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Analysis of the structure material of the bronze object in 3D models point cloud

***Abstract**. The study deals with experimental research of the material of a bronze work of art. It characterizes the visual properties of the metallic material for perception by the human eye and lists the expected undesirable properties that may affect the quality of reproduction of the work in a 3D model of point clouds. The text also presents image capture for the use of the photogrammetry method. This method was used for 3D modelling of a real object in the exterior. The human eye is a significant environment of the perception of the object and the 3D modelling process. Lighting conditions also significantly affect the quality of the captured image and its processing into a point cloud. The results of the image quality of the original art transferred to the 3D environment reveal the essential attributes of the work when capturing the image. The experiment aims to determine the fundamental aspects influencing the image work with metallic objects and its conversion in the form of point clouds into 3D models for use in virtual reality. Attention is paid to the quality and complexity of processing the reproduction of the object into a point 3D model. And the influence of the properties of the metallic material and the surrounding exterior environment on 3D modelling by photogrammetry.*

Streszczenie.** Praca dotyczy eksperymentalnych badań materiału wykonanego z brązu dzieła sztuki. Charakteryzuje wizualne właściwości materiału metalicznego dla percepcji ludzkiego oka oraz wymienia oczekiwane niepożądane właściwości, które mogą wpływać na jakość odtworzenia pracy w modelu 3D chmur punktów. W tekście przedstawiono również przechwytywanie obrazu z wykorzystaniem metody fotogrametrii. Metoda ta została wykorzystana do modelowania 3D rzeczywistego obiektu na zewnątrz. Oko ludzkie jest istotnym środowiskiem percepcji obiektu i procesu modelowania 3D. Warunki oświetleniowe również znacząco wpływają na jakość rejestrowanego obrazu i jego przetworzenie do chmury punktów. Wyniki jakości obrazu oryginalnej sztuki przeniesionej do środowiska 3D ujawniają istotne atrybuty pracy podczas przechwytywania obrazu. Eksperyment ma na celu określenie fundamentalnych aspektów wpływających na pracę obrazu z obiektami metalowymi oraz jego konwersję w postaci chmur punktów na modele 3D do wykorzystania w wirtualnej rzeczywistości. Zwrócono uwagę na jakość i złożoność obróbki odwzorowania obiektu na punktowy model 3D. Oraz wpływ właściwości materiału metalicznego i otaczającego środowiska zewnętrznego na modelowanie 3D metodą fotogrametrii.* (Analiza materiału konstrukcji obiektu z brązu w modelach 3D chmury punktów***)

Keywords: 3D model, photogrammetry, image processing, point cloud
Słowa kluczowe: model 3D, fotogrametria, chmura punktów.

Introduction

Progressive multi-year trend of digitization, 3D modelling brings new challenges in computer vision and image processing to 3D environments, augmented and virtual reality. These processes are already used in many disciplines today. The quality of image data depends on the other purpose and output of the processed data. For example, 3D models and scenes are used in archeology, architecture, [1] art, [2] industry, medicine [3], the military, forensics imaging [4], or criminology. [5] That also brings new possibilities for archiving and reproducing digital image data, modern digital and online presentations, teaching and training programs, or the reconstruction of fragments of objects. Great emphasis is then placed on image quality and processing, especially when modelling natural objects in a long-term environment. The quality of digital reproduction of an object is also affected by high-quality colour reproduction and light in a reversing sensing environment. Significant differences can occur in the process of capturing an image indoors or outdoors. The quality of the captured image is also affected by ambient light or subject lighting.

An original work of art with specific surface properties thus becomes a challenge to an experimental attempt to transfer it to the field of augmented and virtual reality or 3D printing technology. Objects with specific optical properties of metal with a high degree of gloss are not easy to reproduce, even with classical 2D techniques. The transmission and description of the information about objects from the acquired image data to the desired digital form are affected by the variable optical properties of the materials. The quality of the captured image and the subsequent process of processing digital image data have considerable on the quality of 3D models, especially in 3D modelling for creating a full-fledged replica of an object based on the description of information. An essential aspect is whether the created digital description of the image preserves the information about the object's insufficient quality, and the objects can be reconstructed from this description. Some methods of describing information do not allow retrospective reconstruction of the shape of the original area. Other methods of preserving information allow for backward reconstruction of the shape. They depended on the degree of reduction of information during the transformation of the shape into a description. The individual descriptions guarantee a more or less accurate reconstruction of the shape. [6] Significant results can be achieved using knowledge of optical laws, image capture equipment, and appropriately selected scanning methodology. The use of a mobile device camera to collect and describe image data and their subsequent application to specific issues is currently relevant. [7] Emphasis is placed on process optimization, simplification, and acceleration while maintaining high-quality output.

The text below describes the method of 3D reconstruction of a bronze sculpture by photogrammetry (*SFM - Structure From Motion*). More precisely, the method of image capture of an object in the exterior by a camera from multiple angles uses terrestrial multi-image photogrammetry. The aim of the study is an experimental reconstruction of a work of art made of metallic material showing a high proportion of shiny spots and a change in colour during lighting. The material of the bronze sculpture can also be a suitable basis for creating an original background structure for surfaces in 3D models used in virtual reality. The original work of art with an unusual structure of the material thus shows new possibilities of the original processing of the applied material in digital form for further potential artistic creation of the author in a digital and virtual environment.

Characteristics of the scanned object

A concrete data template for creating a 3D model is the artwork "Animal" No. 6 from a sculpture called Mission, which consists of 7 bronze animals covered with a structure created from walnut shells. [8] The work is 60 cm high. The bronze sculpture forms a different colour of material due to light. That is also associated with a high proportion of glossy surfaces, fundamentally affecting the resulting 3D model. This work has been exhibited outdoors for more than ten years. The bronze sculpture thus acquires its original patina due to weather conditions and human interaction, as shown in Figure 1. It is desirable that all these current original aspects of the material also be transferred to the resulting 3D model. It is unlikely that the material of the sculpture will visually change fundamentally in the next few years.

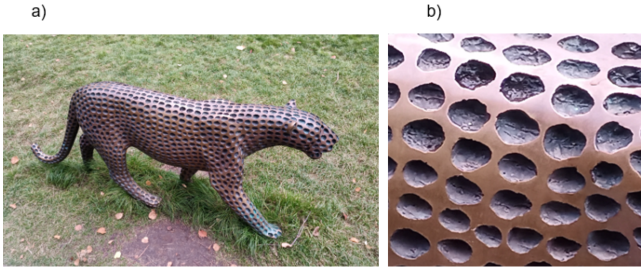

Fig.1. a) Object selected for 3D modelling b) Detail of the bronze structure of the material

Physical-optical phenomena due to light are visible on the structured bronze surface. The object was photographed in daylight without direct sunlight. Daylight as a source of radiation is significantly different from artificial light. The source of daylight is the sun. The difference lies in the spectral composition and variability of radiation intensity. This source has a continuous spectrum with maximum intensity in the visible region. Of the common physical-optical phenomena, shadow, shiny reflections, and diffuse indirect reflection are most pronounced on the metallic material during this illumination: [9]

- *Shadow* is necessary for perceiving an object in three dimensions because, from its position, one intuitively determines the arrangement of objects in space.
- *Shiny reflections* (bright reflections of light) are caused by smooth materials with high reflectivity.
- *Diffuse indirect reflection* manifests itself in reality, for example, as a slow change in the intensity of light reflection.

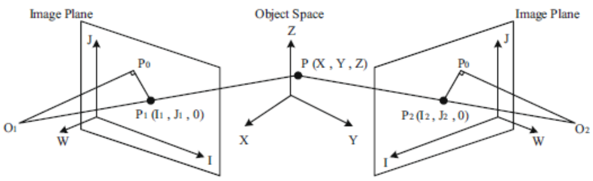

Fig.2. The transformation between the object space reference frame and the image plane reference frame, where the global coordinates XYZ; IJW image coordinates; P0 (pixels) principal a point in the image coordinates (the intersection between the lens axis and the image coordinates) cloud [10]

Ground multi-image photogrammetry method

The ground multi-image photogrammetry method calculates the location of an object in 3D space based on the description of information obtained from individual images taken from multiple angles. In the case of a specific object, whose 3D reconstruction is described below, there are 200 photographs in which the algorithm based on the principle of triangulation finds common points and calculates the individual positions of the camera around the object. Figure 2 shows the basic principle of the transformation between the reference frame of the object space and the reference frame of the image plane. [10] Subsequent calculation of the *point cloud*, each point obtains its x, y, z coordinates and thus defines the basic information about the position, size, and geometry of the object located in place.

The historical roots of photogrammetry and 3D data acquisition are as old as 2D image acquisition. In its simplest form, 3D data can be represented by a *point cloud*.

Such a cloud is a set of 3D data points represented by three *Cartesian coordinates*. Additional point-related data may provide information on colour, intensity, or reflectivity. 2D images, placed in structured arrays, contain explicit neighbor relationships. *Point clouds* in a general plane contain only implicit neighbor relationships, so they are considered unstructured data. *Cloud segmentation* is a more complex research field to threaten direct neighborly relationships [11].

Fig.3. Basic description of information obtained from photographic images (point cloud)

The import of external and internal parameters and the orientation of the scanning device. It is accurate provides data that can be read together with the images and used as initial information for 3D reconstruction of the object. After loading this data, a point cloud can be built. This step involves the main procedures of detecting and comparing information, and the result is a cloud of sparse points. The 3D model representation of critical points of generated data, and point cloud display and *dense cloud*.

Fig.4. 3D model generated in dense cloud

The 3D models of the *point clouds* sowed Figures 3 and *dense cloud* showed Figure 4. For generating data was used the software Agisoft Metashape Professional. [12] Agisoft Metashape Professional Software is sophisticated software for professional 3D modelling and points cloud creation. This 3D modelling software is used mainly in the reconstruction of objects and structures in mapping, geography, recording of cultural heritage, archaeological objects, architecture, and other fields. Tool modules determine Personal Use and have output.

Object capture and the process of taking images

One of the general criteria for high-fidelity display of the object structure, subsequent 3D modelling, and plotting details is the device's high resolution. The prerequisite is a high-quality scanning device. Another measure is the constant angle and distance from the scanned object. In this study, the object of scanning a mobile phone is a middle class without the use of external accessories for taking a quality photo with information recording (e.g., reference colour scale, focusing targets, Etc.). The tripod was also not used. A general requirement is also a high number of acquired images of the best possible quality. Low-quality images or at different heights and angles are often unsuitable for the initial process of our photo alignment. Comparing photo positions is the first step in the process. This step is performed before the first calculation of the point cloud from the whole series of photographs.

The selected work of art for subsequent 3D modelling is captured on 200 images. A series of photographs were taken at a distance of 0.5-10 mm from each other. Of the total number of photos, no photos showed poor image quality. The mid-range mobile phone thus matched that of a digital mirror camera of the same class. The device's camera proved to be entirely sufficient due to the quality of the captured images and the subsequent 3D modelling with Agisoft Metashape software. [12] All images from the entire series, without any further adjustments (e.g., colour calibration, retouching, brightness and contrast adjustment, and other correction options leading to increased image quality and information transfer) proved to be suitable directly for the subsequent modelling process. The model was created, and basic information about the model was defined using point clouds. The device takes photos in a compressed lossy jpg format, so no further image data compression was performed. Reference properties and quality of one captured image are given in tab.1.

Table 1. The parameters of the sensor

Image size	15,4 MB
Image size	8000 × 6000 px
Distinction	72 dpi
Bit depth	24 bit
Color range	sRGB
Aperture shutter	f/1,8
Length of exposure	1/100 s
Exposure	0
Exposure meter	centred
Focal distance	35 mm
ISO	125

Individual images from a series of 200 photographs proved to be sufficient for the entire subsequent process of modelling a 3D object into a model formed by individual points with information about these points' position, colour, and geometry. These individual points together form an overall 3D model, the so-called point cloud.

Modelling an object into the 3D model of a point cloud

The art object selected for this study was captured in 200 images and processed into several basic models and images. The first step in successful modelling was the basic alignment of individually captured images in a series of photographs. The images were aligned to the highest accuracy in the modelling software. In a medium setting, it reduces the image twice on each side (factor 4). For source files with a low alignment value specified, the data accuracy is reduced by a factor of 16, which means a fourfold reduction. The highest accuracy setting thus enlarges the image by a factor of 4. Since the positions and bindings of the points are estimated based on the points found in the source images, it is desirable to adjust the source photos. Due to the high time required, the highest alignment accuracy is only recommended for research purposes [13].

The algorithm based on the principle of triangulation then found common points in the individual images and calculated the camera's position around the object. The basic calculation of the point cloud assigns the corresponding x, y, z coordinates to each point and provides basic information about the size, position, and geometry of the scanned object in space.

From the basic information contained in the sparse point cloud, other points were added by further calculation in the software. These points in the model built a dense cloud of points - a dense cloud. This large number of points more accurately represented the shape of the object and its position in space. The visual difference in the number of points in 3D point models and their display is shown in Figure 5. This created a complete point 3D model, which fully corresponds to the shape of a physical object in real interior.

Fig. 5. Basic description of information: a) Photograph b) Point cloud model c) Dense cloud model

There is a noticeable difference in the number of points in the basic and dense point clouds. A dense cloud describes the complete information obtained from the source photographs. In particular, the description of colours in individual points. This description characterizes the overall appearance of the model, its colour, and the object's structure. The quality of the model can also be affected by the degree of processing quality in the modelling software. The object will be modelling in low, medium, and high quality. The chosen quality measure then determines the density of the point cloud and significantly influences the computational capacity and time. The model was therefore processed in two software-defined quality definitions, as shown in Table 2. This comparison aims to determine what image processing quality is optimal for objects with a metallic material structure to capture material details and properties in a 3D digital model.

Table 2. Difference in image processing in medium and high quality

Quality	Point Cloud (points)	Dense Cloud (points)	Process Time (h)	Memory Usage (GB)
Medium	65 081	16 677 107	3,37	8,15
Hight	65 809	123 246 016	15,26	13,25

3D modelling an object in higher quality is significantly demanding when creating a point model and memory capacity. While the 3D model in medium quality was processed for 3.37 hours, the model in Hight quality was processed for 15.26 hours. That is a significant time difference in the modelling time. Memory usage also differs significantly in both cases. However, the higher quality model was expected to be more memory intensive. The model processed in Hight quality contains 62 809 points, and the model created in Medium quality is 65 081 points. The quality of image information transferred from photographs is comparable. The creating a dense cloud of points in these two qualities, the difference is very pronounced. Specifically, in the case of Hight modelling quality, 123 246 016 points were created. In the second model, 16 677 107 points were created. However, this difference may not affect the visual perception of the colour and texture of the created 3D model. Figure 6 compares the visual appearance of the generated point cloud model.

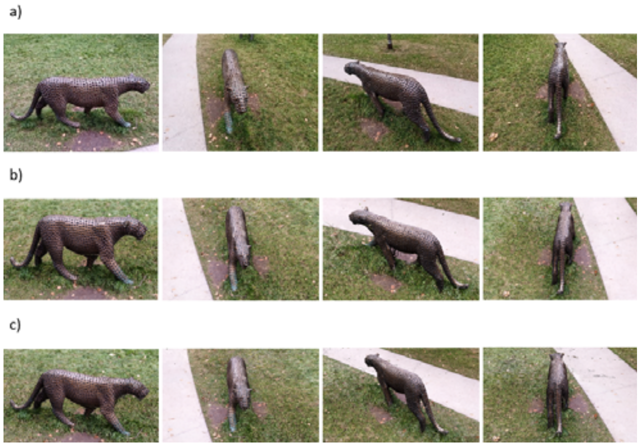

Fig. 6. Comparison of the image and 3D model's quality: a) Photograph b) 3D model of the dense cloud - Medium quality c) 3D model of the dense cloud - Hight quality

Figure 6 shows the image quality of the photo and the created 3D point models in two qualities: b) Medium quality, c) High quality. The process of creating a model in lower quality may insufficiently reproduce a complex object or scene. However, the missing point can be calculated and supplemented by an algorithm. Creating a high-quality 3D model can create the opposite problem. This quality may cause errors in the image due to the excessive number of plotted points. These can degrade the image unnecessarily by a cluster of dots that affect areas. These defects can also be achieved by correcting the number of points. These points are removed. The picture above shows that a 3D reconstruction of an object in Medium quality is sufficient for other purposes. High-quality 3D reconstruction of a work of art takes a long time to calculate high-memory points. That turns out to be a suboptimal solution in this case of 3D reconstruction of the object.

Display of the surface structure of the model

Another attribute for a quality 3D model is to display the surface of the material and its structure. The object chosen for the 3D reconstruction has a specific bronze structure created by walnut shells. A unique structure was created over the entire surface of the building, with many deep elements created on the surface of the material. In addition, the bronze surface shows a more significant amount of gloss when the image is captured. The aim of the study is a faithful 3D reconstruction of a bronze work of art. It is, therefore, desirable for the optical-physical phenomena to manifest themselves and for the entire structure to be transferred to the 3D model in the highest possible quality.

The diagram of the modelling process is shown in Figure 7. The resulting type of 3D model is determined by the output for which the object is reconstructed. A polygonal network (wireframe model) is almost always formed. It is often the basis for other types of models.

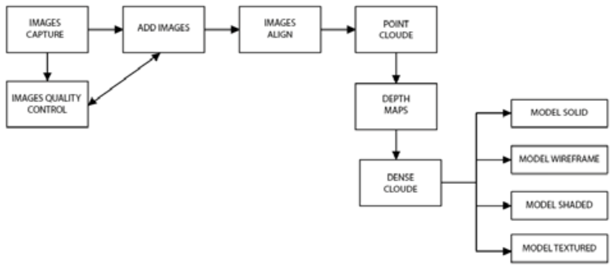

Fig.7. Modelling process by photogrammetry method

Analysis of the image quality and manifestations of defects in the material structure model is therefore necessary. Figure 8 shows the surface structures of the bronze sculpture material on 3D models created in different types.

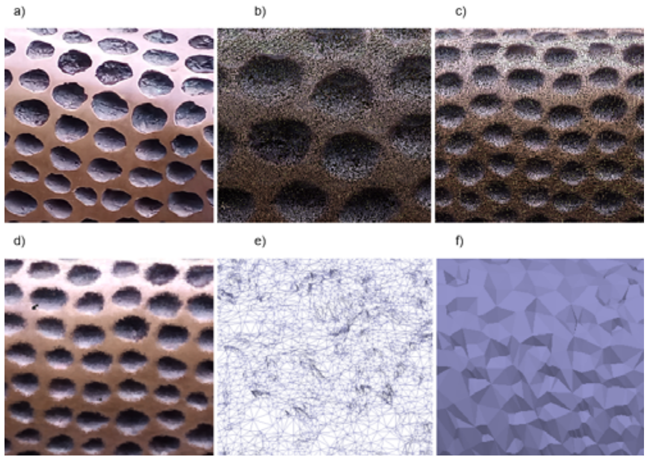

Fig. 8. a) Material surface on the source photo b) Material detail in the Dense cloud model c) Material structure of the 3D point model d) Resulting material structure of the 3D model e) Wireframe material structure of the object f) Material structure in the Solid model

A 3D model in point clouds can be used for occlusion with another point cloud of another object or scene. In this way, we can add and synchronize different objects into one whole. These objects are often created specially or also in another period. In the case of further processing and creation of the overall texture of the model, it is often necessary to create a polygonal network. It connects individual points into a network model. The fabricated structure of the required material can be used for this network. The polygonal network forming the 3D model also often serves as an export file of the 3D object for further processing in another 3D software.

Conclusion

A high degree of digitization of data and transmission of information about the image is required in almost all areas of human life and science. Trends in industry, medicine, art, and other fields are increasingly leading to the automation of human activity. 3D modelling is already commonly used in the creation of prototypes, the production of engineering components, the simulation of acceptable mechanisms, and many other production processes. In some fields, great importance is placed on process optimization while maintaining high image quality. This problem requires high-performance computer technology for the overall image data processing process.

This study aimed to determine whether it is necessary to do the 3D modelling of a real object in high quality concerning the possibilities of the software, storage capacity, and the amount of maintaining the quality of the scanned process. The object for the study was a 60 cm high bronze statue with a structured surface. This object was located in the exterior of a city park and was photographed in daylight without direct sunlight. Photographic accessories to suppress undesirable physical-optical properties have not been used. However, the surface of the material showed some of these phenomena. It was mainly the gloss and visual change of colour in some places of the object. The shadow appeared to a large extent as well. The bronze material of the building was structured using walnut shells. The object was captured by ground multi-image photogrammetry. A total of two hundred photographs of the object were taken for further processing into a 3D model. All images were suitable for the modelling process and were used to create a 3D model of point clouds.

The model was made in two qualitative processes. All modelling procedures were made in medium quality and also in high quality. There was no fundamental difference in the process of creating a point cloud. The basic models differed by only 900 points. However, this number could affect the generation of a dense cloud of points. In this further process of point modelling, the difference was significant. The total difference in the number of generated points was between the model medium and higher 106 568 909 points. It could be assumed that such a large difference affects the visual perception of a 3D dense cloud model. On the contrary, the shadows, glosses, and structure are reflected almost equally in both resulting models. In both cases, the image from the source photographs was very well implemented in these 3D models. There was a significant difference in both cases of modelling in the time of model processing and also in the memory usage of the computing device. High-quality modelling has been more memory-intensive and consistently longer. He can conclude that the modelling in medium quality was of the same quality with regard to these criteria and the whole process was optimal in time and capacity. However, it is important to mention that the required level of quality of the 3D model depends on the purpose of use and the final output.

Accurate 3D models of art objects created after the following modifications can have a wide application in art and culture. In today's modern online world, there is room for a wide range of art presentation options. One of the possible applications of 3D models can be virtual auction halls or virtual galleries for art presentations. New possibilities in the field of digital archiving also provide 3D models with another possibility of use. The potential use of these objects based on actual image data can also be found in other scientific and commercial fields.

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