

---

# Geomatics and Forensic: Progress and Challenges

---

Pablo Rodríguez-González,  
Ángel Luis Muñoz-Nieto,  
Sandra Zancajo-Blázquez and  
Diego González-Aguilera

Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/63155>

---

## 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.

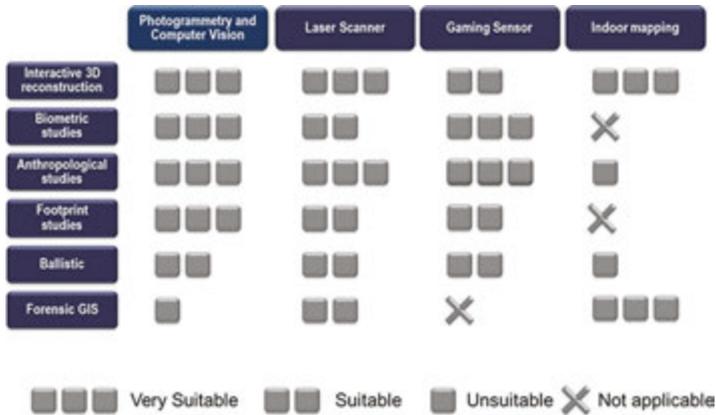
**Keywords:** forensic engineering, photogrammetry, laser scanning, indoor mapping, gaming sensors

## 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].

**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.

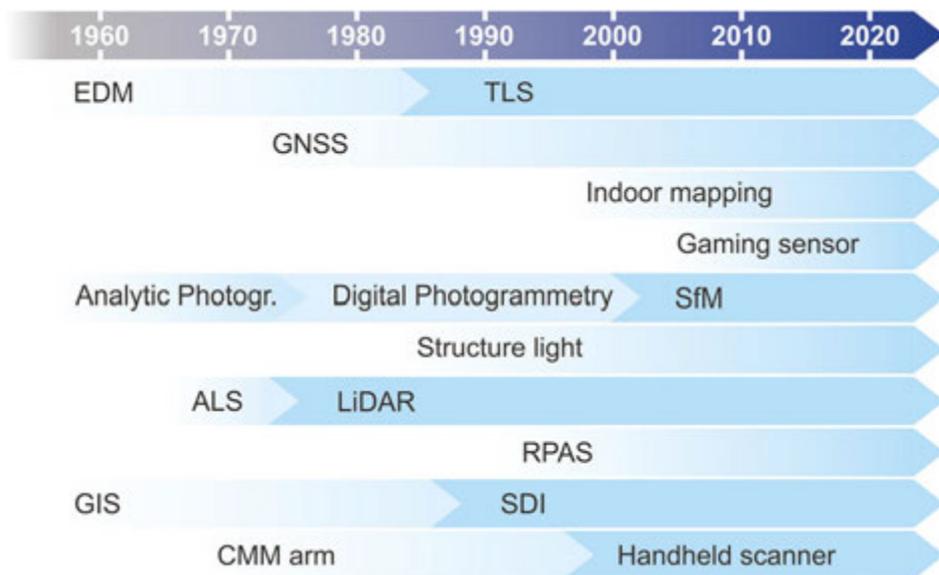


Figure 2. Example of the main goals in forensic infographics.

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.

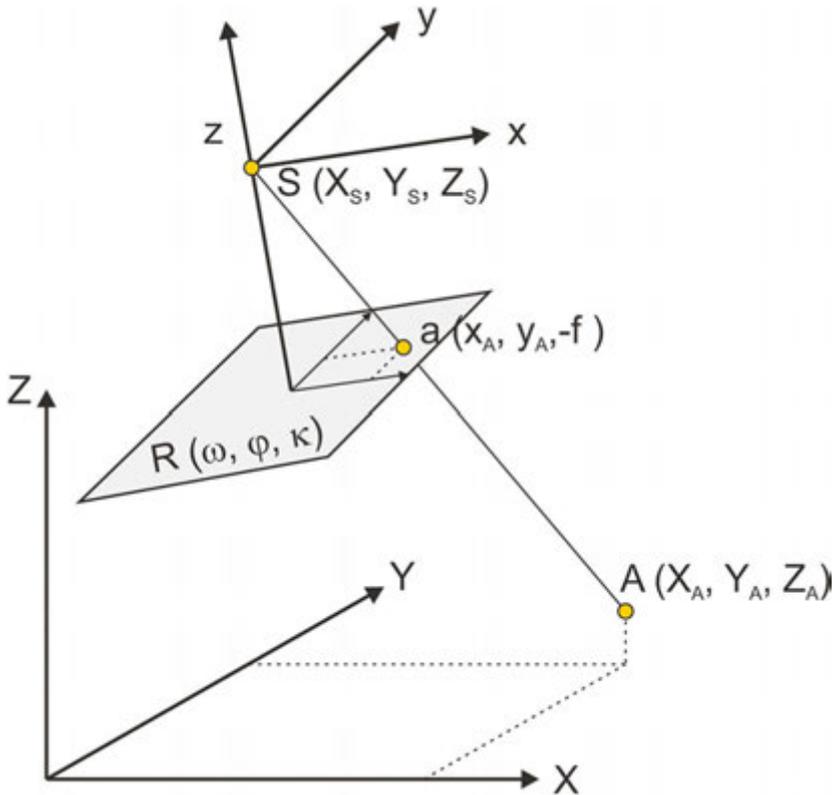
#### 3.1. From photography to photogrammetry

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

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 ( $\omega, \phi, \chi$ ) 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).

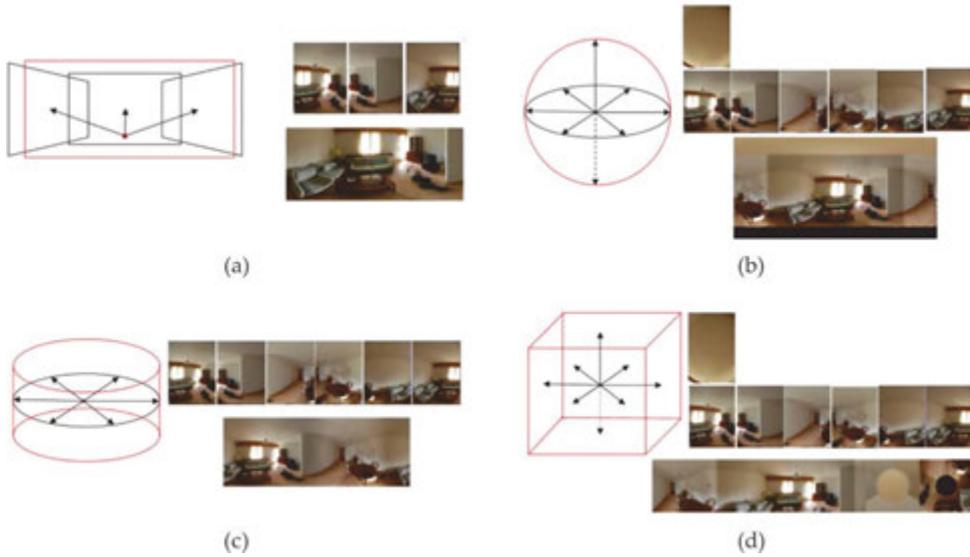


Figure 5. Different projections of panoramic imaging: flat (a), spherical (b), cylindrical (c) and cubic (d).

### 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.

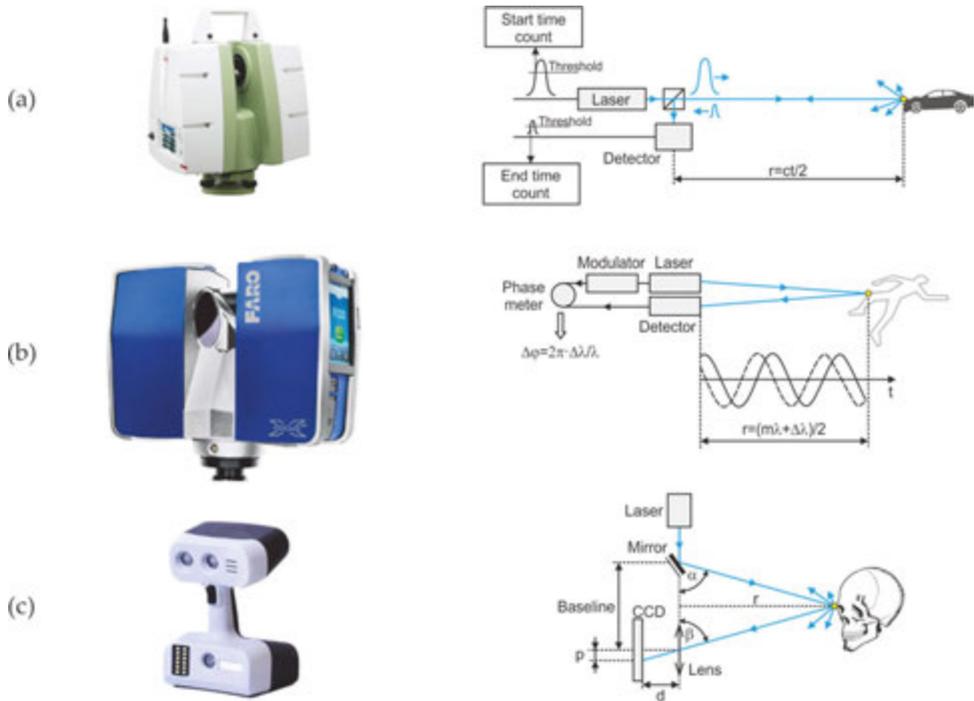
TLS acquires point clouds: a set of three-dimensional points on a Cartesian system. In addition to X, Y, Z coordinates, in every single point, it will be added some attributes (additional information), such as its radiometry (RGB values of colour), its intensity.

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 (meas-

urement 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.



**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 according 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 explo-

ration 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

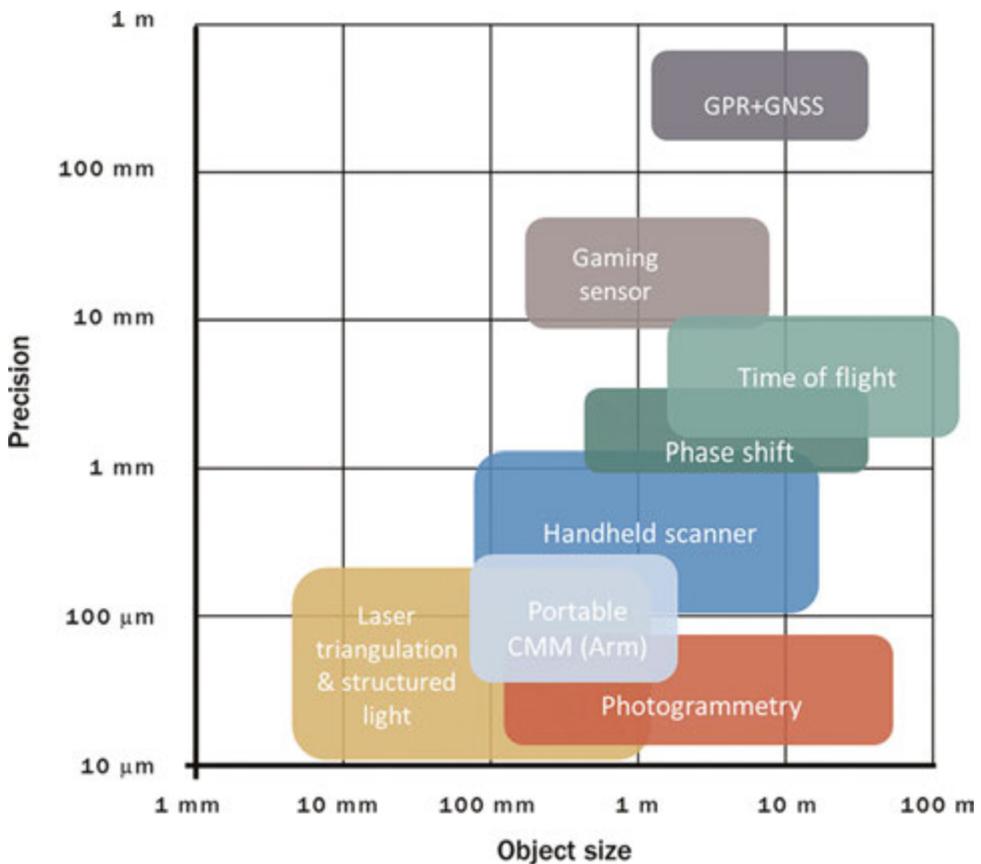


Figure 8. Relationship between different geomatics methods employed in forensic science.

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 disturb 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-

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



**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 specific tools for forensic tasks are aligned with this objective.

## Acknowledgements

The authors would like to thank the CISE (Ciencias de la Seguridad) of the University of Salamanca for the financial support given, as well as to the National Police Corps of Spain for the assistance and expertise given.

## Author details

Pablo Rodríguez-Gonzálvez, Ángel Luis Muñoz-Nieto, Sandra Zancajo-Blázquez and Diego González-Aguilera\*

\*Address all correspondence to: [daguilera@usal.es](mailto:daguilera@usal.es)

Department of Cartographic and Terrain Engineering, Higher Polytechnic School of Ávila, University of Salamanca, Ávila, Spain

## References

- [1] Lewis B. Panoramic imaging technology widens crime scene view. *TechBeat*. 2014(3): 3–5
- [2] Bagchi P, Bhattacharjee D, Nasipuri M, Basu DK. Registration of three dimensional human face images across pose and their applications in digital forensic. In: Muda KA, Choo Y-H, Abraham A, N. Srihari S, editors. *Computational Intelligence in Digital Forensics: Forensic Investigation and Applications*. Cham: Springer International Publishing; 2014. pp. 315–31.
- [3] Paysan P, Knothe R, Amberg B, Romdhani S, Vetter T, editors. A 3D face model for pose and illumination invariant face recognition. In: *Sixth IEEE International Conference on Advanced Video and Signal Based Surveillance, 2009 AVSS '09*; 2–4 Sept. 2009.
- [4] Maté González MÁ, Yravedra J, González-Aguilera D, Palomeque-González JF, Domínguez-Rodrigo M. Micro-photogrammetric characterization of cut marks on bones. *Journal of Archaeological Science*. 2015;62:128–42.

- [5] Luostarinen T, Lehmußola A. Measuring the accuracy of automatic shoeprint recognition methods. *Journal of Forensic Sciences*. 2014;59(6):1627–34.
- [6] Rodriguez-Gonzalvez P, Fernandez-Hernandez J, Gonzalez-Aguilera D, Muñoz-Nieto AL, Perez-Alvarez F, Hernandez-Lopez D, inventors; University of Salamanca, assignee. Spanish Patent ES2492366-B1 (20 July, 2015)
- [7] Stangeland P, de los Santos MJG. *El mapa del crimen: herramientas geográficas para policías y criminólogos*. Madrid: Tirant lo Blanch; 2004.
- [8] Luhmann T, Robson S, Kyle S, Boehm J. *Close-Range Photogrammetry and 3D Imaging*. Berlin: Walter De Gruyter; 2013.
- [9] Parrish J, Jacobs C. *Interactive Panoramas: Techniques for Digital Panoramic Photography*. Berlin Heidelberg: Springer; 2012.
- [10] Vosselman G, Maas H-G. *Airborne and Terrestrial Laser Scanning*. Dunbeath (Scotland): Whittles Publishing; 2010
- [11] Eisenbeiß H. *UAV photogrammetry*. ETH Zurich, Switzerland; 2009.
- [12] Curless B. Overview of active vision techniques. SIGGRAPH 99 Course on 3D Photography. 1999.
- [13] Booth AD, Pringle JK. Semblance analysis to assess GPR data from a five-year forensic study of simulated clandestine graves. *Journal of Applied Geophysics*. 2016;125:37–44.
- [14] Novo A, Lorenzo H, Rial FI, Solla M. 3D GPR in forensics: finding a clandestine grave in a mountainous environment. *Forensic Science International*. 2011;204(1–3):134–8.
- [15] Pringle JK, Ruffell A, Jervis JR, Donnelly L, McKinley J, Hansen J, et al. The use of geoscience methods for terrestrial forensic searches. *Earth-Science Reviews*. 2012;114(1–2):108–23.
- [16] Prahlow JA. *Forensic Pathology for Police, Death Investigators, Attorneys, and Forensic Scientists*. New York: Springer Science & Business Media; 2010.
- [17] Brüscheweiler W, Braun M, Dirnhöfer R, Thali MJ. Analysis of patterned injuries and injury-causing instruments with forensic 3D/CAD supported photogrammetry (FPHG): an instruction manual for the documentation process. *Forensic Science International*. 2003;132(2):130–8.
- [18] Thali MJ, Braun M, Markwalder TH, Brueschweiler W, Zollinger U, Malik NJ, et al. Bite mark documentation and analysis: the forensic 3D/CAD supported photogrammetry approach. *Forensic Science International*. 2003;135(2):115–21.
- [19] Buck U, Naether S, Räss B, Jackowski C, Thali MJ. Accident or homicide—virtual crime scene reconstruction using 3D methods. *Forensic Science International*. 2013;225(1–3): 75–84.

- [20] Urbanová P, Hejna P, Jurda M. Testing photogrammetry-based techniques for three-dimensional surface documentation in forensic pathology. *Forensic Science International*. 2015;250:77–86.
- [21] Zancajo-Blazquez S, Gonzalez-Aguilera D, Gonzalez-Jorge H, Hernandez-Lopez D. An automatic image-based modelling method applied to Forensic infography. *Plos One*. 2015;10(3):e0118719. doi:10.1371/journal.pone.0118719
- [22] Henry P, Krainin M, Herbst E, Ren X, Fox D. RGB-D mapping: using Kinect-style depth cameras for dense 3D modeling of indoor environments. *The International Journal of Robotics Research*. 2012;31(5):647–63.
- [23] Khoshelham K, Elberink SO. Accuracy and resolution of Kinect depth data for indoor mapping applications. *Sensors*. 2012;12(2):1437.
- [24] González-Jorge H, Zancajo S, González-Aguilera D, Arias P. Application of Kinect gaming sensor in Forensic science. *Journal of Forensic Sciences*. 2015;60(1):206–211. doi:10.1111/1556-4029.12565
- [25] Kilgus T, Heim E, Haase S, Prüfer S, Müller M, Seitel A, et al. Mobile markerless augmented reality and its application in forensic medicine. *International Journal of Computer Assisted Radiology and Surgery*. 2014;10(5):573–86.
- [26] Soileau L, Bautista D, Johnson C, Gao C, Zhang K, Li X, et al. Automated anthropometric phenotyping with novel Kinect-based three-dimensional imaging method: comparison with a reference laser imaging system. *European Journal of Clinical Nutrition*. 2016;70(4):475–481
- [27] Preis J, Kessel M, Werner M, Linnhoff-Popien C, editors. *Gait recognition with Kinect. 1st international workshop on Kinect in pervasive computing*. New Castle, UK; 2012.
- [28] Boutellaa E, Hadid A, Bengherabi M, Ait-Aoudia S. On the use of Kinect depth data for identity, gender and ethnicity classification from facial images. *Pattern Recognition Letters*. 2015;68, Part 2:270–7.
- [29] Pagliari D, Menna F, Roncella R, Remondino F, Pinto L. Kinect Fusion improvement using depth camera calibration. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*. 2014;40(5):479.
- [30] Moeini A, Moeini H. Multimodal Facial Expression Recognition Based on 3D Face Reconstruction from 2D Images. In: Ji Q, B. Moeslund T, Hua G, Nasrollahi K, editors. *Face and Facial Expression Recognition from Real World Videos: International Workshop, Stockholm, Sweden, August 24, 2014, Revised Selected Papers*. Cham: Springer International Publishing; 2015. pp. 46–57.
- [31] Hess M, Kuester F, Trivedi M, editors. Multimodal registration of high-resolution thermal image mosaics for the non-destructive evaluation of structures. In: *IEEE International Conference on Imaging Systems and Techniques*. Santorini, Italy; 14–17 Oct 2014.

- [32] Zancajo-Blazquez S, Laguela-Lopez S, Gonzalez-Aguilera D, Martinez-Sanchez J. Segmentation of indoor mapping points clouds applied to crime scenes reconstruction. *IEEE Transactions on Information Forensics and Security*. 2015;10(7):1350–1358. doi: 10.1109/TIFS.2015.2407699
- [33] Keller F, Sternberg H. Multi-sensor platform for indoor mobile mapping: system calibration and using a total station for indoor applications. *Remote Sensing*. 2013;5(11): 5805.
- [34] Sternberg H, Keller F, Willemsen T. Precise indoor mapping as a basis for coarse indoor navigation. *Journal of Applied Geodesy*. 2013;7(4):231–246.
- [35] Puente I, González-Jorge H, Martínez-Sánchez J, Arias P. Review of mobile mapping and surveying systems. *Measurement*. 2013;46(7):2127–45.
- [36] Canter P, Stott A, Rich S, Querry J. Creating georeferenced indoor maps, images and 3D models: indoor mapping for high accuracy and productivity. *The Journal of the Chartered Institution of Civil Engineering Surveyors*. 2010(6):20–22.

