distributions as well as cumulative information of precipitation would help to identify seasonality and mass curves can give information on the temporal variation of the precipitation in the basin. All of this provides a background analysis and a reference framework.

In the hydrologic processes analysis, and due to the fact that the peak discharge and its corresponding hydrograph are associated to a lot of climatic and physiographic factors, their most reliable estimation is based on the probabilistic treatment of the information from historic observations, discharges or water depths. This process has been referred as flood frequency analysis. In addition, the probabilistic analysis of maximum data of precipitation makes possible the construction of intensity-duration return period curves, which characterize storms in the study region. These curves are also a valuable tool to study ungauged basins. Both for precipitation and discharge information, probability distribution functions must be analytically fitted to data. The distribution that fits the best is then selected. Later on, this can be used to evaluate the magnitude of events with different exceedance probabilities or return periods.

Determining the difference between total precipitation and the hydrologic abstractions, that is the effective (excess) precipitation (also called direct runoff), is a must in the analysis. In the case of gaged basins, a simultaneous registry of precipitation and runoff from a storm will be available, and therefore excess rainfall will be calculated based on direct flow determined from the flood hydrograph. Dividing the direct runoff volume by the basin area can do this. On the other hand, if these abstractions are not known, such as in ungauged basins, specific methods can be used, such as the curve number model developed by the Natural Resources Conservation Service [4]. The procedure to be applied in the forensic flood analysis is chosen according to the available information.

As part of the hydrologic process analysis within flood forensics, return periods of precipitation and discharge events should be stated. That is, to determine the time interval in which an event of a given magnitude can be equalled or exceeded on average and over time [5]. It is important to remember that given that the rainfall-runoff relationship is non-linear, the return periods for rainfall and flows need to be differentiated. The return period for a particular rainfall is not the same as the one for the runoff generated by the same rainfall. This is naturally complicated process involving key variables, namely the soil moisture content at the moment of the precipitation as well as changes in vegetation, land use and anthropogenic activities in the basin. Therefore, a rainfall with a 100-year return period does not necessary generate a flow having a 100-year return period. In a basin subject to increasing urbanization or deforestation, the same rainfall generates runoffs having increasingly longer return periods.

One key aspect of flood forensics is to determine the flow associated with the flood event in the list of assigned probabilities using a plotting position formula such as that by Weibull [5]. It should be considered that the record does not include the value of the event under study but rather only historical values, that is, only records up to the year prior to the flood event. If the magnitude of the flow lies within the magnitudes registered by the historical data, a return period for the event can easily be determined empirically directly from the sample. Nevertheless, if the flow is located outside the magnitudes found in the historical record then the return period T of the flood event can be calculated by fitting the sample to a PDF, considering that the fitting process does not include the value of the event in question. For this case, although the magnitude of the flow is larger than those in the historical record, a return period can be assigned to the flow through extrapolation. These two ways to assign T are intended to prevent that the length of the record or the magnitude of the event influence the value. The value of the flow associated to the flood event can be later incorporated into the historical records, which will result in a modification of the fitting of the records to the PDF as well as a change in the recurrence interval values through the plotting position. Thus, the assigned value of T will also change. The above is intended to highlight the fact that the assignment of the occurrence probability is evolutionary and not static.

Nevertheless, if hydrometric records are not available or are too limited to obtain a reliable interpretation or extrapolation, then rainfall-runoff relationships can be very useful because of their ability to infer flow information based on precipitation records.

For this, the application of models becomes very important since it turns the process more efficient and more reliable. Regardless of the model used to simulate the rainfall-runoff process, a calibration process must be included. The calibration makes possible to determine the value of the errors of the model when compare to a measurement or a reference pattern, all of this with sufficient precision and under specific conditions. It is crucial that these errors be sufficiently small and that they are determined with the highest precision possible. Regardless of the different rainfall-runoff models used, it is important to consider the limitations involved in applying each one to the zone, as well as the information restrictions that persists.

With this, a solid base for next phase, phase C. Hydraulic analysis is set. In phase C as in all the others, we look for the process to be efficient but always taking into consideration the limitations of the information and tools available. In this phase, the representation of the hydraulic behaviour of the systems should be obtained and studied; so, the conditions that intervened or favour the event. Simulation models of the river networks, floodplains, impacted urban zones; infrastructure operation and protection works efficiency should be addressed (**Table 3**).

Phase	Stage	Before	During	After
C. Hydraulic analysis	1. Simulation models of the river networks, floodplains, impacted urban zones			
	2. Infrastructure operation and protection works efficiency verification			

Table 3. Phase C of flood forensic analysis, based on Ref. [3].

It is precisely for the hydraulic modelling and simulation of the river network, floodplains and urban areas where the information gathered and integrated in GIS would be of great help.

For the analysis, information will be considered according to the scale needed. Initially, the geometry of the river, both longitudinally and cross-sections, and the hydrodynamic characteristics of the system have to be given. Among the physical characteristics of the river that are needed for the study are: soil type and vegetation in order to better estimate roughness coefficients (usually Manning's n), longitude, slope, elevations and depths, full cross sections and obstacles. Modelling and simulation can be reproduced both, the normal conditions and those present during the flooding event. The hydraulic modelling of a network of channels will provide enough information to determine the overall behaviour and that of the major event in the network. The information also enables determining the boundaries of floodplains during normal functioning and flood zones during major events. This information is important since once the floodplain is delimited and a determination is made as to whether human settlements are located there, a hydraulic analysis of the urban zone can be performed to establish the degree to which the dynamics of a city will be affected. To this end, the hydrodynamic functioning of streets can also be simulated.

Erosive processes and sedimentation cause damages, including the reduction in the productivity of the soil, loss and degradation of soil and sedimentation in reservoirs, drainage ditches and channels, as well as damages to hydraulic infrastructure. For the study case, the damages of most interest are those caused by scouring around infrastructure near or in the river, as well as changes to the flow capacity of the river due to sedimentation.

Changes in the hydraulic capacity of a river can be affected by the degree to which it and its respective floodplains are composed of unconsolidated sediments, which are quickly eroded by floods and high water levels. If the river transports fairly thick sediments during a flood, these will tend to be deposited along the bottom of the river and cause natural dykes to form.

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This could raise the bottom of the river, thereby increasing water levels. When this occurs there is a very high risk of flooding. Natural and induced landslides are also cases that can increase the risk of flooding, in which the amount of sediments transported by the river increases, causing the hydraulic capacity to decrease or, in the worst of circumstances blocking the river.

Another factor is the development of tides, where the over height of the sea level can worsen flooding inland in areas relatively near the coast or cause coastal flooding. Coastal floods are primarily involved in obstructing natural runoff into the sea and blocking the flow of drainage systems, of course with their respective effects on the coastal area.

In general, to evaluate the hydraulic analysis of an urban zone, parameters such as water depth, velocity, permanence of flow and supply of solids should be taken into account.

Particularly in the revision of hydraulic works, as ending part of the hydraulic analysis, observation regarding the failure has to be carried out. In order to establish if the failure was caused by an event that surpassed the design conditions. Among others, the following has to be reviewed.

- Reservoir: The present condition according to the original design has to be verified, through the analysis of volumes routed and discharge of exceedances. From design criteria, a certain risk level is accepted. This is given by the design return period of the structure. This is the reference base.
- Pumping stations: The general objective of these structures is to drain waste water or storm water from facilities or even the streets. Their location and performance according to operation rules and characteristic curves should be revised.
- Channels and drains: The main focus will be in rivers that have been modified or rectified in order to improve the hydraulic system. A qualitative revision can be made prior to include them in the hydraulic model.
- Water supply systems: Their failure could also lead to public health problems, so their study is one of the key issues of flood forensics especially in urban settlements. Depending on the water source different flood problems arise, although the failure is often associated with the location of the infrastructure in floodplains and lower land.
- Drainage systems: The failure arises when the hydraulic capacity of the pipe system surpasses the design values, or because of the fact that sediments and garbage gets into the system obstructing the free flow. Although it is difficult to gather evidences on how the system was functioning just before the event, it is possible to infer the general performance of the network. Discharge measuring in the outlet of the basin and precipitation records may help in the evaluation. However, if no hydrometric information exists, techniques such as the synthetic unit hydrograph method can be used.

Up to this moment, flood forensics has been focused on the analysis of engineering processes, however, in to order to converge to strong and objective conclusions, factor beyond engineering have to be taken into account. Because of this, the next phase is dedicated to the integration of the analysis itself, with the socioeconomic and political part, being named as Phase D, integrative analysis, with its respective stages as can be seen in **Table 4**.

Phase	Stage	Before	During	After
D. Integrative analysis	1. Revision of action and development plans and programs			
	2. Analysis of the emergency management			
	3. Integration of hydrologic and hydraulic analysis with other			
	4. Generations of flooding maps and determination of impacts in human settlements.			

Table 4. Phase D of flood forensic analysis, based on Ref. [3].

This integrative analysis should consider the revision of action and development plans and programs in the region or zone where the flood took effect. The policies and strategies involved in these development plans should be reviewed for clarity and accuracy, and of course they should be evaluated as to whether they have been implemented or are in the process of being implemented. The follow-up of these actions should be reviewed since they are strategic visions for the future and the solutions they offer need to be maintained over time, making them crucial to the population, its safety and well-being. The designs of the plans need to be reviewed to verify that they are sustainable and contain improvements that will remain in the society after the plan has been completed. Thus, a development plan should be aimed at teaching the population to manage latent risks and not only be directed towards restoration actions. Even though this measure is secondary to the main action, it promotes self-sufficiency. Development plans should not neglect issues such as reforestation, protected zones that are directly related with levels of felling and deforestation in the disaster zone, as well as other changes in land use in supply basins which can be analyzed with historical vegetation and land use maps to see the evolution in the zone. Land planning should also be investigated to identify the location of high-risk lands sold at low values. The concentration of vulnerable human settlements should be determined as well as invasion into natural floodplains by urban settlements, commercial zones and other land uses. In particular, the legality of settlements in connection with the plan itself should be evaluated. It is also important to identify marginalization levels in high-risk settlements, as well as factors that influence the settlement of populations in these locations. Furthermore, the government's sensitivity to the risk situation should be identified, as well as any actions that it may have taken in this respect.

It will also significant the analysis of the emergency management itself, because it will consider actions taken prior to the event up to those implemented for the immediate attention of the population and infrastructure during the disaster. Actions in response to the population during an emergency could form the basis of all the procedures to be implemented in the event of an emergency, since everything that is done should be based on the protection and safety of the population and not only on economic losses. Since the actions taken are the result of planning and the projections generated by programs, adequate preparation should be ensured to reduce the impact during a disaster. A review of programs in the study zone should include their specific progress; efficiency and legitimate implementation, since the objectives proposed by each of the programs depend on their correct application. If programs are not executed as planned, then the reason for this should be identified since it can become a determining factor in increasing the magnitude of a disaster.

In this phase, technical factors involved in the flood should be integrated with those of political, social and economic character. Main determining factors in the occurrence of the disaster should be identified. Also the factors that contributed or favoured the impacts of the disaster should be noted. This can be done through a hierarchic procedure in order to determine objectively the causes and effects of the flood event. It would be idyllic to think that all driving forces are taken into consideration; however, the analyst must integrate all elements that could have influence in the problem. If an adequate integration of each of the elements considered is reached, it would be possible to have a close picture of what really happened, minimizing uncertainty.

Finally, it is a good moment to generate the flooding maps and with these to determine related impacts. It should be remembered that flooding maps establish water depths in their relation with the topography for different discharges of interest. To generate flood maps with automated procedures, software that jointly performs hydrological and hydraulic modelling at the street level can be used. A semi-automated procedure can generate flood maps using separate hydrological and hydraulic modelling and perform external integration using GIS software. Flooding maps can be generated as follows. First, a Digital Elevation Model (DEM) is generated and a map of the basins obtained. The DEM is used again and with the detailed topography, the alignment of rivers and the characteristics of the banks and cross-sections are alternately obtained. The hydrological model is used to obtain flows, which serve as input for the hydraulic model. After performing the hydraulic simulation, flood levels are obtained from the cross sections. Finally, these levels are processed and the geographic and hydraulic information are combined to generate the flood maps.

After generating the theoretical flood maps based on the modelling, they can be compared to the actual flood area by analyzing the differences between them, attempting to locate zones that are more problematic and finding their associations with all the factors analyzed previously. The relationships between these factors and the flood zones can thereby be established. Theoretical flood maps delimit the risk zones in a general way and the map of the flood under study delimits the effects that have occurred. This enables objectively the determination of the main reasons why the event reached a particular magnitude.

After using the hydraulic modelling to determine the levels occurring in the urban zones, the percentage of damage can be identified according to type: direct (housing, educational buildings, health infrastructure, public facilities, etc.), indirect (supply of goods, interruption in services and communication systems, loss of work hours, among others) and intangible economic loss (those affected, the injured and loss of human life). The methodology used for this is divided into two steps—quantification of goods affected and the quantification of the costs of these effects.

With all of the above, phase E final diagnosis can be finally established. This corresponds to the culmination of the forensic analysis. The final objective is the identification of factors and giving relative weight to each one. This is be done by establishing a contrast study with historical events, the objective conclusion on the causes and effects, as well as the lessons learned and clearly the proposed actions (**Table 5**).

Phase	Stage	Before	During	After
E. Final diagnosis	1. Comparison with historical events			
	2. Objective conclusions on causes and effects			
	3. Lessons learned and proposed actions			

Table 5. Phase E of flood forensic analysis, based on Ref. [3].

Based on the history of flood events and the destruction caused in the study area, records from communications media and personal testimony from those affected, observers and authorities should be gathered into a document to perform a general analysis. Nevertheless, if complete analyses of previous events are available, those should undoubtedly be used. Thus, it will be possible to compare these events to the one that is currently occurring in order to identify recurring factors that influence floods in the study zone, with similar magnitudes or within a range of association. This will serve as a guide to discover whether the structural and non-structural actions have been adequately applied over the history of the study zone or if other actions not previously considered need to be taken.

An integrated analysis of technical factors (hydrometeorological, hydrological and hydraulic) along with the social and economic dimensions explained previously enables the production of an objective evaluation of the causes and effects. The result will provide documented evidence of how major was the event from the probabilistic point of view and to what degree other external factors contributed to magnifying the impact of the flood. It is important to note that a combination of all the factors may be the best explanation possible in most cases. In that case, a weighting of the causes is recommended, assuring of course that this is done based on objective findings from the analysis.

Undoubtedly, the best way to capitalize the findings and results of a forensic analysis of a flood event consists in the opportunity of learning and the potential development of actions oriented to reduce the impacts of future similar events. Among the lessons learned from this analysis, answers to several questions can be obtained. Questions such as: How extraordinary was the flooding causing event? What is the probability of exceedance (or return period) of precipitation or discharge? To what level, timely and effective warning about the magnitude of the event could have diminished damages? Were the major damages located in floodplains and high risk areas? What was the role of the hydraulic infrastructure? Was the infrastructure well operated? Did the operation of infrastructure help to control the event? The operation policy was the one pre-established or a change was made? The hydraulic design criterion of structures is the adequate? Plans for urban development were respected? Are these plans adapted for flood cases? If a risk atlas exists, is it necessary to make adaptations to it in order to consider flood risks? In what measure, lack of conservation of higher basins contributed to damages?

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How adequate was the response to the emergency? Was the coordination among institutions favourable?

Duration for each phase and stage is given in **Table 6**.

Phase	**Stage**	**Before**	**During**	**After**			
				1 week	**1 month**	**3–6 months**	**Up to 1 year**
A. Information gathering and integration	A.1	X	X	X	X		
	A.2	X					
	A.3	X	X	X	X	X	X
	A.4	X					
B. Hydrometeorological and hydrological analysis	B.1			X			
	B.2	X			X		
	B.3	X					
	B.4	X			X		
	B.5				X		
	B.6				X		
	B.7	X			X		
C. Hydraulic analysis	C.1	X			X	X	
	C.2			X	X		
D. Integrative analysis	D.1	X					
	D.2			X			
	D.3					X	
	D.4					X	
E. Final diagnosis	E.1					X	
	E.2					X	
	E.3					X	X

Table 6. Suggested duration to complete stages and phases of a flood forensic analysis, based on Ref. [3].

Another product flood forensic analysis can provide is the proposal of actions, all oriented to reduce damages produce by future flood events. Clearly, general ideas always arise, but the courses of actions will depend on the particular case. Just to name a few of them, these can include:

- Hydrologic and hydrometeorologic monitoring networks strengthening
- Early warning system development (hydrologic)

- Review and adaptation of infrastructure operation policies
- Review of the hydraulic capacity of cross sections of the river in bridges and of other draining strictures
- Review of urban infrastructure vulnerability (water supply, sewage, treatment and etcetera)
- Determination of the vulnerability of irregular human settlements in face of floods
- Current status of natural streams and river in regard of obstructions and invasions
- Development of a Flood Risk Atlas
- Projects for works and actions for flood control
- Development of hydrologic criteria and its consideration in urban development plans
- Development of reforestation plans, soil control projects
- Incentives for the use of measures of rainfall control in the source (in site). Best management practices such as the ones considered as 'sustainable urban drainage systems'.
- Review of coordination plans among the different level of government.

3. Forensic analysis of droughts

Drought is a phenomenon that has always existed, even though mankind perceives it as atypical. This perception has caused that drought has not been studied as deep as it deserves. There are still few tools to address drought issues from the perspective of decision makers [6]. Because of this, forensic analysis of droughts can have a high relevance at the present and certainly it will be even more important in the future because of incremental climate variability and the eventual climate change.

Differences in hydrometeorological variables and socioeconomic factors as well as the stochastic nature of water demands in different regions around the world have become an obstacle to having a precise definition of drought [7]. For example, a definition of drought in terms of an insufficient humidity condition caused by a deficit in precipitation over certain period of time has been proposed [8].

Forensic analysis of droughts, because of the characteristics of the natural phenomena, will help to the establishment of the beginning and the end of a certain event. Effects derived from a drought are cumulative both in time and magnitude, making it a slow process that can extend for long periods even when the moisture condition is partially recovered by precipitation. This turns the phenomenon into a very complex one.

The general methodology presented here sets the basis to address the topic by looking the establishment of theoretical elements and applications that can help in the comprehension of the causes and impacts of droughts. Forensic analysis of droughts will provide a better

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understanding of the phenomena on a solid base favouring the access to better information and products.

In order to carry out a forensic analysis of droughts, the following factors and variables must be at least considered:

- Geographical
  - General aspects
  - Edaphology
  - Land use and vegetative cover
- Climatic
  - Hydrometeorology
  - Historical climatology
- Hydrologic and water use
  - Flows and levels of surface and groundwater sources
  - Extraction zones subject to prohibition
  - Water availability
  - Water pressure degree
  - Water uses
  - Water demands
  - Water quality
  - Infrastructure for storage, recharge, conduction, treatment and distribution of drinking water, waste water, irrigation, etc.
- Socioeconomic and political
  - Population
  - Poverty and social backwardness
  - Economic and productive activities
  - Attention and mitigation plans and programs
  - Action and development plans and programs
- Historical events
  - Historical records regarding drought indicators
  - Documentation of historical droughts (categorized)
  - Paleoclimate studies if available

The general methodology recommends the fulfilment of the following processes and analysis:

- Integration of a Geographical Information System (GIS), by the use of commercial tools or freeware. An important step is the construction of the base map. Physiographic, geomorphologic and edaphologic characteristics have to be determined. Maps of vegetation and land use or economic activities will be of help. Information from agriculture, cattle rising, urban, etc., will contributed to the better understanding of the study area. All of these have to be integrated in the system for the study zone. The integration of the information allows the possibility to work with map algebra and other geo processes, making a lot easier any subsequent spatial analysis.

- Edaphology and vegetation analysis. With the help of the GIS, a detailed analysis on the edaphology of the study region and its vegetative covers should be carried out. Soil degradation and loss because of erosion are two important factors to consider. These topics, with special emphasis in edaphology, are not sufficiently addressed in drought studies.

- The forensic approach will seek to provide indicators of the internal biologic activity of the soil, among other processes associated to water storage and the resistance to deficits. As it is well known, vegetative cover favours water retention in the basin, reducing with it, the surface runoff. This helps to aquifer recharge and the better performance of the whole water system.

- Analysis of the status and quality of hydrometeorological records and climate in general. We seek to have flow records, surface water information and groundwater levels, rainfall, drought indices, operational policies, soil moisture and evapotranspiration. Observation, interpretation and analysis of sufficient data are of great importance for this type of studies. Basically, error or absence of a particular data may have effects on the estimates of probability of extreme events with high return periods. Before using a data set, its validity and accuracy should be verified. The accuracy is the correctness of the data, while validity refers to the applicability of the data for the purpose for which the values will be used [9]. The World Meteorological Organization recommends some techniques for data validation in its Document No. 168 [10]; for example, graphical representation of the rainfall or flow depends on the height of the water, in order to detect small bumps (or any episode of flooding) not accompanied by significant rainfall, and vice versa. The success of the analysis results and subsequent decision-making process depends on data quality.

- Spatial and temporal distributions: Once data have been validated, a geostatistical analysis can be performed. With this, spatial-temporal distributions can be constructed from recorded information. There are several methods to make this statistical spatial analysis, for example, inverse distance weighting, splines or even kriging [11]. Any of these techniques can be used, in order to determine the magnitude of the phenomena in space, which according to its causes, can be from local to regional. Of course, each method should consider its own restrictions. In the case of the time series analysis, it will allow characterizing the drought event in duration, both inter annual or seasonal. It should be noted that a drought variable should be able to quantify the drought for different time scales for which a long time series is essential [7]. With this process, we look forward to establish the permanence, duration and frequency.

- Drought indices determination: Several indices of drought exist nowadays. These have been developed for a number of authors and most of them consider as the main or unique input variable the precipitation, either monthly or annually). From the Palmer Drought Severity Index (PDSI) developed by Palmer himself [12], up to the Standardized Precipitation Index (SPI) proposed by McKee [8] of wide use at the present, several indices could be used to characterize and evaluate severity and intensity of the drought event under study. An appropriate record should be considered both in type and length for each one of the cases. It is important to notice the restrictions and limitations of each index.

- Climate indices determination: It must be recognized that climate is related in some way to hydrometeorological variability. Climate indices allow the identification of climate variability at major scales. The most common indices in this regard can be averages and extremes, linear trends and standard deviations of long time series available. Other indices can be also studied, depending on the region, some of them can be of high importance, such as El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO) or even just the Sea Surface Temperature (SST). The history of these indices can provide information regarding the frequency of the event.

- Probabilistic frequency analysis: Flood frequency and precipitation frequency analysis as well as of other climatologic variables can be taken as a base. The basic premises of this kind of analysis must be taken into account: statistical independence, randomness of the process and equal distribution in time [13]. It is quite common that the records have gaps. Kalma and Franks [14] document that restrictions in the probabilistic method selection are among other: (i) characteristics of time and variability of the precipitations in arid and semiarid regions, (ii) external factors that influence decadal variability, such as ENSO and (iii) reduced availability and extension of information records. In Ref. [15], based on the work in Hosking and Wallis [16] a methodological guide for the regional frequency analysis based on L-moments has been established. This guide, when applied to droughts has given good results in the evaluation, estimation and mapping of the probability of drought occurrence in several pilot regions in Latin America. The procedure considers that several sites, within homogeneous regions, have a common frequency distribution, except for a specific scale factor, represented by the mean value of the variable under study. Since drought is a spatial condition, regional analysis is a better tool that conventional onsite analysis.

- Establishment of the return period of precipitation deficit: After the application of statistical, geostatistical and probabilistic methods, the next step is to determine the return period of the event under study. Return periods links the magnitude of the event to its frequency of occurrence. In such a way, this information can be compared with the system capacity. This allows to identify if the return period of the event is bigger than the one used to design all the works and establish the operation of the systems.

- Water balance integration: This balance allows to quantify diverse water cycle components by the establishment of relationships among hydrologic variables such as water offer and demand and by considering spatial and temporal distributions. This is used to calculate the so-called 'hydric pressure', as a result of the balance between offer and demand. This balance allows the quantitative evaluations of water resources and the modifications because of human activities, both past and present. A water balance can also be used to predict the impact derived from those modifications. Drought forensic analysis is used to identify the influence of those factors on the magnitude of the event and on its frequency, that is, its return period. Water balance is based on the mass conservation principle, sometimes called continuity equation, in which in a simple manner, the variation in volume, in each period, is given by the difference between inflows and outflows of the system. This can be stated as [17]:

$$P + Q_{S_I} + Q_{U_I} - E - Q_{S_O} - Q_{U_O} - \Delta S - v = 0$$

where

P is the precipitation in form of rain or snow (self-basin), Q_{S_I} and Q_{U_I} are the surface and groundwater inflows (both from within the basin or from outside), E is the evaporation from the water surface, Q_{S_O} and Q_{U_O} are the surface and groundwater outflows (both from within the basin or from outside), ΔS is the storage and v is the residual term in the difference.

The analysis can be more or less simplified depending on the available information and the different components in the study case: water bodies such as reservoirs, lakes, rivers, creeks, etc.; hydrologic characteristics (basins, sub-basins, etc.) and the period under analysis. Computation of the components should be independent as much as possible, avoiding the 'closure' of the balance with unknown components. Once the balance is finished, a series of different scenarios can be studied.

- Hydraulic analysis of actual Infrastructure in terms of resilience: More than just an audit, infrastructure must be revised in order to find the capacity that the region had to adapt infrastructure management and resist alterations without disturbing its functionality in a significant way. Infrastructure requires adaptation in accordance to needs of the region in order to satisfy demands. Because of this, responsible institutions or organizations must have a strategic vision plans, more preventive than reactive and corrective. In the ideal case, systems should have been designed adequately and in comply with standards and norms. Infrastructure should have been operated according to the policies established.

- Population and productive activities status and growth: Emphasis in this point is on classifying the study zone in terms of the main activities so the effects and impacts of drought in them can be clearly determined. By considering the differences for example between agricultural and urban sector, a more precise analysis can be performed. For all sectors considered, according to the productive activity, the social and poverty indices should be taking into account. With these and the action and development plans and programs, the identification of the level of services and social exclusion can be clearly identified. All of these should be considered in relation to the infrastructure growth and development. It is clear for example that when large reservoirs exist, the impacts of short duration droughts can be hardly perceived.

- Action and development plans: This is a socially sensible topic. So, as in the flood forensic analysis the designs of the plans need to be reviewed to verify that they are sustainable and contain improvements that will remain in the society after the plan has been completed. Plans and programs should prioritize preventive actions in order to have integral solutions both scientific and technologic. This revision is important from two points of view: prevention and mitigation. In each plan or program, one should identify the different entities from government and civil associations involved in drought management and clarify the processes on how the drought event was handled: surveillance, warning systems, impact evaluation, emergency response, risk management, recovery and logistics.
- As in the case of floods, there will be factors, that even though they are not critical, could have favoured the severity of the impacts, as changes in land use in supply basins, soil degradation, deforestation, extensive agriculture, etc., considered all within the environmental degradation topic. For example, with the use of GIS historical vegetation and land use maps can be analyzed to see the evolution in the zone.
- Integration of damages and help provided: The effects of droughts are gradual and with great extension both in space and time (they remain for prolonged periods). These effects are not so noted as the ones associated with flood events, since the latter are observed almost immediately. That is why specialists refer to those kinds of damages with the adjective direct. Even though, impact of droughts can be even huge since social aspects are included beside the economic ones. These are type of impacts are called indirect and they are much more complicated to evaluate. Damages caused by droughts will be present in agriculture, as a reduction in production; urban zones can be affected in their economy or a reduction in production; also, in urban zones some it can be some other economic effects not only in the poorest sectors, but also in other segments. In extreme conditions and special conditions even deaths can occur. In this regard, reports from the civil protections agencies or disaster prevention centres should be considered. These reports will integrate damage evaluation and costs involved but not necessarily will report the supports and help received, so there is an extra task for the integration of such information which has to be oriented to governmental and non-governmental organizations.
- Comparison with historical events: Existing information regarding the impact of historical droughts should be gathered and integrated. Review of past news in informal sources will be of value because it will show how the information flowed, how the event was lived, damages perceived, problems with water supply systems, fires, etc. Reports from governmental and academic organizations as well as official declaratives of drought. Reports on the actions that were taken, programs executed and economic help are of high value. The magnitude and frequency of the event under analysis when compared to the

help and support granted would serve as a base to determine if the application of those resources was efficient. The construction of performance indicators would be appreciated for future analysis and future use of the damages—support—effects relationship. For example, Jiménez [18] shows methodological guides for the construction of indicators, defining them as a tool that offers quantitative information with respect to achievements of results in the delivery of products or services generated by the institution, covering both quantitative and qualitative aspects. Also, historical water demand data and its relationship to drought declaratives need to be analyzed. In the forensic analysis, even paleoclimatology studies can be considered, such as tree ring studies that can offer information of long past events.

- Integration of analysis and objective establishments of causes: In this phase, the integration must classify each variable and factor analyzes, giving them the adequate weight. Based on all analysis performed, an integral model with matrix array for the evaluation of categories, variables and factors in a weighted form can be implemented. The results of the model may show two groups, historical trend if it exists, and the causes directly associated to the event under study. Once the causes that favoured or increased the impacts of the phenomena have been determined, the making of a simplified tree diagram can be built. This tree will show the main causes, asking and answering in a very concise and objective manner the why's and what's. This will converge to the main cause of the disaster and to the actions that should be taken immediately. Also it will establish the strategies to be followed in order to reduce the impacts of this phenomenon in the region under study.

- Integral actions: The final report should include (a) prioritized causes, (b) lessons learned, (c) actions and recommendations for the immediate time and short and medium terms, (d) critical elements for prevention and preparation in case of droughts and (e) fundamental cultural elements to be implemented so the lessons would become effectively lessons learned in the emergency management. Inclusive vision should be taken as seriously as possible. More than a policy that must be adopted, it will be an action that should be implemented. No stakeholder or decision maker should be excluded. Just remember that drought is a phenomenon that is not scale selective, nor sectorial. It affects big spaces and affects the least resilient systems. Integrative actions favoured by drought forensic analysis should include the institutional, methodological, public and operational parts, so they allow success in the face of a new event. Inclusive vision considers, for example, investments in monitoring and early warning systems, implementation of prevention and mitigation programs, legal framework strengthening, institutional coordination, capacity building, communication and of course research. It is well known that something that can be measured, can be improved, so evaluation and action updating as well as adaptive capacity towards resilience represent step to success. Those are the type of things drought forensic analysis is seeking.

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4. Final conclusion

Forensic analysis in hydrology can provide the necessary and sufficient information for the authorities and decision makers to establish programs of attention and control of these phenomena in the future elements. Though this to some extent has been given, it is desirable that the process rests on objective technical reports based.

It seems obvious to say that the issues in which forensic hydrology can be applied are numerous and varied. Cases of floods and droughts are perhaps the most evident, especially urban pressure that every day affects the ability of natural streams that drain a basin or a cultivated area.

As a result of all this, forensic hydrologists, a specialty with a great future, can apply a large number of technical tools in order to make detailed studies on the precise causes of a disaster. From our ability to select, the best forensic techniques depend largely harm reduction or the safety of our sources of supply.

The results of forensic analysis in hydrology effectively contribute in the search for better alternative solutions to recurring problems in all our countries.

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Section 2

Forensic Entomology

Parasitic Hymenoptera as Forensic Indicator Species

David B. Rivers

Additional information is available at the end of the chapter

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Abstract

Necrophagous insects are the most important ecological evidence associated with a decomposing corpse. Insects provide insight into estimating the post-mortem interval (PMI), assessing whether a corpse has been moved, use in toxicological analyses, and provide utility in surveillance and as sniffer systems. Necrophagous Diptera are regarded as the most important forensic indicator species, largely because they colonize a corpse within minutes of death. Other types of carrion-inhabiting insects also offer value, although more limited than flies, to forensic investigations. Perhaps, the most neglected of these groups is the parasitic Hymenoptera, a group comprising several species that utilize necrophagous flies as natural hosts. Parasitic wasps extend the PMI window to include the period of time after necrophagous flies have emerged to when a corpse is discovered. Wasp host preferences and seasonal occurrences can reveal if a body was moved from another location prior to discovery. Foraging behavior of adults can be used to locate concealed bodies and potentially aid in combating entomological terrorism agents. Presently, the full potential of parasitic Hymenoptera as alternate forensic indicator species has not been explored. This chapter relates the life history characteristics of parasitic wasps to their potential usefulness in forensic applications.

Keywords: forensic entomology, host-parasitoid association, parasitism, synanthropic flies, Calliphoridae

1. Introduction

Forensic entomology is the subfield of forensic science that relies on insects and related arthropods for use in the judicial system. More specifically, the discipline uses information about terrestrial arthropods, namely insects (e.g., their occurrence, activity, seasonality), to draw conclusions about legal matters. Several species of insects are important physical evidence in issues relevant to civil, criminal, and administrative law [1]. By understanding the biology of necrophagous and synanthropic insects, predictions can be made as to why and when certain insects will become associated with human habitation, stored food, or colonizing a corpse. For example, several fly species are attracted to animal remains, including humans. Deciphering which species arrive in specific biogeographical and artificial (e.g., man-made) locations to a corpse, when during the decomposition process, and how long they take to complete development under varying environmental conditions, these insects become useful pieces of physical evidence in the investigations of homicides, suicides, and unexplained deaths [2]. The use of insect biology in this deductive manner is the basis for forensic entomology. However, forensic entomology is much broader than just death investigations. The legal issues addressed range from insects invading food and related stored products, to infestation of human habitation, to insect attraction to and use of animal remains. The latter also encompasses cases of neglect and abuse of humans and domesticated animals, as well as wildlife poaching. These examples broadly define the three subdisciplines of forensic entomology: stored product entomology, urban entomology, and medicocriminal entomology [1]. Medicocriminal or medicolegal entomology has received a great deal of attention in the past three decades because of the direct impact on the human condition [3] and is the focus of this chapter.

What is the basis for insect usefulness in medicocriminal entomology? The keys are foraging behavior of necrophagous species and subsequent development of immatures on a corpse. Necrophagous insects recognize and are drawn to the odors emitted from the dead, especially from the remains of warm-blooded vertebrate animals [4]. No matter the size of carrion or location of a carcass (inside or outdoors), chemical signals associated with decomposition activate foraging in a wide range of saprophagous, predatory, and parasitic insects associated with carrion [5, 6]. This is particularly true of several families of flies. The linkage between animal death and necrophagous flies can be summed up with just one word: protein. For a female fly belonging to the families Calliphoridae and Sarcophagidae, animal tissues are rich sources of protein that are essential for producing or provisioning eggs [1]. Protein is so important to females that some males have evolved a keen chemical acuity to locate a freshly dead carcass with the goal of finding mates. The "need" for protein as well as other nutrients leads to intense competition for any type of animal remains. The fact that carrion is a finite source of nutrients, and that the occurrence (ephemeral) and location (patchy) of animal death are unpredictable, contributes to the frenzy in securing at least a portion of the nutrient prize [2]. So when a death event occurs in natural environments, many animals take notice and quickly mobilize for action. The same can be said for the occurrence of a corpse in a concealed location, with the realization that detection of emitted odors is slower and reaching a corpse is hindered by physical barriers such as seclusion in a dwelling, burial, or placement in an artificial container [1, 7]. Such barriers favor colonization by small-sized insects, but that is not necessarily what always occurs.

Competition for animal remains has shaped several aspects of the life history characteristics of insects that depend on the dead for survival. Nowhere is this more on display than with the reproductive strategies demonstrated by necrophagous flies. One group, the blow flies and bottle flies (Family Calliphoridae), is recognized as first responders to death [8]. In other words, many species are the earliest colonizers of carrion; often arriving within minutes of death or

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just after a corpse becomes detected. This generally means that adults are especially efficient at detecting and finding human or other animal remains [6]. Even in this shared pattern of early colonization by multiple species, there are several adaptations that permit various species to decrease competition with each other. For example, some blow fly species prefer large carcasses over smaller for oviposition; others demonstrate preferences for carrion placed in full sun, shade, or partial shade; and some are influenced by location on the body [7]. The latter is manifested in terms of depositing eggs in concealed locales such as natural body openings versus exposed on skin, hair, fur, or plumage. Many oviposit in exposed wounds, while others only deposit eggs on very moist surfaces such as in saturated soil or carpet under a body, or on clothing or hair/fur/plumage soaked in exuded body fluids. Even eggs and larvae are adapted for competition, as eggs hatch quickly so that neonates can begin a period of rapid and continuous feeding [9]. Larvae feed cooperatively in large aggregations (maggot masses) that maximize the rate at which larval development can proceed [10]. Maggot masses are unique microhabitats that permit larvae to thrive in carrion communities [1]. Importantly, the life history characteristics of these flies and the subtle nuisances that allow each to use a corpse differently, even if just slightly, contribute to resource partitioning. The latter is a necessity for necrophagous insects utilizing an ephemeral, patchy resource as a primary food source.

Multiple groups of insects, not just calliphorids, utilize a decomposing body, arriving in waves to colonize a carcass when it is appropriate for progeny development and/or maximizes fitness of the mothers, or food/hosts is (are) abundant for predatory and parasitic species. For example, flesh flies (Sarcophagidae) can arrive in the first wave of colonizers or later during decomposition, and reduce the competition with blow flies by preferring small carrion instead of larger, depositing larvae (larviposition) instead of eggs, and the young of some species are predatory on other species [11]. Some fly species (families Phoridae and Piophilidae) do not lay eggs until the body is very dry, long after calliphorids and sarcophagids no longer have an interest in the body. Many species of beetles (Order Coleoptera) arrive early but generally after the initial wave of fly colonizers so that they can feed both on the corpse and fly eggs [12]. A few species of beetles (families Dermestidae and Cleridae) prefer dry remains, when the tissues are leathery in consistency and nearly devoid of moisture. Once the body has been reduced to bone, cartilage, and hair, insect interest wains but is not totally absent. A few moths (Lepidoptera) will feed on hair and remnants of clothing, parasitic wasps (Hymenoptera) that specialize on wandering fly larvae or puparia scattered about the remains are present, and a small number of beetle species can be found searching for scraps on the bone [13]. By specializing on different stages of decay, many organisms can successfully utilize the same resource, thereby forming thriving communities in a rapidly vanishing microhabitat.

Few of these “other” carrion inhabitants receive the attention of necrophagous flies. The net effect is that the potential of non-dipteran insects to serve as alternative forensic indicator species has not been examined in any detail. This chapter examines the parasitic Hymenoptera associated with carrion communities that offer potential utility to forensic investigations. The biology of the most common families of parasitic wasps is discussed in terms of how the life history characteristics relate to specific forensic applications.

2. Necrophagous Diptera: Primary forensic indicator species

Before turning our full attention to parasitic wasps for the remainder of this chapter, it is worth briefly examining the features of necrophagous flies that make them especially well suited for use in death investigations. This in turn will serve as a foundation for making comparisons to the traits of parasitic Hymenoptera associated with carrion communities. Certain species of flies are invaluable for estimating a portion of the post-mortem interval and also in assessing whether a body has been moved. The first key characteristic was already addressed, and it lies in the need of adult females to find protein for provisioning eggs. In reality, this is true of only some species, those that are anautogenous. Such flies tend to be first wave colonizers, often arriving shortly after death. Thus, the timing of oviposition often closely approximates the perimortem window after the agonal period. Several species of calliphorids are anautogenous, early colonizers. Many autogenous calliphorids species are also early colonizers, motivated to forage for oviposition sites that maximize female fitness. This essentially means locating carrion while protein resources for progeny development are still abundant. The latter comment leads to a second feature of necrophagous flies: faunal succession is relatively predictable for specific stages of physical decomposition [1]. Really the same is true for non-dipteran insects with the exception that the period of insect activity is often more broad than for flies serving as primary forensic indicator species. What this also means is that the absence of particular species can convey relevant information as well. For example, lack of first wave or early colonizers suggests that the body was not accessible for a set period of time, or that environmental conditions were not favorable for insect activity until a later stage of decomposition. The third key characteristic is that necrophagous fly larvae feed exclusively on the corpse, thereby linking immature development to the post-mortem existence of the deceased, which includes the habitat and environment where the remains are located [14]. A linkage to the environment is also a key feature of flies in that they are poikilothermic and derive thermal energy from the local microenvironment for development. By understanding the duration of development under a range of temperatures and environmental conditions, calculations can be made of how long a fly larva has been present on a corpse [15]. This, in turn, permits an estimation of the minimum length of time that the remains must have been available for colonization for the fly of interest to reach the stage of development found at the time of body discovery. What this means is that larval development of flies can be used to calculate the minimum post-mortem interval [16]. Such predictions based on environmental conditions also necessitate that the stage of fly development can be determined, a process that is aided by the fact that flies exhibit determinant development, meaning that there are a fixed number of larval instars regardless of changes in abiotic and biotic factors in the environment [17]. Other insects that inhabit carrion generally are not exclusively saprophagous/necrophagous such as certain species of flies and/or experience indeterminant development, and thus offer more limited use in criminal investigations.

Despite the value of necrophagous flies to medicocriminal entomology, there are shortcomings or limitations to their utility in death investigations. The most obvious is that after third instar larvae complete feeding, they disperse from the corpse [18]. This does not end the usefulness of flies, but it does reduce their value as physical evidence. Diminished value is due in part to

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the fact that the larvae are no longer feeding and thus a direct linkage to the corpse has ceased. The length of the wandering stage also can be highly variable between species, decreasing the precision in estimating a minimum PMI based on any developmental stage post-feeding [19, 20]. As well, recovery of dispersed flies from the crime scene can be challenging dependent on body location, soil type, and fly species, the latter of which show a great deal of variability in terms of distance dispersed from the remains [18]. The most important factors limiting the value of flies as physical evidence are those that impact the rate of immature development [1, 15]. The key to this statement is that use of fly development in predicting the PMI is based on the underlying assumption that a linear relationship exists between the rate of larval development and ambient temperatures. Obviously any factor that influences growth independent of temperature violates this assumption and thus diminishes the value of flies, and most importantly, leads to less precise estimations of the PMI. Such factors as maggot mass temperatures, overcrowding, competition, cannibalism/predation among and between fly species, and nutritional quality of corpse tissues are just some of the influences known to alter the rate of fly development. Each of these factors is highly variable, reflecting the unique conditions of independent death events, which in turn makes them extremely challenging to incorporate into fly growth models. Thus, there is a need to compliment the use of necrophagous Diptera with other ecological evidence collected from crime scenes, such as in the form of alternative forensic indicator species. One such group is the parasitic Hymenoptera, which possess life history traits that overcome some of the limitations encountered with fly larvae.

3. Parasitic Hymenoptera as alternate forensic indicator species

All parasitic wasps that frequent animal remains rely on a parasitoid lifestyle, regardless of the species or developmental stage of host used for progeny development. What this means is that the host will die as a result of the parasitic association, because of the action of venom injected by females at the time of oviposition, envenomation via larval salivary secretions, or through the feeding activity of developing larvae on or in the host [21, 22]. Parasitic wasps are distinct from most carrion-inhabiting flies in that they are necrophilous, or attracted to carrion, but are not necrophagous, and thus do not feed on animal remains. In most instances, the small wasps utilize larvae, prepupae, or puparial stages of flies belonging to the families Calliphoridae, Sarcophagidae, and Muscidae that are feeding on, under, or near a decomposing carcass. The wasps are best known to forensic practitioners through unfortunate encounters during death investigations, when their parasitic efforts compromise attempts to raise flies in the laboratory for species identification or during developmental experiments [1]. While these frustrating occurrences are common, parasitic wasps possess untapped potential to serve as forensic indicator species; filling in key information gaps remaining after fly evidence has been considered.

The idea of using parasitic Hymenoptera as forensic indicator species is not new, but in practice, their biology is rarely applied to criminal investigations [23–25]. Why? Part of the problem stems from the fact that parasitic wasps often go unnoticed at crime scenes. The oversight is attributable to their small size (most that frequent carrion are less than 2 mm in length) and tendency to arrive during later stages of decay, when the early fly colonizers have already dispersed or are nearing the wandering stage associated with post-feeding. In practice, early colonizers are favored as ecological evidence for all the reasons given for necrophagous Diptera. More significant than size or period of activity on carrion is that the life history characteristics of most parasitoids, other than the pteromalid *Nasonia vitripennis* (Walker), that frequent carrion have not been examined or only limited aspects of the biology and behavior of a few species are known [26, 27]. For example, developmental thresholds and temperature-influenced developmental data have been worked out for only two parasitoids, *N. vitripennis* and *Tachinaephagus zealandicus* Ashmead (Hymenoptera: Encyrtidae) [28–31]. Even less is known about seasonal occurrences of parasitoids, with the most extensive work being conducted on *N. vitripennis* and to a much lesser extent with *T. zealandicus* and *Alysia manducator* (Panzer) (Hymenoptera: Braconidae) [29, 31–34], and the parasitoid fauna of most biogeographical regions has never been examined [35–37]. The data available for most species relates to their potential as biological control agents of filth flies, namely muscids, which generally do not translate to carrion communities, or the parasitoids of such flies are not encountered on animal remains [29, 38]. Despite these limitations, several parasitoids have been collected from forensically important flies in Australia, Europe, South America, and United States, and thereby are purported to be potential forensic indicator species [25, 29, 36, 37, 39–41]. In Section 3.1, an examination of whether such potential truly exists for parasitic Hymenoptera is discussed, as will the areas of parasitoid biology in need of further investigation to put them in line as alternative forensic indicator species.

3.1. The case for forensic relevance

Many species of parasitic wasps do show promise as alternative forensic indicator species, especially pupal parasitoids. The question that must be asked is if parasitic Hymenoptera were not overlooked at crime scenes (and, of course, the needed life history data were available), what information could they reveal about death? There are at least four pieces of information that can be derived from parasitic wasps in forensic investigations: (1) Parasitic wasps can extend the PMI window to include the period of time after necrophagous flies cease feeding to when a corpse is discovered, (2) wasp host preferences and seasonal occurrences can reveal if a body was moved from another location prior to discovery, (3) artifacts of past wasp activity remain at the scene for many years after they have dispersed permitting interpretation of period of activity and seasonality, and (4) foraging behavior of adults can be used to locate concealed bodies [1, 23, 42, 43]. In some instance, parasitic wasps have already been useful in case studies (i.e., PMI estimations; [23, 25, 40, 44]), and in yet others, the full potential of fly parasitoids has not been realized because key aspects of their biology remains poorly understood.

3.1.1. Extending the PMI

In many ways, parasitoids offer similar evidence as necrophagous flies, only with regard to a different period of time. For instance, many species of Hymenoptera parasitize older larvae, prepupae, or puparial stages of fly hosts, and do not emerge from the host until a few to several

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weeks after unparasitized necrophagous flies have eclosed. Thus, if the developmental parameters of a given parasitic wasp are fully understood, such species can extend the PMI window from the time flies initiate dispersal behavior until the corpse is discovered. This window of time can potentially represent 2–4 weeks or longer depending on the environmental conditions and season. The best example is with *N. vitripennis*, a wasp that parasitizes the puparial stages of flies predominantly in the families Calliphoridae and Sarcophagidae, although muscids are readily utilized if discovered by foraging females. Fly hosts cannot be parasitized prior to hardening of the puparium; meaning after pupation is complete, but prior to the onset of eclosion behavior. Thus, a precise window exists into the minimum length of host development on a corpse prior to parasitism by *N. vitripennis*. A similar relationship exists for other pupal parasitoids in the genera *Trichomalopsis*, *Muscidifurax*, *Pachycrepoideus*, and *Spalangia*, but they rarely are associated with carrion, and even then, parasitism is typically restricted to muscids [35, 45]. Larval parasitoids from the families Braconidae, Diapriidae, Encyrtidae, and Ichneumonidae show less host specificity than pupal parasitoids, preferring post-feeding larvae as hosts, but also ovipositing in younger larvae and pre-pupae [26, 46, 47] (**Table 1**). Their use in PMI estimations would yield broader time ranges than those based on pupal parasitoids development on fly hosts. A similar trend is true for members of the family Figitidae that deposit eggs in young fly larvae [48], although their host age preferences are narrower than more common larval parasitoids found on carrion. The reality is that PMI estimations based on parasitoids is markedly more complex than those derived from flesh-eating flies. It is also not as simple as the suggestion by Frederickx et al. [37] that the developmental time of a given parasitoid is just added to the duration of host development. Why not? Parasitoid progeny development is influenced by multiple factors beyond just ambient temperatures, including host age, size, physiological state, species, whether the fly has been previously parasitized or not, and the size of larval feeding aggregations experienced by the host [31, 49–52]. Developmental data for a particular species of parasitic wasp must also be derived from each relevant host species for use in PMI or period of insect activity calculations [29]. This thought must be extended to also include a wide range of developmental parameters that influence parasitoid growth for *each host utilized by each parasitic wasp* discovered at a crime scene. Such data are available for very few parasitic wasp species.

Family	Fly hosts	Host stage parasitized
Braconidae	Calliphoridae	Larvae
Diapriidae	Calliphoridae	Larvae
Encyrtidae	Calliphoridae, Muscidae, Sarcophagidae	Larvae, prepupae
Figitidae	Calliphoridae	Young larvae
Ichneumonidae	Calliphoridae, Sarcophagidae	Larvae
Pteromalidae	Calliphoridae, Muscidae, Sarcophagidae	Pupae, pharate adults

Table 1. Common families of parasitic Hymenoptera collected from human remains

Further complicating the host-parasite relationship in terms of predicting wasp development times is the physiological state of the parasitoids and conditions of parasitism. Female age directly influences efficiency of foraging behavior for hosts, the length of time needed to parasitize a host, which can be especially long for parasitoids using concealed hosts, and the quality of eggs deposited on a host. Eggs from older females may fail to hatch or larvae may spend more time feeding than is typical of progeny produced by younger adults [53, 54]. A similar effect is associated with larval development on flies that have been previously parasitized by conspecifics or allospecifics [55–57]. Failure to take into account each of these influences can lead to inaccurate calculations of developmental thresholds and estimations of wasp development times, as in most instances unfavorable host conditions increases the duration of parasitoid development [51, 58, 59]. The complex interactions between parasitoids and their hosts underscore the need for standard protocols in collecting wasp development data for use in forensic entomology [31].

3.1.2. Host preferences

The limitations discussed in terms of information required to improve the precision of PMI estimations using parasitoids can be overcome with more focused research. It is also important to note that the forensic potential of parasitic wasps is not diminished by gaps in basic knowledge of life history characteristics. In fact, parasitoids have far more potential as alternative indicator species for estimating the PMI than predatory species because of their specificity as parasites. What this means is that though some species may show variability in host preferences, progeny development is entirely tied to feeding on the host. As the fly hosts are linked directly to a corpse, the parasitoid's immature development is a second-level linkage to the conditions associated with the deceased. The same features are not true with predators that visit carrion. Another key difference is that the window of time in which a host is suitable for parasitism is more predictable and generally represents a narrower time period than that in which suitable prey are available for predation. The later is reflective of necrophilous beetles that may feed on animal remains as well as prey upon eggs and fly larvae for several days to weeks, depending on the season and ambient conditions. In comparison, the window of opportunity is quite short when pupal parasitoids (e.g., pteromalids) use puparia of calliphorids. Hosts are only of useable age for 3–5 days during warmer months, and somewhat longer as temperatures decline. Even this assessment is complicated by the observation that puparial development of *Lucilia sericata* is shorter in the presence of *N. vitripennis*, thereby reducing the window for parasitism by almost 1 day at temperatures near 25°C [60]. By contrast, the puparial stages suitable to serve as hosts for some sarcophagids extend over a much longer duration (1–2 weeks) [51], decreasing the precision of a PMI calculated from wasp developmental data as the age of the host at the time of parasitism is not known (**Table 2**).

3.1.3. Seasonality

Seasonality of parasitoids is especially useful for the determination of whether a body has been moved. As with other aspects of parasitoid biology, seasonal occurrence of parasitic wasps is directly linked to fly hosts. For pupal parasitoids, those that enter winter dormancy in the form

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of diapause generally do so within the hardened puparium of a fly host. Depending on the timing of diapause onset, which is influenced by latitude, several species of calliphorids are eliminated as potential hosts as they diapause as either larvae or in an adult reproductive diapause [1]. As a consequence, sarcophagids often serve as the overwintering host for pupal parasitoids that frequent carrion. Collection of parasitized hosts with diapausing wasp larvae or parasitism of hosts by a wasp that should ordinarily be in diapause can be an indicator that the body has been moved from another region in which the seasonal conditions are substantially different from the site of discovery. Widespread use of seasonal information for pupal parasitoids is quite limited at present because diapause details are only firmly established for *N. vitripennis*, and even then, only for specific biogeographical locales within North America and parts of Europe [32, 61]. The situation for larval parasitoids is similarly bleak in that though the seasonal occurrence of a few species has been reported [29], diapause has only been examined in the braconid *A. manducator*, which synchronizes dormancy with that of its calliphorid hosts [33]. Presumably other species synchronize diapause with that of their hosts and/or enter dormancy during a time that certain fly species are not available for parasitism. It is also quite likely that in certain biogeographical regions, a true diapause does not occur and that senescence similar to that of calliphorid adults that rely on reproductive diapause occurs. Much more research needs to be devoted to examining the seasonality of parasitic Hymenoptera, as the resulting data would open new opportunities for applying parasitoid biology to medicocriminal investigations.

Idiobiont	**Koinobiont**
Utilize puparial stages as hosts	Utilize young or old larvae, or prepupae as hosts
Manipulate host through maternal and/or larval venom injection	Host manipulation has not been examined but presumed to rely on endosymbiotic viruses of maternal origin
Host typically dies shortly after parasitism	Host continues to fed and develop following parasitism
Parasitoid development not synchronized with host and generally lasts from 2–4 weeks	Parasitoid development is synchronized with host in some cases, not in others, and development is generally longer than idiobiont species (4–6 weeks)
Adult parasitoids emerge from puparia	Adult parasitoid emerge from puparia

Table 2. Characteristics of idiobiont and koinobiont parasitoids associated with carrion breeding flies

3.1.4. Wasp artifacts

The vast majority of parasitoids utilizing carrion-inhabiting flies as hosts emerge as adults from host puparia, regardless of whether they are larval or pupal parasitoids. Exit holes chewed in puparia reflect species preferences for emergence location and the size of the hole often typifies species [1]. Pupal exuvia also remain within the puparium, along with any unemerged larvae or pupae, providing clues regarding species identity and possibly developmental duration, which are useful in establishing a PMI based on a particular wasp species and host. Such information has also proven useful to the specialized discipline of forensic archaeoentomology, in which parasitized puparia provided insight into the burial practices of pre-Columbian civilizations in Peru [42].

Molecular artifacts may also be associated with parasitic wasps, potentially revealing information regarding developmental conditions for the wasps and/or host species. The artifacts are in the form of heat shock proteins (hsps), produced in response to various stresses experienced during development, most frequently while progeny are feeding on fly hosts. For example, larvae of *N. vitripennis* demonstrate up-regulation of hsp 23, 60, and 70 when developing on hosts that have experienced overcrowded conditions in larval aggregations [52]. Hsp expression levels correspond with species and size of maggot masses experienced by the host. Similarly, fly hosts synthesize specific hsps in response to maggot mass dynamics, and the expression continues during pupal and early pharate adult development [62], a window of time in which pupal parasitoids oviposit on discovered flies. These observations suggest the possibility that molecular markers associated with hsp expression or associated with altered gene expression of other proteins may be useful in deciphering the developmental conditions experienced by parasitic wasps prior to discovery, and may also reveal limited but useful information concerning ambient temperatures realized by their fly hosts [52]. Much more research is needed to determine if such possibilities are feasible.

3.1.5. Biosensors

Parasitic wasps do offer some advantages to forensic entomologists not yet exploited with necrophagous Diptera, namely in the form of chemical detection of decomposing bodies [43]. Under natural conditions, most species of parasitic wasps rely on chemical cues during foraging to locate potential hosts and their food resources [63]. At least with one species, *Microplitis croceipes* (Braconidae), a wasp that utilizes the larval stages of agricultural pests (Lepidoptera: Noctuidae) as hosts, can be trained through Pavlovian conditioning to associate a wide range of factitious chemicals with food [64, 65]. Odorants common to decomposition of animal tissues, that is, cadaverine and putrescine, have been used to successfully condition adult females, which, in turn, demonstrate foraging behavior in the presence of the odors [66]. Thus far the research is still in its infancy and has not yet been tested in a field setting to determine if *M. croceipes* can successfully locate a decomposing corpse emitting odors recognized by the wasps. For practical use, the parasitoids need to be tractable like has been done with honeybees, *Apis mellifera* (Hymenoptera: Apidae) equipped with GPS or radio signal detection when used as a sniffer system [67]. Other species have not been tested yet to determine how widespread is the ability of parasitic Hymenoptera to be used for the location of decomposing bodies. The technique would be especially valuable for finding concealed remains, such as buried, trapped in secluded locations, or those hidden in artificial containers.

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4. Future directions

Though parasitic wasps show tremendous potential to serve as alternative forensic indicator species, their full utility cannot be realized until key gaps in information are understood. Developmental thresholds and durations of development for most parasitoids are unknown. Any experiments performed to fill this void must take into account factors that influence the host-parasite relationship, as outlined earlier, and also consider optimal host-parasite ratios during parasitism [31]. The parasitoid fauna and seasonality based on biogeographical distribution are poorly understood throughout most regions of the world. What is known represents just a few parasitic wasps from a limited number of locations (Brazil, the United States, and parts of Australia and Europe), and even then, species from just a few locales within a region have been examined. This represents a considerable deficit in background information for application of parasitoid biology to medicocriminal entomology. Parasitoids are also known to alter the development of their fly hosts dependent on the parasitic strategy adopted yet few details are understood in terms of how this impacts the use of parasitic wasps in PMI estimations. For example, larval parasitoids such as *A. manducator* and *T. zealandicus* rely on a koinobiont strategy, whereby the host remains alive and in some cases, continues to feed following oviposition [26, 47]. Parasitism is not evident usually until pharate adult development of the fly host, which means that parasitized hosts may be used for estimations of the PMI. What is not known is whether the development of such hosts has been significantly altered by comparison to unparasitized flies. There is, thus, a need to examine the impact of koinobiont parasitoids on fly development and to uncover developmental markers relevant to staging both the flies and wasps. The latter is especially critical for species that utilize multiple stages of the same host, which likely are not equally suited for parasitoid development, and consequently would be expected to yield different developmental rates for a given parasitic wasp [26]. Host manipulation by idiobiont parasitoids is much different than occurs with a koinobiont strategy in that the fly typically does not continue to develop or only in a limited capacity following parasitism, and host death usually ensues quickly after oviposition [56]. That said the only detailed work with idiobiont parasitoids of carrion flies is with *N. vitripennis*, which is a pupal ectoparasitoid. Venom injected by females during oviposition alters several keys aspects of host physiology and development [68, 69]. In less desirable hosts for progeny development, such host alterations do not occur and larval development requires a significantly longer period of time to complete [70]. This again emphasizes the need for collecting data on developmental thresholds and durations of development for each host species of interest for each parasitoid encountered at a crime scene.

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Section 3

Crime Scene Investigation

Chapter 5

Molecular Genetics and its Applications in Forensic Sciences

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Additional information is available at the end of the chapter

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Abstract

The way to medico legal identification was open at the end of the twenty-first century by the "digital fingerprinting" represented by the multifactorial phenotypical trait, determined by both polygenic and environmental factors, followed by group-specific antigens, or with specificity for blood and tissue, and ending with the DNA molecule in use today. Because of this aspect, the framework of modern forensic medicine includes a new field, that of forensic genetics, that mostly involves working with investigations that have human genotype identification as a goal.

Keywords: forensic genetics, human identification, DNA genotype, polymerase chain reaction (PCR), short tandem repeats (STR), single-nucleotide polymorphisms (SNPs)

1. Introduction

Forensic identification is a universal method used to establish the truth in the process of forensic investigation. The evidence includes, among other components, the identification but without being mistaken for it or being reduced to just this.

Both medico-legal and criminalities identification are integrative parts of forensic identification, having probative value. The value of an identification method resides in the expert's ability to compare traces left at the crime scene with traces found on other materials such as reference evidence. Through this method, one can compare: traces of blood left at the crime scene with those found on a suspects' clothes and with samples from the victim. Furthermore, the rifling can be compared with fingerprints left on the weapon and with the rifling of other weapons.

Medico-legal identification is based on intrinsic scientific methods or scientific methods absorbed from other sciences, usually bio-medical sciences. Scientific progress from the last 30–40 years has highlighted and continues to highlight the role of the specialists in identification. Their role proves its importance in cases that have to do with civil and criminal law, family law, as well as in cases of catastrophes with numerous victims (natural, accidents, wars, terrorist attacks).

Together with the discovery by Mullis in 1983 of the polymerized chain reaction (PCR), Sir Alex Jeffreys will introduce in the field of forensic genetics this technique by studying a set of DNA fragments that proved to have unique characteristics, which were nonrecurring and inherent for each individual, the only exception being monozygotic twins. Alec Jeffreys named these reaction products "genetic fingerprints".

In this chapter, we will present the utility of molecular genetics techniques in the case of forensic identification, as well as in criminalistics cases.

2. Short history of forensic genetics

In 1880, British anthropologist Sir Francis Galton published the first studies on digital fingerprinting as an identification method of a certain person.

Another important step in forensic identification was discovering the protein polymorphism of the AB0 blood groups by the Austrian doctor Landsteiner at the beginning of the twentieth century.

After year 1950, in the forensic serology, laboratories were tested a number of blood and tissue antigens, culminating with researching the major histocompatibility complex (HLA).

Sir Alec Jeffreys introduced for the first time the DNA fingerprinting in the field of forensic genetics, proving that some regions from the DNA contain repetitive sequences which are variable among individuals [1]. He was the first to prove the importance of using genetic fingerprinting in the case of forensic personal identification (crimes, filiation, consanguinity, sexual abuse, immigration).

Due to this discovery, the first case of forensic genetics could be solved using the DNA analysis [2]. After murdering of two girls in 1983 and 1986, the police organized the blood sample collection from 5000 men living in the area where the murder took place, and finally found the killer by his DNA profile [3].

In 1983, Kary Mullis developed the polymerase chain reaction (PCR) technique which opened new ways in DNA analysis in the forensic genetics. Thus, from each biological human trace or micro-trace containing nucleated cells, the DNA is extracted to be subjected to amplification reactions. The method is an enzymatic process by which regions of the DNA are replicated

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(multiplied) 28–34 times, generating about one billion (10^9) copies. This technique highlights the number of repetitions of the base unit and turns them into alpha-numeric values, known as genetic profiles.

Genetic analysis of a very small number of nucleated cells, namely a very small amount of biological material, is made by a different approach from the usual situations and aims to generate, through the reaction of amplification, the sufficient quantity of copies of DNA fragments to obtain an exploitable genetic profile. This method is applicable to biological samples with a DNA matrix containing <50 pg., to biological micro-traces, to biological samples that are in an advanced stage of decay, with single source or multiple sources.

For the last two decades, the results of the DNA analysis have been accepted as evidence in the court in many countries [4]. Since February 1992 when The European Council issued the **Recommendation No. 92**, regarding the use of the DNA analysis in the criminal justice the DNA test is accepted in the Court [5].

3. Biological sample collection

3.1. Samples

Biological samples consisting of nucleated cells are essential for forensic genetic profiling [6].

Biological samples belonging to this category are as follows:

- Liquid blood or dry deposited on supports;
- Liquid semen or dry deposited on supports;
- Various biological secretions (saliva, semen) or mixtures of secretions originating after sexual acts;
- Hard tissues (bone, teeth);
- Hairs with follicles (“root”);
- Slides and cytological smears.

3.2. Sample collection, storage, and characterization for DNA analysis

Nowadays, whole blood is considered to be the most widely used source of DNA. It is harvested on anticoagulant EDTA (ethylenediaminetetraacetic acid). It can be conserved at 4°C for a maximum of 5–7 days; after this time, the DNA sample being kept at -20°C for a few weeks, or at -80°C for longer periods of time [7].

In the case of blood harvested during autopsy, it does not need anticoagulant and it can be harvested from the following organs:

- Heart chambers;

- Skeletal muscles or heart muscle;
- Peripheral vessels;
- Long bones;
- Other tissue types.

Apart from whole blood, epithelial cells from oral mucosa as well as hair are considered to be important sources for DNA analysis, being frequently used. In the case of epithelial cells, they are harvested with a sterile bud or brush. After harvesting, they are wrapped in a paper envelope and put to dry. Hair is taken by pulling, 5–10 with the root being enough for the analysis.

The hair is wrapped in paper envelopes or plastic wrapping and is kept in a dry environment, at room temperature [8].

In comparison with the biological samples mentioned earlier, in the case of tissue, muscles, organs, or skin, the harvested volume needs to be between 2 and 4 cm. Right after harvesting, the DNA extraction and isolation follows because both its quantity and quality decrease in time and depend on the storage conditions.

3.3. Characterization of the DNA analysis

DNA analysis is a complex process which consists in the following phases:

a. DNA extraction;

b. DNA quantification;

c. DNA amplification;

d. Detection of the DNA amplified products.

4. Methods used in forensic for human identification

4.1. Autosomal STR profiling

In forensic DNA typing, short tandem repeats (STR) or microsatellites are the most frequently genotyped in order to distinguish between individuals, to tie an individual to a crime or to exonerate the innocent. STRs were discovered in the 1980s [9] and since then, they are the "gold standard" in human identification in forensic investigations. They consist of mono-, di-, tri-, tetra-, penta-, and hexa-nucleotide repeat. An individual can be either homozygous (with the same number of repeats) or heterozygous (different number of repeats) in a certainly locus. Tetra-nucleotide repeats are used for genotyping in forensic DNA analysis [10].

STR profiles obtained from biological samples found at crime scenes are compared with other profiles of known suspects and are identified by police or are included in a national forensic DNA database [11]. Also, the STR profiling is used in paternity/maternity testing, disaster victim identification (DVI), rape perpetrators identification, and kinship testing [12]. Due to the STR profiles, in numerous cases, the persons have been excluded from involvement in crimes and have been exonerate.

A main advantage of the STRs markers consists in the fact that they can test in a rapid, simple, and simultaneously way more than 10 STR loci by multiplexing [13]. Due to this characteristic, it offers an increased degree in the identification of different biological samples.

The tetra-nucleotide and penta-nucleotide systems are included in the multiplex analysis kits because they can provide results with an increased index of exclusion. The nomenclature of the STR loci and the allelic variants was established in 1993 by the DNA Commission of the International Society of Forensic Genetics (ISFG). Except their usefulness in forensic DNA analysis, STRs became used in medical genetic research, because it has been demonstrated that the trinucleotide STR loci is associated with some genetic disorders. The DNA profile refers to the genotype (the number of repeats found in each allele of the analyzed STR marker) of a suspect, victim, or crime scene sample.

In the development of STR typing system, in 1997, the Federal Bureau of Investigations (FBI) introduced the database named CODIS (Combined DNA Index System) that included 13 autosomal loci and the amelogenin sex test [14]. These loci are highly polymorphic, localized in non-coding regions which are on different chromosomes. As an improvement in their efficiency, the new multiplexes that amplify 16 loci or more, in a single reaction (including amelogenin too), have been introduced in the last years [15]. The most common STR kits used in the forensic laboratories for the identification are manufactured by three companies: Life Technologies, Promega and Qiagen.

The forensic DNA analysis is made through multiplex PCR amplification of 10–16 STRs or more, followed by automated sequencing equipment, such as capillary electrophoresis (CE) [16].

The STR-based forensic DNA analysis has been well accepted by population and professionals, as an important tool in human identifications and in the criminal justice.

Other sources of genetic variations that have been demonstrated to present more specialized uses in forensic identification are as follows: autosomal SNPs, the markers on the Y chromosome and mitochondrial DNA (mtDNA).

4.2. Analysis of the Y-chromosome

In forensic medicine, the Y-chromosome has only one useful property: It is present only in males. Thus, in crime cases, the investigators expect to find Y-chromosome at the scene. Also, when talking about male–female ratio in body fluid mixtures, such as rapes, by analyzing the Y-STR component, the investigators can obtain more information regarding the male component. It is well known that vasectomized or azoospermic rapists do not leave sperm traces, and it is impossible to find spermatozoa on the microscopic examination. In such cases, the Y-STR profiling is very useful, offering information regarding the identity of the rapist [17].

4.3. Analysis of mitochondrial DNA (mtDNA)

Mitochondrial DNA (mtDNA) is inherited on the maternal line; thus, all the members of a matrilineal share the same haplotype. Its advantage relies on the fact that it has a number of 200–1700 copies per cell and has an increased probability of survival compared to the nuclear DNA. Therefore, the forensic applications for mtDNA include analysis of biological samples that are old or severely degraded, and analysis of biological samples which contain a low amount of DNA (e.g., hair shafts). MtDNA has been used to identify the Tsar Nicholas II and his brother Georgij Romanov [18].

4.4. Autosomal single-nucleotide polymorphisms (SNP) typing

Single-nucleotide polymorphisms (SNPs) have a lower heterozygosis when compared to STRs. The advantage of SNP typing consists in the fact that the DNA template size can be as large as 50 bp, compared to the STRs which need the DNA template size of 300 bp, to obtain a good STR profiling [19].

Due to this, the SNPs became important tools in analyzing degraded samples. Thus in 2001, SNP typing was used in identifying the victims from the World Trade Center disaster [20, 21]. Related to the use of SNP analysis in degraded biological samples, the European Network of Forensic Science Institutes (ENFSI) and the US FBI Scientific Working Group on DNA Methods (SWGDAM) are working on recommendations regarding the standardization of the SNPs [22].

5. Impact of genetic identification on justice

At the present time. genetic testing using DNA has wide applicability to the field of justice, this method being used for the following:

- Identification of suspects and confirmation of guilt;
- Exculpation of innocent parties;
- Discovering of persons who commit crimes, or serial killers;
- Researching biological filiation;
- Establishing consanguinity in more complex cases;
- Establishing biological bloodline relations that serve in finding the historical truth (the Romanov case, the case of Louis XVII of France, the Nazi doctor Joseph Mengele)
- Identification of victims of terrorist attacks or natural catastrophes;

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- Identification of certain probes for medical testing (tissue for histology testing, blood alcohol content testing, other toxicological tests).

6. Emerging biomarkers in forensic identification

Forensic genetics will continue to develop and improve its methods, due to the advances in the technical development. The key element in forensic protocols is to identify the origin of biological traces found at the scene. In the last 5 years, some studies have demonstrated that messenger RNA (mRNA) can be useful in forensic identification. Zubakov et al. [23] have identified some mRNA stable in body fluids, such as blood and saliva.

In recent years, the European DNA Profiling Group (EDNAP) has performed some studies on the RNA/DNA co-extraction and proved once again the usefulness of mRNA as a tool for the identification of semen and saliva in forensic cases, compared to the DNA methodology [24].

Another important application of mRNA is in the forensic identification of the skin, using the RT-PCR methods [25].

Since 2009 Hanson et al. [26] have been explored miRNA for their use in forensically body fluids identification. The advantage of these new markers over the mRNAs markers consists in the fact that they have a smaller size containing around 18–22 bp, thus being more stable than mRNA to degradation conditions.

Since last decade new steps have been done in "forensic molecular pathology" and in "post-mortem pharmacogenetics".

Studies regarding the molecular diagnosis of genetic cardiac arrhythmia or long QT syndrome which leads to sudden death [27] and the post-mortem analysis of gene CYP2D6, which encodes a drug metabolizing enzyme whose variation leads to adverse drug effects and finally to death [28] are new tools which evolve in forensics.

7. Conclusions

Currently, the DNA genotyping of all types of biological traces or micro-traces containing nucleated cells is possible if they are not entirely destroyed, either chemically or bacterial. The DNA analysis represents an important tool in solving caseworks in forensic medicine, such as establishing the custody of a child through paternity or maternity tests, identifying victims from disasters or crimes, exonerating innocent people convicted to prison.

Due to the recent advances in molecular genetics, other biomarkers have been proposed to be used in forensic body fluids identifications, such as messenger RNA (mRNA), microRNA (miRNA), and DNA methylation.

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Chapter 6

Usage of Infrared-Based Technologies in Forensic Sciences

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Additional information is available at the end of the chapter

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Abstract

Infrared (IR) radiation comprises a beam located in the electromagnetic radiation family; it arises from the thermal vibrations of radiation that have longer wavelengths than visible light, but shorter wavelengths than microwave radiation. Its wavelength is between 750 nm and 1 mm. The amount of thermal IR radiation emitted by an object is associated with the temperature of the object, the surface area of the object and the spreading of light. IR-based technologies have been demonstrated as a method of evidence identification in forensic sciences in addition to many daily uses.

The combination of IR-based spectrophotometry with several techniques ushered in a new era in crime scene investigations and the identification of evidence obtained from crime scenes. Furthermore, the use of IR-based photography techniques has significant advantages. IR fluorescent automated DNA sequencer and thermal analyser for deception detection are other techniques that take advantage of IR technology.

In this chapter, we aimed to present the IR-based technologies used in forensic sciences and forensic photography techniques to define the current situation, the importance and the advantages of IR thermal imaging among these techniques, as well as to describe the operating principles of IR thermal imaging technologies that may be generated in the future based on this technique.

Keywords: Infrared, Thermal Imaging, Scene Investigation, Post-Mortem Interval, Spectrophotometry

1. Introduction

Radiation has been defined as “the emission or transmission of energy in the form of waves through space or through a material medium” [1]. Electromagnetic waves are different from sound waves because they do not require a medium for propagation. As they spread in the air and solid materials, the spread in the empty space does not contain substances [2]. It has been reported that the term radiation includes electromagnetic radiation (e.g., radio waves, visible light, x-rays and gamma radiation), acoustic radiation (e.g., ultrasound, sound and seismic waves) and particle radiation (e.g., alpha radiation, beta radiation and neutron radiation) [1, 3]. The electromagnetic spectrum is a concept that comprises all possible electromagnetic radiation based on the rules of physics anywhere in the universe and the relative locations of this spectrum according to the wavelength or frequency of different radiation derivatives [4, 5].

Infrared (IR) radiation comprises a beam located in the electromagnetic radiation family that arises from the thermal vibrations of radiation with longer wavelengths than visible light, but shorter wavelengths than microwave radiation **Figure 1**. Its wavelength is between 750 nm and 1 mm, and its frequency is between 300 GHz and 400 THz [5]. The amount of thermal IR radiation emitted by an object is associated with the object temperature, and IR may be used to remotely determine the temperature of an object [6]. IR radiation is also referred to as thermal radiation and is defined by three groups. Far IR radiation is between 300 GHz and 30 THz frequency and between 1 mm (=1000 μm) and 10 μm wavelength. Mid-IR radiation is between 30 and 120 THz frequency and between 10 and 2.5 μm wavelength. Near-IR (NIR) radiation is between 120 and 400 THz frequency and between 2.5 μm (=2500 nm) and 750 nm wavelength [2, 5].

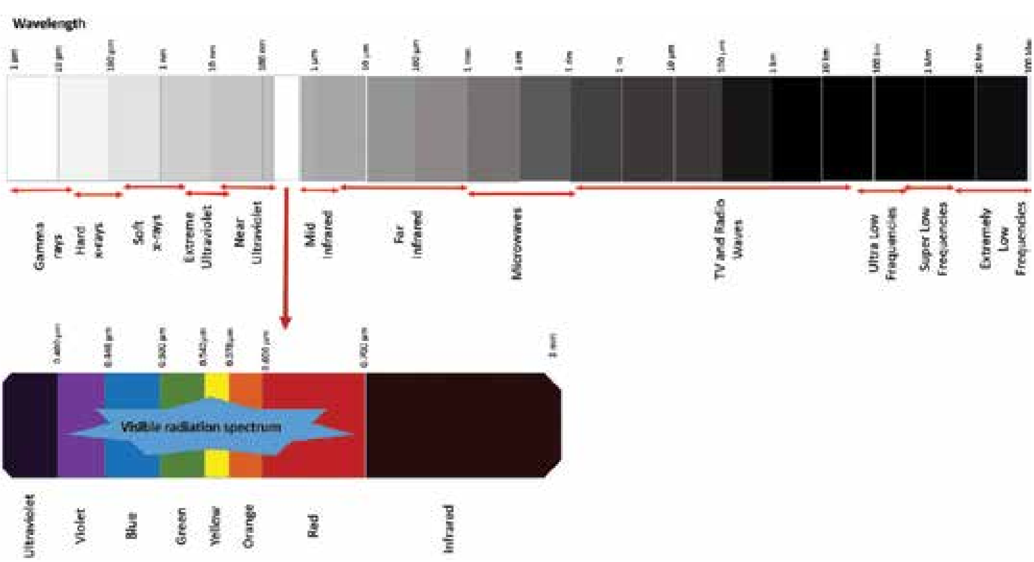

Figure 1. Location of infrared radiation in the electromagnetic spectrum.

2. Brief history of IR radiation

The interaction of light with matter has attracted attention for 2000 years. First, Claudius Ptolemy (100–170, who was known as a mathematician, astronomer, geographer, astrologer and writer) defined the refraction of light in objects in the early 1300s. In 1305, Theodoric of Freiberg (1250–1310, who was a theologian and physicist) created a simulation rainbow with water-filled glass spheres [7].

For the first time in history, IR radiation was defined by Frederick William Herschel (1738–1822, who was a British astronomer). In his studies in the 1800s, he discovered radiation in sunlight by passing it through a prism and holding a thermometer just beyond the red end of the visible spectrum. This radiation was referred to as "below red". This below red radiation was described as IR radiation in subsequent years [8–10].

In 1905, William Weber Coblentz (1873–1962, who was a German physicist) demonstrated that certain molecular groupings, currently referred to as functional groups, had absorbed specific and characteristic IR wavelengths, and he recorded the spectrums among 1–1,15 micrometres of several hundred functional groups [7, 11]. In the first half of the twentieth century, many scientists expanded the spectral database of organic compounds and determined the specific spectral properties of functional groups [7].

2.1. Brief history of IR imaging

In 1829, Nicéphore Niépce (1765–1833, who was a French inventor) and Louis-Jacques-Mandé Daguerre (1787–1851, who was a French artist and photographer) had developed a photographic plate sensitive to NIR radiation. Based on this invention, Sir William de Wiveleslie Abney (1843–1920, who was an English astronomer, chemist and photographer) and Edward Robert Festing (1839–1912, who was an English army officer and chemist) performed NIR radiation measurements in history [7]. In 1860, Gustav Robert Kirchhoff (1824–1887, who was an American physicist) recorded the atomic spectra of many elements and defined that "a hot solid object produces light with a continuous spectrum, a hot tenuous gas produces light with spectral lines at discrete wavelengths (i.e., specific colors) which depend on the energy levels of the atoms in the gas and a hot solid object surrounded by a cool tenuous gas (i.e., cooler than the hot object) produces light with an almost continuous spectrum, which has gaps at discrete wavelengths depending on the energy levels of the atoms in the gas" [12]. Kirchhoff's law of thermal radiation, Stefan-Boltzmann law, Planck's law and Wien's displacement law defined four basic laws of IR radiation [13].

The first thermal camera was invented by Kálmán Tihanyi (1897–1947, who was a Hungarian physicist, electrical engineer and inventor) in 1929. It was used for anti-aircraft defense in Britain [13, 14]. An evaporograph, which is considered the ancestor of thermal imaging, was initially discovered in 1956. In this technique, a thermal imaging device converts an IR image into a visible image via the differential evaporation or condensation of oil on a thin membrane [15].

In the following years, especially after the year 2000, the IR image capture conversion kits of digital cameras began to be developed. In 2006, the first professional digital camera, which was developed using ultraviolet (UV) and IR technology, was introduced [16].

3. Usage of IR-based technologies in daily life and reflections on forensic science

To date, IR-based technologies are a component of daily life. This technology is used in many applications in automotive technology, the petroleum industry, photography techniques, the security sector, agricultural inspection, the forestry sector and medical applications.

3.1. Usage of IR-based technologies in automotive technology

In terms of driving safety, IR-based technology comprises a method that may be used routinely in the future. Currently, it is used by a limited number of companies. One of these systems is based on NIR integration on the basis of existing head-up display systems in vehicles. This system aims to warn of car drivers using a screen in connection with a NIR camera mounted in the front bumper. The NIR camera will distinguish cars, people, animals and other objects on the road, especially at night, based on their heat. One reason for the lack of routine use of this system is that IR cameras transfer images from only 100 meters [17]. It has been indicated that the IR cameras may be used for passenger safety and comfort. IR cameras enable data to be obtained, such as whether there is a seat passenger and the estimated weight if there is a passenger, especially in a bus. In light of these data, equipment based on NIR and IR may be added to vehicles, such as an adjustment system for the air bag pressure according to passengers, indicators regarding accurate issuance of the seat belt warning, passenger-oriented climate control systems, a radar based mass movement sensor for automotive security applications, a driver monitoring system that warns a fatigued driver to pull over and rest, advanced driver assistance systems, including features such as a lane departure warning and switching between autonomous and manual driving mode and systems that disable the vehicle in situations such as drunk driving [17–20]. These systems that improve vehicle safety will cause a decrease in the number of traffic accidents, as well as the number of deaths and injured individuals in traffic accidents. Thus, this system will be an important service for preventive medicine, which is an important task in forensic science.

3.2. Usage of IR-based technologies in petroleum industry

One key area that utilizes IR has been the refinement of petroleum products. In the production of rubber, relatively simple techniques have been used for the analysis of C_4 hydrocarbons. NIR spectroscopy has been used for petroleum refining, especially for petrochemicals and polymers. The major advantages of NIR spectroscopy include its fast, non-destructive and easy approach to extend to online analysis in conjunction with optical fibers. Based on these advantages, oil companies have used IR spectrophotometry and Raman spectrophotometry for the online control of product quality [21, 22].

Spectroscopy is a specific analytical technique used in the structure determination of organic compounds. This technique assesses the changes in the wavelength of the radiation, which was passed from the material to be examined, and measures the amount of radiation absorbed in different wavelengths by the material. As a result of the substantial number of different absorption bands in the spectra of organic substances, organic substances are facilitated to be compared with each other. The spectrum of an organic substance is similar to its fingerprints, and there are no two different substances that provide the same absorption spectrum in theory. Utilizing the originality of the IR spectrum of the substances, qualitative and quantitative analyses may be performed via IR spectrophotometry [23, 24]. IR spectrophotometry has been used in several areas of forensic sciences. NIR spectrophotometry may be used for the determination of ignitable liquids, which are used as accelerants in forensic laboratories. The use of these techniques in forensic science is subsequently described in detail in the section under "Usage of IR-Based Technologies in Forensic Sciences".

3.3. Usage of IR-based technologies in photography techniques

Each object that has a temperature above absolute zero (0° Kelvin, −273°C) emits radiation in the IR region [6]. The IR spectrum is broad from the visible radiation spectrum. IR radiation is related to object temperature, and the IR radiation emitted by objects increases when the object temperature increases. This IR radiation ensures the visibility of objects without lighting. In thermographic imaging, emission, transmission and reflection occur via heat transfer between the camera and the object [25]. A thermographic camera detects changes in temperature as a result of this radiation in the range of the electromagnetic spectrum from 0.9–14 μm [6, 13]. On the basis of thermal camera imaging, the reflected differences in temperature transfer the image [6]. Several conditions are necessary to create the images of thermal cameras. Thermal camera imaging may be used for objects that have different heat conductivities, objects that have the same emissions but different heat, objects that have the same heat but different emissions, objects that have radiation reflection or the same objects under different weather conditions [14]. The non-contact IR thermography (IRT) technique comprises a non-destructive inspection method. It uses IR irradiation to identify and record the thermal pattern and temperature that spread across an object surface. This equipment converts temperature by sensing IR radiation, and it provides the converted image of this distribution [6].

Typical IR cameras include semiconductors to detect IR energy from the target object and cooled detectors. The typical IR camera signal processing mechanism may be summarized as follows: (1) the image is created using radiation in the IR wavelength range by the optical system; (2) radiation detected by the thermal detectors is converted into electrical signals via the thermal detectors; (3) some systems require the scanning mechanism, whereas other systems do not require, in general, a large detector array to completely cover the field of view of the camera; and (4) an electrical signal is converted to a video signal by the electronic processor, and an image is formed by transmitting the video signal to the display unit [6, 26].

In general, IR cameras use a single sensor, and they do not differentiate different wavelengths of IR radiation. Color is not significant in areas outside the visible wave lengths. Color IR cameras have a more complex structure. In these cameras, the colors used in the camera structure are pseudo-coloring, which demonstrate changes in the incoming signals [6].

IR cameras with uncooled detectors were implemented after 1990. In the following years, the prices of IR cameras steadily decreased, and their usage was widespread as the parallel of the rapidly developing technology [26]. IR imaging is an important technique used in forensic science, especially crime scene investigations. The use of these techniques in forensic science is described in detail in the section under “Usage of IR-Based Technologies in Forensic Sciences”.

3.4. Usage of IR-based technologies in security sector

Several techniques based on IR radiation have been used in security sectors. Examples of these techniques are as follows.

3.4.1. Personal identification by IR-based technologies

Personal identification systems have been used to identify individuals in situations that require security in the entrance of the building or building parts. The most important component of the palm vein authentication systems, facial recognition systems, iris scanning systems, smart surveillance systems, IR finger imaging systems and palm print recognition systems comprises IR cameras [27, 28]. These techniques are important tools for crime prevention, as well as the arrest of criminals in forensic sciences.

3.4.1.1. Palm vein authentication systems

The heat pattern of the human body may easily be determined by IRT. The heat pattern of veins in the human hand is specific to each individual. Thus, the structure of the hand veins may be determined, and private ciphers may be created [28, 29]. Sarkar et al reported that “the red blood cells (hemoglobin) present in the veins absorb the rays and show up on the map as black lines, whereas the remaining hand structure shows up as white” [29]. Some companies have begun to use palm vein authentication systems in automatic teller machines (ATMs) worldwide. These systems have also been used in the entrance into a country from the airport, as well as the entrances of several security buildings.

3.4.1.2. Facial recognition systems

Facial recognition systems consist of three modules, including image acquisition, face recognition and face matching. In this system, visible light, IR light and thermal cameras are used to obtain a three-dimensional image and improve the image resolution [29].

3.4.1.3. Iris scanning systems

The iris is in a position to be seen at first glance and is easily defined in the IR cameras and visible-light cameras. Therefore, the iris may be easily used in automatic recognition systems.

In this system, cooperation in the placement of the eye in the correct place of the device is sufficient [27–29].

3.4.1.4. Smart surveillance systems

Smart surveillance was defined as the use of automatic video analysis technologies in video surveillance applications. To date, digital video surveillance systems are one of the most widely used types of systems. The tasks are to capture, store and distribute a video. The task of threat detection has been the duty of human operators [30].

However, Prokokski reported that "IR identification smart surveillance systems will provide the ability to automatically survey an area in the dark, find each face within the scanned area, and match it against a Watch List of visible images". Smart surveillance systems will provide important advantages for the security of society. They may be used to monitor criminal suspects and high-density crime areas, control the parole or access of high crime-prone offenders to restricted areas and check for terrorists on watch lists when they enter airports, custom areas or courts [27].

3.4.1.5. IR finger imaging systems

Lee et al. reported a new technique that includes recognition accuracy compared with the use of only finger vein patterns by logically including both finger vein and finger geometric components. In this technique, both the finger pulp and the finger dorsum are examined [31].

3.4.1.6. Palm print recognition systems

Palm print has been defined as a unique and reliable biometric characteristic with high usability. The principle of this technique was defined using a palm line orientation code as features. The use of NIR techniques obtained better results than traditional methods. The reason for this difference was that palm vein structures are visible when NIR is used [32].

3.4.1.7. Talking head video compression

During speech, some muscles of the face form facial expressions that may be seen as movements. The coding of these facial muscle movements during some applications, such as videophone, videoconferencing, video email, synthetic speech and face animation by the use of IR cameras are considered as new methods of personal identification to be used in future years [27].

3.4.2. Computer security by IR-based technologies

Computer security systems associated with IR cameras obtain real-time images of the user, give permission to the user to enter the system and define its user authorities. These systems may automatically turn off or lock the computer, and they may apply the commands with head movements by following the movements of the user's head and body [27]. This technique may be used to prevent computer crime.

3.4.3. Fire security by IR-based technologies

Most industrial fires occur from electrical short circuits. An important application of the IR imaging technique has been defined as the inspection of high-voltage installations, which cannot be easily accessed because of the high risk [14]. This technique is one method for determining the cause of fire.

3.5. Usage of IR-based technologies in agricultural inspection

NIR applications, especially NIR spectroscopy, have been used for the analysis of forages and feedstuffs, small grain crops, oilseeds and coarse grain, coffee, tea, spices, medicinal plants, aromatic plants, and related products, fruits and vegetables, sugarcane, cereal food products, baking products, beverages and brewing products, fats and oils, dairy and eggs, meats, timber and paper, animal by-products, wool, cotton and soils [33]. NIR spectroscopy has been used to evaluate the parameters for estimating the maturity of different fruit species, check the ripening status of fruits on trees or grade fruits in the packing house, assess fruit quality, such as sugar and acid contents, soluble solids, firmness of fruit, decide when to harvest and select the quality and suitable seeds in breeding programs [34]. This technique is used in forensic sciences to identify counterfeit food products.

3.6. Usage of IR-based technologies in forestry sector

The applications of NIR Spectroscopy have been used for the non-destructive quantitative analysis of the solid wood density, the moisture condition and the lignin content in the bulky wood of trees, to predict the stage of decay of decomposing leaves and for biosecurity inspection [34]. Investigations of allegations of illegal tree cutting may take advantage of this application in forensic sciences.

3.7. Other non-medical uses of IR-based technologies

In the construction sector, IR imaging has been used for the thermal assessment of buildings, such as the determination of the requirements of ground insulation, the evaluation of the adequacy of isolations, the evaluation of the humidity level of buildings and the detection of hot and cold air entered or exited outside from doors and windows. It is a screening tool used to determine the durability of buildings [35]. In forensic sciences, this method provides a significant contribution to the determination of building durability in the case of buildings that collapsed because of an earthquake or structural problems.

IR imaging is an important application for electrical engineers. Electric current that passes through the resistance element generates heat. Thus, electrical engineers may determine incorrect connections, internal damages, high resistance connections, corroded connections, oxidation, internal fuse damage, internal circuit breaker failures, high-voltage switch failures and insulation faults in an electrical circuit. The determination of engine warming via IR imaging and the activation of the cooling system increases the motor efficiency. This system facilitates engineers and forensic examiners in many engineering fields [14].

Missiles that focus on heat using IR sensors have been constructed, and missile systems have been developed to follow the heat emitted by aircrafts [9].

3.8. Usage of IR-based technologies in medical applications

Digital infrared thermal imaging (DITI) is an IRT method used to determine radiation between 8 and 14 μm emitted from the skin surface and for mapping the heat on the body surface with 0.01°C sensitivity. In this method, heat emission may be detected from the skin surface to 6 mm in tissue depth. Thus, the body heat pattern may be determined. To date, the usage of DITI has become widespread because it does not contain a high-dose radiation risk, it is painless, there is no contact with the patient during application, it has an ability for security usage in pregnant women and children, and it enables fast, easy and comfort usage. DITI is used for specific diagnostic methods or auxiliary diagnostic methods in several illnesses. DITI was defined as an auxiliary diagnostic method for the early diagnosis of several illnesses as early as 10 years ago [5, 36].

Several medical application areas of IRT are subsequently presented.

3.8.1. Screening of breast cancer

IRT was approved by the U.S. Food and Drug Administration in 1982 as an auxiliary diagnostic method for breast cancer screening. It has been reported that abnormal findings in IRT indicate 10 times more cancer risk compared with family history. In this illness, the rate of early diagnosis is 95% with a multifocal medical approach, which includes physical examination, IRT and mammography findings [37].

3.8.2. Screening of diabetic neuropathy and vascular disorders

IRT has been defined as a fast and reliable diagnostic method for neuropathies and vascular disorders in diabetes [38]. Thermoregulatory disorders in feet comprise an early sign of sympathetic dysfunction in diabetic patients [39]. It has been reported that "diabetes at-risk subjects have a significantly increased mean foot temperature (30.2 ± 1.3°C) compared with normal subjects (26.8 ± 1.8°C)" [38].

3.8.3. Usage in Raynaud's phenomenon

IRT was initially tested in 1991 for the diagnosis of Raynaud's phenomenon to determine temperature differences, which is one of the pathognomonic signs of this phenomenon [37]. In 1998, von Bierbrauer. et al reported that DITI is a useful tool in the diagnosis of Raynaud's phenomenon in vibration-induced white finger, which is an occupational disease and is triggered by vibration and/or cold exposure [40].

3.8.4. Usage for body temperature monitoring

Methods based on IRT have been used for body temperature screening of a population in public spaces, such as airports and bus terminals, to prevent the spread of epidemics, such as severe acute respiratory syndrome (SARS), avian influenza and swine influenza [38].

3.8.5. Usage for diagnosis of skin diseases

In general, skin diseases have an inflammatory origin. One of the diagnostic signs of these diseases is a temperature increase in the skin surface. Thus, IRT has been accepted as a reliable method for the diagnosis of skin diseases [38].

3.8.6. Usage for diagnosis of rheumatic diseases

IRT has been defined as a reliable diagnostic method of diseases characterized by local temperature increases, such as rheumatoid arthritis, inflammatory arthritis, gut, tennis elbow, fibromyalgia, acute muscle injuries and spasms, enthesopathies and complex regional pain syndrome [38, 41].

3.8.7. Usage for diagnosis of ocular diseases

In medical studies using IRT, an ocular temperature increase was determined in patients with ocular diseases, such as anterior uveitis, hyperemic bulbar conjunctiva, post-herpetic neuralgia, Graves' ophthalmopathy, glaucoma and dry eye syndrome [42, 43].

3.8.8. Usage for diagnosis of pain

IRT is also used to determine the body's painful point. Gratt et al. classified temperature differences in patients with oropharynx pain following their 6-year clinical assessment. They reported that "patients with 'hot' thermograms had the clinical diagnoses of sympathetically maintained pain, peripheral nerve-mediated pain, temporomandibular joint arthropathy, and maxillary sinusitis. Subjects with 'cold' thermograms were demonstrated to have the clinical diagnoses of peripheral nerve-mediated pain and sympathetically independent pain. Subjects with 'normal' thermograms were demonstrated to have the clinical diagnosis of cracked tooth syndrome, trigeminal neuralgia, pretrigeminal neuralgia, or psychogenic facial pain" [44]. Furthermore, the linear-polarized near-infrared light irradiation (LPNIR), a non-invasive method, was defined as a relief treatment for patients with chronic pain from frozen shoulder, osteoarthritis, rheumatoid arthritis, post-herpetic neuralgia and other disorders [45].

The medical applications of IR-based technologies may help forensic scientists in medical malpractice claims, provide a preliminary diagnosis of the cause of death and detect the signs of trauma.

4. Usage of IR-based technologies in forensic sciences

Fast, accurate and complete application in forensic analysis are of substantial importance for the delivery of a right to the justified person, as well as the fast, accurate and complete manifestation of justice. In this context, many forensic analysis methods have been improved and implemented in the previous century. Spectrophotometric methods were developed in parallel to the developments in optics and microscopy. Since the end of the twentieth century, the use of technologies based on IRT and IR spectrophotometry has been an important cornerstone [36]. Physical evidence obtained by IR photography provides critical clues for investigators in crime scene investigations. One advantage of this evidence is that it is suitable for re-examination after a long time [16]. IR imaging has been defined as two categories, including passive IR imaging and active IR imaging. Passive IR imaging may be used to detect non-contact radiation, without an external energy source. In this method, heat traces left by humans and objects may be investigated. Active IR imaging requires external heating or cooling of objects prior to imaging. While the external heat or cool source may be a component of the system in some applications, they profit by heat of a human body, domestic heating or air-conditioning system in some applications [46]. Currently, IR spectrophotometry has been used to analyse general polymers and materials, such as fibers, coatings, tapes and adhesives [36]. Chemical imaging, including visible-near IR chemical imaging, macroscope, in addition to the visible chemical imaging macroscope, visible chemical imaging microscope and light sources and liquid tuneable filter specification techniques have been defined as methods with substantial potential for the forensic analysis of materials, including paints, tapes and adhesives, inks and firearm propellants [47].

In this section, the use of several technologies based on IRT and IR spectrophotometry in forensic science is described.

4.1. Detection of post-mortem interval

It has been reported that IR cameras that use passive IR imaging technique may be a substitute for traditional rectal thermometers for the estimation of the post-mortem time interval; moreover, these cameras eliminate the risk of contamination and the potential loss of evidences of sexual assaults [46].

4.2. Detection of tire prints

Invisible prints of objects, such as tires on clothes, may be determined using IR photography. Tire prints found at a crime scene have been matched with a suspicious vehicle, and a match was identified [48].

4.3. Differentiation of gunshot residues

In a study performed using a VSC 2000 system to determine gunshot residues on dark clothing in 2006, as well as another study performed using a modified Griess test to determine gunshot residues on dark or multicolored clothing in 2006, researchers suggested that the use of IR or

IR-enhanced photography may enhance the gunshot residue pattern [49, 50]. In a study performed in 2007 by Lin et al., gunshot residue was collected from dark cloth samples following firing from 15, 30 and 60 cm ranges using a 9-mm pistol (Smith & Wesson) with 9-mm bullets (NPA 01 3). Components that absorb the IR of gunshot residue were determined. The authors indicated that "the number of black particles observed using IR was approximately 418, 317 and 63 within a 10 cm radius around the entrance hole when the firearm was discharged at distances of 15, 30 and 60 cm of shooting, respectively". Other features of this assay for the determination of distance shooting are that this test permits records and is not destructive for gunshot residue [48]. In another study, Patne et al. claimed that chemical imaging technology may be used to eliminate different brands of ammunition based on the fluorescence characteristics of the propellant grains on clothes without destroying the evidence before further analysis may be conducted [47]. Furthermore, Bueno et al. suggested the use of NIR-Raman microspectroscopy combined with advanced statistics to detect gunshot residues in 2012. Researchers claimed that NIR Raman microspectroscopy has the potential for reagentless differentiation of gunshot residues based on forensically relevant parameters, such as the calibre size, and this method should have a significant impact on the efficiency of crime scene investigations when fully developed [51].

4.4. Differentiation of blood stains

Blood is a substance that absorbs IR rays.

Yazımı düzeltilmiş şu sorgu için çevirileri görüyorsunuz: Dolayısı ile olay yerinde ***kızılötesi*** dalga boylarını kaydeden bir cihaz kullanılması neticesinde kan lekelerinin fark edilebilirliği artmaktadır.

Yine de girdiğiniz şu sorguyu mu aramak istiyorsunuz? Dolayısı ile olay yerinde kızıl ötesi dalga boylarını kaydeden bir cihaz kullanılması neticesinde kan lekelerinin fark edilebilirliği artmaktadır.

Thus, the differentiation in the availability of blood stains in crime scenes increases when using a device noting IR wavelengths. This method is advantageous for precisely determining the morphology of blood stains. Furthermore, this method reduces the number of samples obtained from the crime scene depending on the quicker determination of materials at the crime scene and prevents the time spent and economic losses [16, 52]. Two studies demonstrated that in the detection of blood stains with an IR camera, better results were obtained by other methods even in blood stains 10-times diluted or found on the floor, which absorbs blood [16, 52]. In another study performed by Lin et al., blood stains diluted to a 1/8 ratio were viable in 8 of 10 different cloth samples by IR photography. Nevertheless, blood stains diluted to a 1/2 ratio were not viable in two fabric types, including 35% rayon and 65% polyester and 5% lycra and 95% cotton, via IR photography [48].

It has been reported that the determination of blood samples and the identification of their ages on fabrics are possible using IR cameras. In the identification of the ages of blood samples, the cross-validated standard error of calibration was less than 1 week in optimal conditions [53].

4.5. Analysis of explosives

Fourier transform infrared (FTIR) and Raman spectroscopic techniques have been defined as powerful techniques used for the optimal identification of a broad range of explosives and related compounds. It has been reported that FT-Raman spectroscopy, which has a longer wavelength, is the preferred method for the fluorescence-free analysis of explosives when the conventional Raman spectra cannot be measured because of the fluorescence background [54].

4.6. Determination of blunt force injuries

The presence, extent and pattern of contusion in victims with blunt force injuries have been defined as important evidences in the determination of the manner of death, individual abuse and sexual assault and identification of the striking object. The presence of situations such as skin opacity, surface texture and pigmentation, overlying abrasions and erythema may comprise an obstacle to a correct evaluation of skin lesions. IR radiation may penetrate the skin and be selectively absorbed by the blood. Thus, the determination of subdermal hematomas is possible using IR-imaging. IR-photography may be used to interpret and analyse traumatic injuries, determine the pattern of blunt force injuries and identify real abrasions from surface interferences, such as abrasions, lividity, dark pigmentation and post-mortem and artificial injuries. Furthermore, when an incision is not an option, IR-photography is an invaluable technique in forensic examinations of living victims of domestic violence, rape/sexual assaults and motor vehicle accidents [55].

4.7. Determination of bite and tooth marks

Human teeth may leave characteristic prints on the human body or objects. These prints are referred to as bite marks when associated with only the skin and bite injuries when the bite perforates the skin and passes through to the subcutaneous tissues. Tooth prints on foods, wood, plastic or metal objects are referred to as tooth marks [56]. In general, a human bite mark comprises a 2–5 cm oval or circular mark, which is shaped as two opposing concave arcs with or without associated ecchymosis [57]. One method for the determination and recording of bite marks and tooth marks is IR photography. In the photography of non-visible light images, IR and/or UV photography techniques may be utilized. When using these techniques, bruises that are no longer visible to the naked eye may be detected [56–58].

4.8. Fingerprint identification

One of the most common methods used by forensic experts at a crime scene is the identification of fingerprints. The pattern of ridges formed on the tips of human fingers has long been regarded as unique to each individual. In a straightforward IR chemical imaging technique, procedures such as the sample preparation, derivatization or addition of fluorescent antibodies are not required, and fingerprints in a crime scene may be converted to images and made searchable in a database [59]. Williams et al. reported that the latent fingerprints of children may be recovered after extended periods of time have elapsed using Fourier-transform IR microspectroscopy [60]. This technique has been used for adults, and successful results were obtained [25]. King et al. demonstrated that the use of a novel powder that emits fluorescence in the NIR indicated high-contrast fingerprints with excellent ridge detail on polymer banknotes and magazine pages [61].

4.9. DNA analysis

As a result of the differential arrangements of each individual's DNA molecules and the construction of fast separation of these differences via an IR fluorescent automated DNA sequencer, DNA mapping may be rapidly performed. The use of this technique may enable the determination of who the DNA belongs to without losing time [62].

4.10. Forensic document examination

IR spectroscopy and X-ray diffraction techniques may quickly determine the types and rates of molecules in a paper structure without causing damage to or installing contact with examined materials. These two techniques enable the detection of variations in the structure brought about by different processing parameters, manufacturing conditions and formulation of additives [63]. The differentiation of photocopy documents and documents published in printer toners may be discriminated by reflection-absorption IR spectroscopy [64]. In a study performed by Merrill et al., many toners of photocopies and printers have different IR spectrums. When these differences are recorded in a system and compared with a spectral library, it is possible to identify the make and model of a copy machine or obtain a list of machines that use toner with comparable spectral characteristics [65]. It has been demonstrated that places with unreadable eyes in burned documents may be read using an IRT technique [16, 48]. In studies regarding inks and paints, it was determined that individual inks and paints have different spectral characteristics. If there was a spectral library of inks and paints, a questioned document may be examined based on the pen type used in the construction of a document or spuriousness of a picture or document [66–69]. Erasures and changes on the documents may be determined using technologies based on IR techniques [16, 67]. Technologies such as VSC 2000, VSCHR, VSC 5000, VSC 6000, Forensic XP 4010 and Forensic XP 4010 D have been used for forensic document examination [67]. One study investigated the detection of writing on fabric, in which three different black pens (fountain pen, ballpoint pen and permanent marker) were signed on three different black fabrics. The researchers reported that these invisible signs became visible using IR imaging. They determined that "fountain pen ink could be visualized using IR light less effectively than the permanent inks but was recorded on considerably more occasions than the ball point pen" [39]. During this examination, a lack of destruction on the examined document, facilities for simultaneously analysing all substances on the entire material and the repeatability of the method were defined as advantages of these techniques [47].

4.11. Determination of tattoos

IR imaging has been defined to detect tattoos that have been ablated by lasers, as well as an assisting method for the identification of known criminals and organized crime groups [69, 70]. Starkie et al. reported that IR reflectography was beneficial in the investigation of tattoos post-mortem in corpses, which included partial mummification and skin discoloration [71].

4.12. Other usages in forensic sciences

Spray paints [68], paints [47, 69], multilayer paint coats [72], adhesive tapes [47, 73], soils [74], the identification of drugs and added adulterants, drugs dissolved in alcohol, drug residues on clothing, drugs in herbal medicines and the quantification of cocaine-added adulterants [75] may be analysed using spectroscopic methods based on the IR spectrum. Schotsmans et al. reported that IV cameras are useful to determine mass graves and buried human remains [76]. Sumriddetchkajorn and Somboonkaew defined a polygraph (lie detector), which was referred as the thermal analyser, for deception detection. This system analyses far-IR data obtained remotely from a suspect around the eyes and nostril areas during interrogation and records thermal changes in these regions [77].

5. Future of IR-based technologies in forensic sciences

With the enhancement of the spectrum of IR techniques and the development of the detection ability of appliances, hematomas in deeper than subcutaneous tissues may be detected, patients who simulated pain may be distinguished as a result of the determination of real pain regions and the identification of criminals and the reconstruction of crime scenes may be realized even during the night using surveillance cameras that integrate IR-imaging. Moreover, the evidence that cannot be currently identified may be detected via the dissemination of IR usage in laboratories in the future.

The most important development of IR-based technologies expected in the future will involve the usage of passive IR imaging. Depending on the use of this technology, humans and objects at crime scenes may be easily detected using the heat traces of humans and objects even if they are not present at the crime scene during the crime scene investigation.

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It is my pleasure to place before you the book ''Forensic Analysis - From Death to Justice'' which presents one of the major portions of the broad specialty of Forensic Science comprising mainly of Thanatology and Criminalistics. This book has been designed to incorporate a wide range of new ideas and unique works from all authors from topics like Forensic Engineering, Forensic Entomology and Crime Scene Investigation. I hope that it will be useful to practitioners of forensic medicine, experts, pathologists, law makers, investigating authorities, undergraduate and postgraduate medical school graduates of medicine.

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