Application 3D Forensic Science in a Criminal Investigation

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Abstract: - This manuscript discusses the modern approach and application of 3D digital imaging in forensic science. It presents the basic principles and approaches of 3D modeling methods. Selected methods of image capture and its subsequent processing into a 3D model are applied to a specific object. This object is captured by a mobile phone camera, a LiDar sensor, and a 3D scanner for further image processing for different desired image outputs. The text describes the photogrammetry method, the workflow with the LiDar sensor, and the 3D model of the object intended for 3D printing. The paper discusses the potential of the selected methods and their application in forensic sciences.

Key-Words: - forensic science, criminal investigation, 3D model, photogrammetry, LiDar sensor, 3D print

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1 Introduction

Modern digital methods of displaying objects and scenes find application in many fields. Digital image data capture reality or faithfully create a new reality. 3D modeling methods are currently commonly encountered in many commercial and scientific fields. 3D visualization and virtual and augmented reality (VR/AR) are used today in music, [1], architecture, [2], art, [3], medicine, [4], forensics science, [5], advertising, military, industrial design, and agriculture, for capturing and digitizing cultural heritage and forgeries. Many methods of 3D modeling and visualization find their application across the fields of human activity.

Modern procedures and methods of 2D and 3D visualization are also applied in criminology and forensic sciences, [6]. Currently, 3D reconstructions of objects are used in courts, [7]. Investigators use them to support evidence from the crime scene and are also used in expert opinions. Thus, a specific branch of forensic science emerged: 3D forensic science (3DFS), [8]. This new field provides new perspectives in forensic art and technology. 3D scanning methods and visualization can faithfully reconstruct the appearance of the victim of a crime, the crime scene, and the evidence found at that location, [9]. 3DFS can also be used for the reconstruction of historical image 2D data. It is essential to mention that this is a virtual representation of the data; therefore, the outputs from the 3DFS methods are only supplementary in case of investigation. Nevertheless, the use of 3DFS methods is also in great demand in court proceedings. The created 3D objects are used for display on court monitors and for creating a database of evidence in criminal proceedings, [8].

The issue of 3DFS connects many fields. These are mainly computer graphics, computer vision, machine learning, image capture and display, and other scientific disciplines. The output can be a virtual digital image for display on screens or in virtual and augmented reality. Image data can be used for 3D printing, [10]. Selective image capture and image data processing procedures are chosen depending on the type of output. Individual procedures differ slightly, especially for the display of material and its accurate, realistic display. Reconstruction of metallic materials with a high gloss level tends to be problematic. Structured materials also often require an individual approach when processing image data, [11]. Therefore, when investigating a crime and securing evidence using 3DFS, emphasis is placed on optimizing the entire process and speed of managing input image data.

This manuscript presents selected basic methods of 3D reconstruction of a real object for 3D visualization and obtaining a virtual model for 3D printing purposes. The experiment uses the method of photogrammetry and 3D scanning. The experiment's goal is to rapidly process image data into a 3D model for further use based on the required outputs. A smartphone is used in this experiment. These devices are currently equipped with a standard camera for obtaining high-quality photos. The object scanned by the smartphone was transformed into a 3D model using the photogrammetry method. Next, a LiDar sensor was used to capture the same object. This sensor was part of only highly professional and costly devices in the past. Currently, it has reached the higher class of tablets for ordinary users. These two devices can replace classic cameras and streamline the work of technicians and processing image data from the crime scene. The object was then scanned with a scanner for 3D printing output. Here, high and accurate quality of the reproduction of the details of the object's defects is assumed. This work aims to demonstrate the contribution of new modern devices and their application in criminalistics. Especially at the crime scene as a tool to secure evidence and quickly transform it into a digital 3D environment.

2 3DFS Methods and Procedures

This chapter presents the basic 3DFS methods and procedures for obtaining a 3D model of an object. The object for 3D reconstruction is the spent charge. The object is made of plastic and metal, with a relief marking the charge. The experimentally created models are presented in the following chapters.

2.1 Image Capture

Several imaging devices were used in this experiment. The following devices were used to obtain a digital image for the subsequent reconstruction of the object using the photogrammetry method:

- Cubot X30 mobile phone
- iPad 11 Pro with LiDar sensor

To 3D model for subsequent output in the model to 3D printing, the following equipment was used:

- 3D scanner Atos Triplescan II 5M / GOM

It is clear from the listed image capture devices that these are three different devices. In the case of a mobile phone and tablet with a LiDar scanning function, it is possible to easily create data for output through 3D printing. Acquiring a 3D model with an Atos scanner and transforming it into a 3D color model is complicated by the absence of color in the base 3D model.

2.1.1 Photogrammetry Method

This method was applied and perfected already at the time of analog image processing. With the development of digitization, this method finds other, more comprehensive applications. That is a method that is not demanding in the requirements of the sensing device.

In this experiment, the method of multi-frame ground photogrammetry was used. The principle of this method is to calculate the object's location in 3D space based on the description of the information obtained from individual images of the object. The algorithm finds a common point based on triangulation. It then calculates the individual positions of the sensing device around the scanned object. By subsequent calculation of the point cloud, each point gets its own *x, y, z* coordinate and thus defines the basic information about the position, size, and geometry of the object located in 3D space, [12]. The following Figure 1 shows the basic point cloud and the position of individual points in 3D space. Figure 1 shows the basic shape of the reconstructed object, and at this stage of the process, it is ready for further processing into a 3D model.

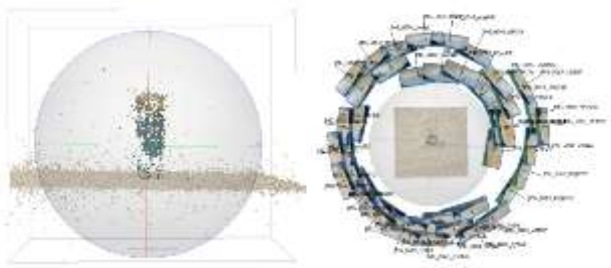

Fig. 1: The basic principle of the photogrammetry method.

2.1.2 LiDar Technology

This technology has been used since the 1960s. LiDar (Light Detection and Ranging) is a standard sensor nowadays. However, not all capturing devices have it yet. Only the latest Apple devices use LiDar technology, which is available to the average user today. As the technology has advanced over the years, LiDar has been used by many other experts and scientists in agriculture, archaeology, automation, mapping, and scientific fields. Use of this technology, it is possible to determine the distance between objects in space. LiDar also enables a 3D representation of space and objects in it, [13], [14].

In the experiment presented in this manuscript, the emphasis is on the specific object and the quality of the generated actual 3D model.

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Fig. 2: The 3D object visualization using LiDar technology.

Figure 2 shows the experimental 3DFS imaging of an object by LiDar technology. This method of displaying scanned data is described in more detail in the chapter presenting the experimental results of selected 3DFS methods.

The obtained image data from the sensing mentioned above devices were subsequently processed in the professional 3D modeling software *Agisoft Metashape Professional*, [15]. The object was photographed indoors with standard cold light discharge lighting. Figure 2 shows the shine of the wooden material on which the object was photographed. In this case, however, the scanned material is of a larger display of the metal part. The degree of its shine is due to the lighting of the space and its surroundings.

Approaches for processing the materials of a real object into a 3D model currently represent challenges in image processing. Especially since each material has different surface properties, these properties can also be seen in the environment where the object artifacts are manipulated and behaved. In the new case studies, the procedures involve the use of CAD 3D models, which can lead to incorrect simulation results. New alternative methods are thus created to generate the most accurate 3D models with retopological procedures to simplify the model for further processing. These procedures find application in digitization and 3D modeling of large objects, [16].

2.1.3 Capture an Image for 3D Printing an Object

The method for capturing and processing the image for 3D printing is different in this experiment, [17]. A 3D scanner *Atos Triplescan II 5M / GOM* was used to obtain a virtual 3D model of the object. Figure 3 shows the resulting 3D model of the object.

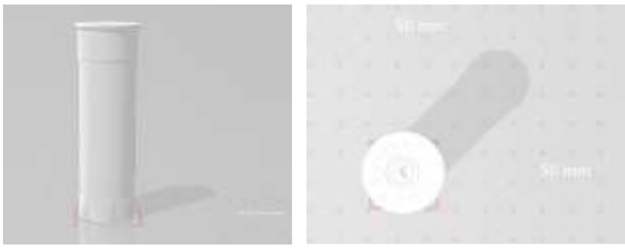

Fig. 3: The 3D object model intended for 3D printing.

In this case, the 3D model of the object is scanned without the ability to define the object's colors. That is a 3D model intended for 3D printing; there is no information about the primary colors of an object.

3 Experimental Results of 3DFS

In this experiment, a small object was chosen in the form of a spent charge. The deformation of its shape characterizes this object due to shooting. The object's material is plastic with a black description and metal with an engraved marking. In the 3D modeling process, the influence of the shine from the metallic material on the process display is assumed. This effect is due to the cool discharge light in the room. The object and the effect of light can be seen in Figure 4.

Fig. 4: An object intended for 3DFS display.

3.1 3DFS Imaging Process

The hands-on experiment that this manuscript describes is based on the sensing of several types of sensing devices. A 3D scanner, a mobile phone camera, and a tablet with a LiDar sensor are used.

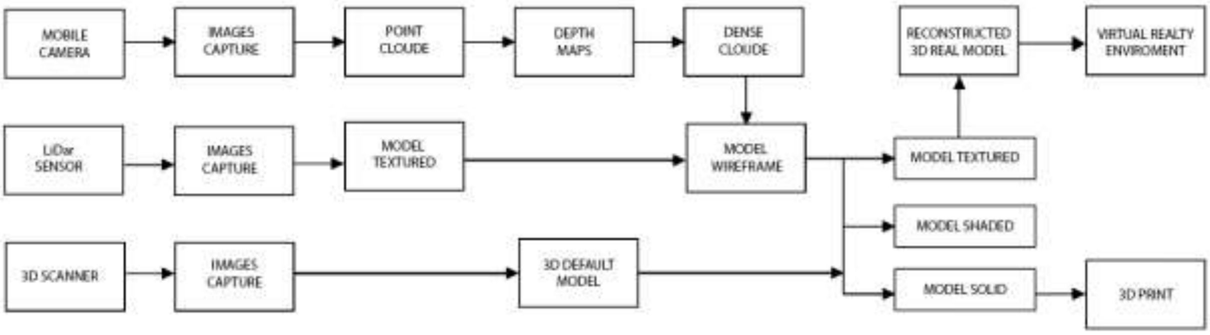

Fig. 5: The 3DFS basic methods image processing.

All the mentioned types of sensing devices require a different approach for capturing turnover data and image processing for the final output. The possibilities in the field of 3DFS are very extensive. Figure 5 describes the basic procedures of image data processing by individual input devices for obtaining image data.Figure 5 describes the image processing process of individual scanning devices. Images captured by a mobile phone and processed using photogrammetry have six basic steps. The first step is to generate a point cloud from captured photos and then process it into a 3D dense cloud model. After this image processing, a 3D network model can be created. This model provides the basis for generating a solid, shadow, or textured 3D model. The type of 3D model is chosen according to the desired final output. The 3D model created in this way can be transformed into a virtual reality environment or for 3D printing.

By using a scanning device with a LiDar sensor, some image processing steps can be omitted. Although it is possible to generate point clouds in some applications, in the case of the application used in this study, a 3D polygonal mesh was generated from a direct textured 3D model. The next step is to generate a 3D model for the desired output. This procedure significantly reduces the time for creating a 3D model of an object without using high-performance computing equipment.

The third type of 3D model discussed in this text is an object model created by a 3D scanner to apply the output to a 3D object by 3D print. This procedure is swift. That is practically a direct route. The disadvantage is the generated 3D model without textures and colors, as seen in Figures 3 and 8. This problem can be solved by creating a custom color texture model to the 3D model if the goal is a 3D digital model applied in a digital, online, or virtual environment. A 3D model created by 3D printing can then be created manually with a colored texture. However, this procedure is time-consuming and requires skill.

In the next chapter, individual 3D models are visually compared.

3.2 The 3D Forensic Imaging Process

Visualizations of individual types of 3D models and final models with texture are in the following images.

3.2.1 The 3D Model by Photogrammetry Method

A mobile phone with a camera, which was used to create a 3D model using the photogrammetry method, is a commonly available device. A significant advantage is the speed of use in the case of photography. It is possible that taking pictures in the dark can be difficult when most current cameras on mobile phones do not have a flash of sufficient quality. In this experiment, 47 images were used for the 3D modeling of the object using the photogrammetry method. Figure 6 shows the 3D processing of an object image into outputs obtained by photogrammetry for forensic investigation.

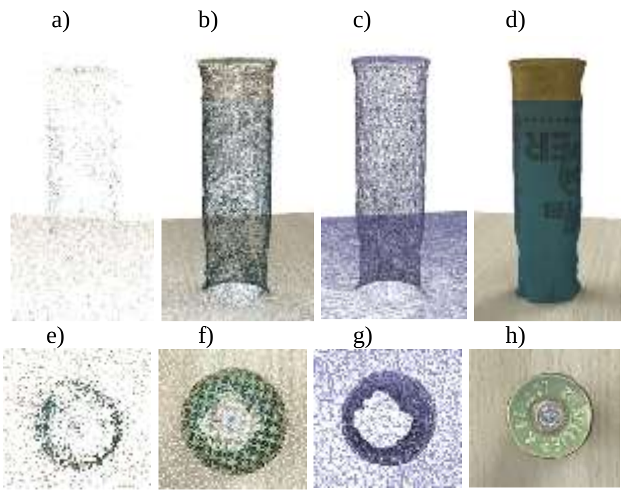

Fig. 6: 3DFS model of the object by photogrammetry method: a) 3D model of the primary point cloud, b) addition of points in the form of a dense cloud model, c) 3D object model wireframe, d) resulting 3D model with material

texture, e)-h) detail the 3D model of the metal part of the object in the same image processing procedure.

As can be seen from Figure 6, the photogrammetry method is suitable for modeling this object. It is more time-consuming for the entire process and the quality requirements of all images from which the model is created. However, the great advantage of this method appears to be the possibility of editing image information already in the first two stages of image processing, Figure 6 a), b), e), f). When this method is applied correctly, the 3D model of the metal part of the object can be successfully modeled, as seen in Figure 6 h).

3.2.2 The 3D Model using by LiDar Sensor

A tablet with a LiDar function provides a primary image. That function allows us to work with both video formats and photos; both outputs can also be combined. The photos taken can be modeled using the photogrammetry method. It is also possible to determine the captured video into individual sequences and photographs. In this experiment, the entire image was acquired in one step.

The freely available *Scaniverse Pro* application was used in this experiment. This application enables the direct transformation of the scanned object into a 3D wireframe model. However, it does not allow working with the model in the form of point clouds. The scanned model was exported to the professional modeling software *Agisoft Metashape Professional* to compare the created 3D object with the 3D object created by the photogrammetry method.

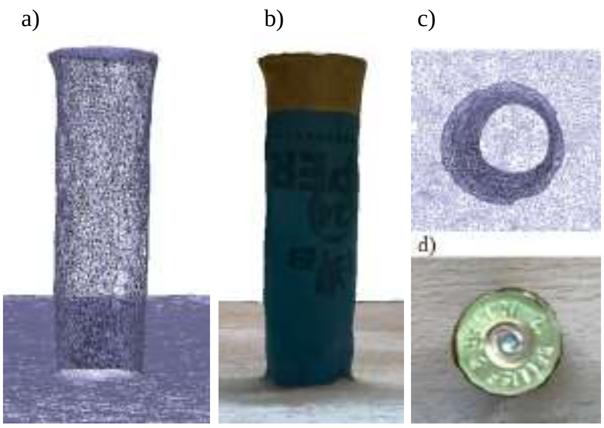

Fig. 7: The 3DFS model of the object by LiDar sensor: a) 3D wireframe model, b) 3D model with material texture, e) and d) detail of the 3D model of the metal part of the object.

From the set of images 6 and 7, it can be seen that different sensors of the sensing devices also provide a different result in the final display of the 3D model of the object. Differences are also visible in the polygonal network density (wireframe) connecting individual points in the object. In Figure 7 a), it is seen that the 3D wireframe model contains a significantly higher density of polygonal mesh structure. With this phenomenon, the requirements for the capacity of computing technology in image processing and final display in a virtual environment also grow.

3.2.3 The 3D Object Model for 3D Print

This process of capturing the image for the final 3D model is different from the previous two cases of 3D modeling. A 3D scanner scans an object with higher accuracy but without information about the color and structure of the object. Currently, 3D printing cannot work with this attribute. As Figures 3 and 8 shows, the shape of the 3D model for the final print output contains a minimum of defects. However, the difference in the materials of the object is not noticeable.

Fig. 8: Detail of the 3D object model intended for 3D printing.

The advantage of the 3D printed model is the detailed capture of the deformation of the cartridge case material. The metal part of the object and its relief are also clearly visible. In a forensic investigation, these models can simulate the original object to find another fact when analyzing the evidence. In this digital 3D model, the deformation of the material due to mechanical damage to the object can be marked in more detail during further image processing. These procedures can be applied to the digital archiving of evidence. The disadvantage is losing image information about color, material, and texture.

4 Discussion

Modern procedures in the area of forensic science, but also in many other scientific fields, require the flexibility of approach and solving given problems. Especially in the progressive, dynamic pace of digitization and work with acquired information and data.

The details that lead to a successful solution are often crucial in criminal investigations, trials, and expert opinions. Modern forensic art today works with a wide variety of tools and procedures. A 3D forensic science (3DFS) currently has a rather complementary character. The created 3D models must be understood as a secondary tool designed to present and demonstrate given facts. The created models cannot be perceived as a primary means of evidence because they are a virtual representation of the natural environment, object, or evidence. These models do not have a physical character, and neither do 3D printing reproductions of the object are not objective facts. Nevertheless, this discipline can significantly help in an investigation or a criminal case.

In the experiment described in this manuscript, there are several procedures for quickly and efficiently creating a 3D model of an object. The applied methods in this work can be considered fast in securing evidence at the crime scene. Nevertheless, the appropriate choice of the 3DFS method depends on the desired output. Therefore, it is necessary to approach them individually depending on the purpose of their use. The choice of the capture device, image processing, and final output depends on the environment where the image data is captured.

The object that is the subject of this experiment is made of two materials and structures. As seen in the set of figures 6 and 7, there is a material with a high degree of variable physical-optical properties in this subject. Generally, difficult materials and structures for 3D modeling are, for example, metals, glass, liquids, and gels. These are materials with variable properties due to the influence of light, temperature, weather conditions, and other phenomena affecting the objects' shape, structure, and material.

5 Conclusion

In conclusion, it can be stated that optimizing the entire process of creating a 3D model or environment is not simple and hides many challenges for further research into 3D imaging of natural objects or environments, especially concerning the large quantities of problems that occur in the entire image processing process. There are significant potential and challenges for the future in the field of forensic science hidden in this issue. One can consider a very high degree of application of machine learning within the framework of image segmentation and other computer and color vision methods.

Applying and using 3DFS in crime scene investigations makes it possible to work with evidence on a completely different scale. As a complementary tool, 3DFS presents new challenges in forensics. Simultaneously with the progressive development of new technologies and devices, the process of creating 3D models of objects or environments can also be significantly shortened. This trend is currently represented by commercial devices that include the LiDar sensor. These devices are affordable, easily portable, and easy to operate. The scanning devices contain a high-quality camera and a scanning sensor. Image acquisition and processing are faster and easier than using classic single-lens reflex cameras (DSLR) or mobile devices without LiDar sensors. When reconstructing an image from these devices using the photogrammetry method, not only a large capacity of external storage and high performance of computing devices but also a significant time fund for 3D reconstruction is required. Mobile devices with the LiDar function represent a technology where it is possible to eliminate some of the steps of the image processing process and export the resulting 3D model. A significant advantage is also that it takes less time. However, it is also necessary to consider the resulting quality of the 3D model for the desired output. Therefore, further image processing on a powerful computing device is not entirely omitted. However, that technology fulfills everything required by the photogrammetry method. And for reconstructing a 3D object for output to a 3D printer too.

It can be stated that a device with a LiDar sensor can, in some cases, replace entirely both classic cameras, a mobile phone, and the mentioned 3D scanner. Nevertheless, this technology presents additional challenges in sensor research, sensing devices, and image processing. All these aspects will be considered in further research in the 3D reconstruction of objects in the field of 3DFS. Attention will be focused mainly on working with point clouds and 3D reconstruction of more complex natural objects. Here, emphasis will be placed on the processing of the object's realistic colors, materials, and textures and its transformation into a 3D and VR environment for use in forensic science.

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