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360 scanning devices for the reconstruction of 3D digital twins

***Abstract**. This article discusses the possibilities of using the terrestrial multi-frame photogrammetry method in industrial fields. It focuses mainly on the types and possibilities of displaying the captured image in 3D models of point clouds. Three basic types of point cloud models are presented, depending on the sensing device with which the image was captured. These devices include a professional laser scanner and a 360° camera. These devices are complemented by a 360° outdoor camera commonly used by the public. The thesis aims to outline the possibilities of using 3D models of point clouds as information carriers in industrial research fields.*

***Streszczenie.** W artykule omówiono możliwości zastosowania metody naziemnej fotogrametrii wieloklatkowej w dziedzinach przemysłowych. Skupiono się głównie na rodzajach i możliwościach wyświetlania przechwyconego obrazu w trójwymiarowych modelach chmur punktów. Przedstawiono trzy podstawowe typy modeli chmur punktów, w zależności od urządzenia pomiarowego, za pomocą którego wykonano zdjęcie. Urządzenia te obejmują profesjonalny skaner laserowy oraz kamerę 360°. Uzupełnieniem tych urządzeń jest kamera zewnętrzna 360° powszechnie używana przez społeczeństwo. Praca ma na celu zarysowanie możliwości wykorzystania trójwymiarowych modeli chmur punktów jako nośników informacji w przemysłowych dziedzinach badawczych. (**Urządzenia skanujące 360° do rekonstrukcji cyfrowych bliźniaków 3D**)*

Keywords: photogrammetry, 3D model, digital twins, point cloud
Słowa kluczowe: fotogrametria, model 3D, cyfrowe bliźniaki, chmura punktów

Introduction

This manuscript discusses the possibilities of 3D imaging and its subsequent application in scientific fields. The dynamic development in the field of image digitization and especially in the field of computer graphics today expands possibilities in almost every branch of human activity. Today, 3D modelling and 3D visualization of objects, scenes, interiors, or exteriors are integral to modern computer image processing. In the current understanding of this issue, 3D imaging can be divided into two primary groups. The first is creating objects, scenes, or spaces in graphic computer software (SW), where the goal is to simulate the actual form of the object, environment, or scene as accurately as possible. The second approach is to strive for the most faithful reproduction of a real object, environment, or scene into a digital and 3D display. [1-3] This approach is the subject of this manuscript. The text aims to present and compare technical possibilities, methodologies and approaches to creating and processing images in three-dimensional form.

This text focuses on the *Structure from the Motion* (SfM) method and types of image processing into primary 3D point clouds according to the captured image type and the user capture device. At the same time, the manuscript also mentions 3D models created by the laser scanning method. Even in this case, however, the image can be reconstructed using images recorded during the scan. [4], [5] In these cases, one can talk about a realistic digital twin of an object or space.

Many image processing imaging devices are available on the market today to process the image into an actual 3D model. Professional 3D and 360° laser scanners complement professional 3D, 3DR, 360° cameras, and *Digital Single-Lens Reflex camera* (DSLR) and compact cameras. [6] Nowadays, there is no longer a problem with the quality of the images taken with smartphones and tablets. [7] Currently, some of these devices also have a sensor *Light Detection and Ranging* (LiDAR). [8] The present text focuses on the sensing device. The focus is on a professional laser scanner and a 360° professional camera. These devices are complemented by a 360° outdoor camera, commonly used by the general public. Compared to the two professional devices mentioned, this type of camera is not only widely used by the public, but it is primarily a device with a significantly lower price than the other professional devices mentioned.

Photogrammetry method

The *Direct Linear Transformation* (DLT) method was proposed as early as 1971 as a basic mathematical photogrammetric model. [9] That is a non-contact method of recording an object in space. The basic principle of photogrammetry is a definable point located in space represented by at least two methods. Photogrammetry generates 3D point positions by projecting lines from the camera position through a *Charge Couple Device* (CCD) into space. When using two photos, the lines' intersection indicates the point's position. Therefore, the camera angle plays a crucial role in the accuracy of this method. Incorrect camera position or orientation will generate an incorrect 3D point position.

$$(1)\quad I' + \frac{l_1X + l_2Y + l_3Z + l_4}{l_9X + l_{10}Y + l_{11}Z + 1} = 0 \ \cup \ J' + \frac{l_5X + l_6Y + l_7Z + l_8}{l_9X + l_{10}Y + l_{11}Z + 1} = 0$$

where $I' = I - I_0$; $J' = J - J_0$; $l_1 - l_{11}$ is the *Direct Linear Transform Parameter* (DLT). Coefficients l_1 to l_{11} are functions of external landmarks and internal points. The initial values of the external and internal orientation elements are not needed in the calculation. [10]

The Structure from Motion (SfM) method is a photogrammetric method. This method uses the principles of stereoscopic photogrammetry and the intersection photogrammetry method. So, it is a combination of these two methods. A 3D model of a real object is created by overlapping images and combining parallel and convergent axes. In this case, we can talk about a realistic digital twin.

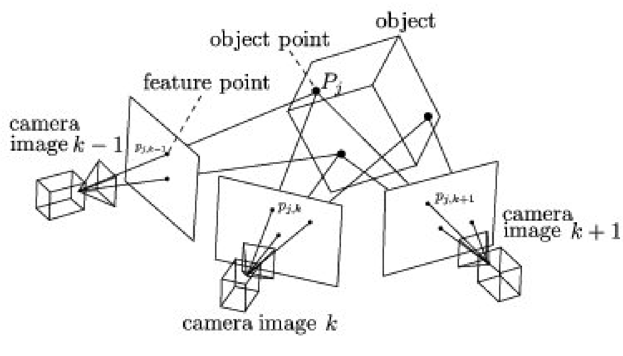

Fig.1. Structure from Motion (SfM) photogrammetry method [11]

Tens to hundreds of images can be used for 3D reconstruction. [12] The triangulation algorithm finds a common point in these images. Subsequently, another algorithm calculates the camera's position in space during object acquisition. Each point is then assigned individual x, y, and z values according to the Cartesian system. [13] That determines basic information about the position of the object, its size, color, and geometric shape in space. [12]

Representation of 3D image data in point clouds

3D image data in its basic form is a cloud of points and can provide secondary information about color or intensity. [12] Information from a 2D image is contained in mathematically structured fields. This data already explicitly contains relationships between neighboring bodies. However, in a general 3D domain, point clouds contain neighbor relationships only implicitly. Imported internal data, the sensing device's orientation, and its settings' accuracy can be supplemented as information for 3D reconstruction of the object, providing image data that can be loaded together with the images. Figure 1 a) shows the point cloud of the interior by DSLR camera.

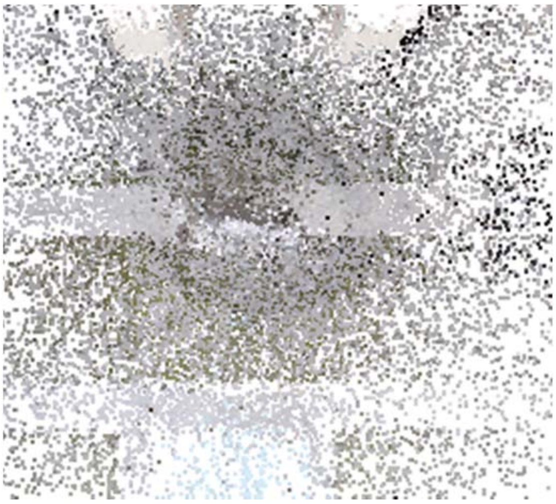

Fig.2. Basic point cloud by DSLR camera

Figure 2 a) shows the point clouds of bundles defining the object by 360° laser scanners.

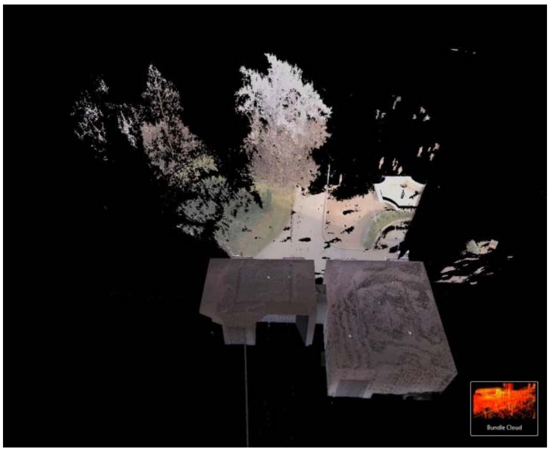

Fig.3. Point cloud by 360 laser scanners

However, differences in the display of image data in 3D point clouds represent different imaging devices and image data processing.

Sensing devices

In today's electronic imaging market, there are many available imaging devices. 3D models of the natural environment can be created using compact and single-lens reflex (DSLR) cameras, mobile phones, and devices equipped with a LiDar sensor. However, this text compares two professional imaging devices: a laser scanner and a 360° camera with six lenses. The comparison of these two devices is completed by an outdoor 360° camera, which is available to the general public, especially in terms of the purchase price.

360° laser scanner

The *Leica BLK360* laser 3D scanner is a simple and effective device for many fields. The device's effortless handling and scanning speed is an immediate 3D image capture advantage. The scanning range is 360° x 300°. The scanner provides data up to a distance of 60 m. Multiple applications can process the registered data, and the scanned data can be exported to many output formats for further image processing. Individual point clouds can be connected to a coordinate system. The scanner works in a full-color panoramic image and two modes with precise positional definitions of point clouds. [14] Figure 4 shows the sensing device.

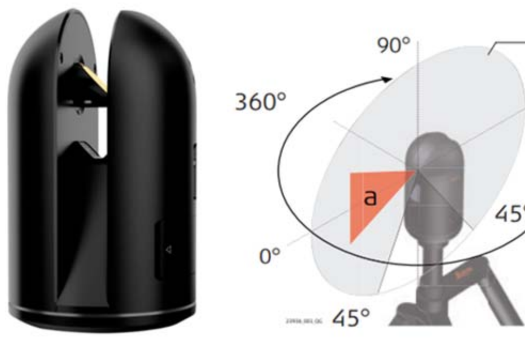

Fig.4. 360° scanner: Leica BLK360 body, and angle and rotation of image capture

Figure 5 shows the positions of the 360° scanner in the interior of the building.

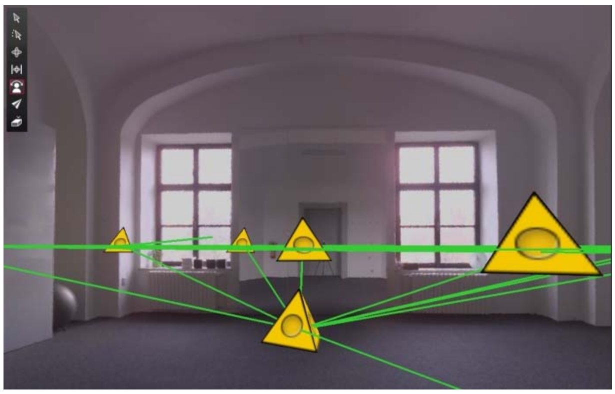

Fig.5. Sensing position in interior by 360° scanner Leica BLK360

This scanner can collect two types of image data. The first is a panoramic 360° spherical HDR image with three calibrated cameras, and the second is a thermographic image with an infrared camera.

360° camera

The 360° panoramic camera has six fisheye lenses with 200° F2 lenses around the perimeter of the aluminum spherical body. This makes it possible to take high-quality 360° images. The four microphones also provide good sound when recording video. In normal mode, the camera takes six still images at a resolution of 4000 x 3000 px. These images can then be used to stitch and post-process 8K monoscopic and stereoscopic spherical images. The Stitching Insta360 application is used for subsequent processing and stitching of the image into a single unit. Insta360 Player is used to play linked images. Insta360 Pro records data captured using an SD card (V30 speed class) and USB SSD (USB 3.0 interface). Insta360 Pro has still image modes: Normal mode, RAW mode, HDR mode, Burst mode. [15]

a) b)

Fig.6. 360° camera: a) Insta360 Pro body, b) type of captured image in gallery environment

As can be seen in Figure 6, the spherical shape of the camera body with six lenses around its circumference provides the basic positions of all six images for application in 3D space. In this way, a basic 3D model of the interior can easily be created.

a) b)

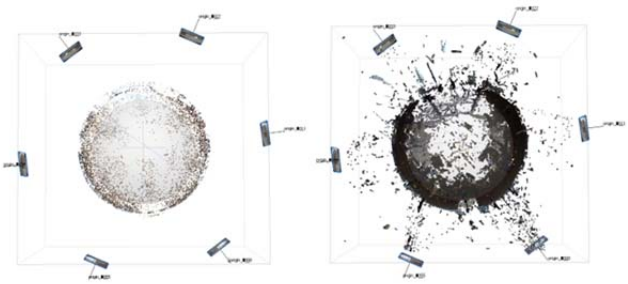

Fig.7. Type of the 3D model by 360° camera: a) 3D model point cloud, b) 3D mode dense cloud

Figure 7 shows the created 3D model in cloud and dense point cloud. These 3D models of the interior show the disadvantages of using this sensing device. The burden is the creation of a compact image around the entire perimeter. The elements and objects have thus become part of the created 3D background of the environment and cannot be further manipulated. Further processed. This shortcoming, especially if there is a requirement for the segmentation of elements inside the space, can be solved by calibrating the photos taken in the classic photo.

360° outdoor camera

The Insta360 One R 360° camera with a dual "fisheye" lens is used for the experiment with photos of the object space from the captured video. The Insta 360 One R is a modular outdoor camera with a waterproof design. The shooting mode is possible with a wide-angle 4K / 60p lens, a 360° lens with a 5.7K resolution, or a 1" sensor with a 5.3K resolution. The video has a range and records at a 5.3K / 30p solution. The captured image was processed with ONE R applications and Shot Lab. [16]

a) b)

Fig.8. Outdoor camera: a) Insta360 ONE R body, b) type of captured image

Figure 8 shows the body of the Insta360 ONE R camera and the characteristic image captured by the fisheye lens. Figure 9 shows the character of the 3D model in a dense cloud captured by this 360-sensing device.

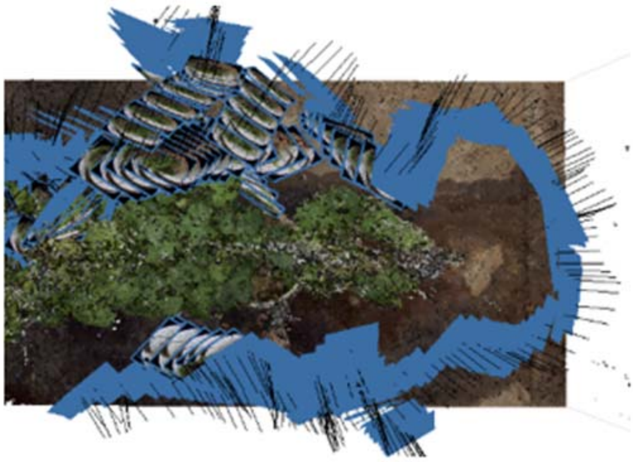

Fig.9. position photos of the total 379 images in the 3D model dense cloud

Figure 9 shows individual positions of photographs (379 in total) used for 3D modeling of the object from the recorded video. This way, a specific 3D object in space can be easily modeled. This procedure is straightforward and fast, especially for the easy handling of the 3D camera and the speed of image capture.

Conclusions and discussion

This text presents three sensing devices for controlling the 360° image—the image acquisition aimed to generate 3D point clouds from the captured photographs. The ground multi-frame photogrammetry method was chosen as the primary method for the 3D modeling process. That method of triangulation of findings uses points in the Cartesian system, or determining the positions of points on the x, y, and z-axis. Since the individual-generated bodies are the carrier of information about their position, color, geometry, and others, there are point clouds of varying degrees of further image processing. Especially when working with a dense point cloud, which is generated from a basic point cloud, based on the information from the individual points, we can find out whether the point belongs to the object, the environment, or is part of point noise that was accidentally generated additionally. It is, therefore, possible to segment parts of the image already at this stage or parts of the point cloud. This procedure allows individual objects and their attributes to be accurately processed before further image processing into the final 3D model. It is thus possible to work, for example, with color attributes and thereby achieve, for example, the best possible colors, structures, and textures of an object or environment.

However, a realistic 3D model can be created from almost any digital sensing device (3D scanners, 360° cameras, digital cameras, smartphones, Etc.); it is necessary to consider the quality of the resulting image and especially the resolution of the sensing devices. Their purchase price is also related to this. Professional sensing devices with high-quality sensors range in hundreds of thousands of crowns. In contrast, for tens of thousands of crowns, outdoor 360° cameras, digital cameras, smartphones, or tablets can be purchased. Nevertheless, device types can help capture and process image data for many outputs (3D printing, online environment, virtual environment).

In modern criminology, security issues, and forensic sciences, but also the field of engineering and Industry 4.0 and digitalization of the arts a high degree of application of the sensing as mentioned above devices, as well as photogrammetry methods and image work in the point cloud model, is assumed. Today's information point clouds are the source files for other methodologies and procedures. For example, in computer and color vision, documentation of natural objects and environments, protection of data files, segmentation of artifacts, and much more. The point cloud can be effectively used in those cases where it is necessary to accurately capture a scene or an object that changes rapidly due to the surrounding environment. An example can be a change in lighting or weather conditions, but also living structures that change their color, size, structure, and texture over time. These changes can be captured over time, and the information can be preserved in individual points and the entire cloud of points.

Current experimental results in this text indicate that in digital technologies and their application in modern image processing methods, less expensive devices can be used to achieve the set goals. In this regard, however, it remains true that the choice of sensing device depends on the given device's purpose.

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