УДК 528.7:004.92; JEL classification: C63, O31, I23 **DOI: https://doi.org/10.36887/2415-8453-2025-4-45**

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СТВОРЕННЯ 3D МОДЕЛІ ОБ'ЄКТА ЗА ЙОГО ФОТОЗНІМКАМИ
GENERATION OF A THREE-DIMENSIONAL MODEL OF AN OBJECT BASED ON ITS PHOTOGRAPHIC IMAGES

Лук'янченко Ю. О. Створення 3D моделі об'єкта за його фотознімками. *Український журнал прикладної економіки та техніки*. 2025. Том 10. № 4. С. 231 – 234.

Lukianchenko Iu. O. Generation of a three-dimensional model of an object based on its photographic images. *Ukrainian Journal of Applied Economics and Technology*. 2025. Volume 10. № 4, pp. 231 – 234.

The creation of drawings and object models constitutes an essential component of a wide range of scientific, engineering, and even everyday tasks. Consider, for instance, a situation in which a new technological device must be designed to conduct scientific experiments. In such a case, it is necessary to develop a detailed model of the object to support precise calculations of various characteristics. Another example can be found in civil engineering, where, for instance, the strength analysis of a bridge requires a complete model with all geometric dimensions and material properties to correctly estimate the maximum permissible load. Even in everyday applications, three-dimensional (3D) models are increasingly used — for example, in the design and 3D printing of small household items. All these cases require specialized software that allows for working with 3D models. One of the fundamental concepts of photogrammetry is central projection. When photographing an object, its image is always subject to distortion, regardless of viewpoint, making it impossible to perform accurate measurements directly from raw photographs. Therefore, before images can be used as cartographic or metric materials, they must undergo specific photogrammetric processing. These distortions arise because the recording device is typically located at a single position, and the image is therefore formed by central projection. This work addresses the creation of a 3D model of an object using ordinary photographs, with the aim of making the process accessible to non-specialist users — that is, without requiring deep knowledge of photogrammetry or expensive equipment. The study considers the principles of central projection, its key points, and lines. Based on this theoretical foundation, corresponding points between photographs were identified, followed by the generation of a sparse point cloud. The cloud was subsequently densified, and a three-dimensional model of the object was constructed, with the final step involving texture mapping. The proposed approach enables relatively fast 3D reconstruction of small objects without the use of costly instruments. Such a method can be effectively applied to create three-dimensional models of laboratory instruments and devices, which can in turn be used in remote learning environments to simulate and teach practical work with real equipment.
Keywords: *3D model, photographic surveying, point cloud, central projection, search for common points between photographs.*

Створення креслень та моделей об'єктів є важливою складовою величезної низки наукових інженерних та навіть, побутових задач. Розглянемо випадок, коли необхідно створити новий технологічний об'єкт для проведення наукових експериментів. У цьому випадку не обійтись без деталізованої моделі об'єкта, яка буде використана для детальних розрахунків різноманітних характеристик. Так, наприклад, іншим інженерним об'єктом може бути міст, для розрахунку міцності якого необхідно мати його модель зі всіма розмірами та характеристиками, щоб вірно розрахувати максимально допустиме навантаження. І навіть на побутовому рівні можуть використовуватись 3Д моделі, наприклад, для друку об'єктів на 3Д принтері. Всі ці випадки потребують спеціалізованого програмного забезпечення, яке дозволяє працювати із 3Д моделями. Одним із базових понять фотограмметрії є центральна проекція. При фотографуванні об'єкта, його зображення на знімку завжди спотворюється незалежно від ракурсу, що унеможливлює використання неопрацьованих знімків з метою виконання різного роду вимірювання. Тому, для того, щоб знімки могли використовуватися, як картографічні матеріали їх спочатку необхідно опрацювати. Такі спотворення пов'язані з тим, що прилад, який веде фотофіксацію зазвичай знаходиться в одному місці, відповідно отримане зображення утворюється в наслідок центрального проєктування. В роботі розглядається створення 3Д моделі об'єкта за допомогою звичайних фотознімків, щоб даний підхід був доступний звичайному користувачу без глибоких знань фотограмметрії та наявності дорого обладнання. Розглянуто центральну проекцію, її основні точки та лінії. На основі цих відомостей знайдено спільні точки фотознімків, створено розріджену хмару точок, згущено дану хмару точок та побудовано 3Д модель об'єкта із подальшим накладенням текстур. Даний спосіб дозволяє досить швидко та без використання дорогого обладнання відтворити 3Д модель невеличкого об'єкта. Такий підхід може використовуватись для створення три-вимірних моделей приладів, які в свою чергу можуть використовуватись для дистанційного навчання роботи з такими приладами.
Ключові слова: *3Д модель, фотознімання, хмара точок, центральна проекція, пошук спільних точок фотознімків.*

Statement of the problem

The creation of drawings and object models is an important component of a wide range of scientific, engineering, and even everyday tasks. Let us consider a case where it is necessary to create a new high-tech object for conducting scientific experiments. In this case, it is impossible to do without a detailed model of the object, which will be used for detailed calculations of its various characteristics. For example, another engineering object may be a bridge, for which it is necessary to have its model with all dimensions and characteristics to correctly calculate the maximum permissible load. Even at the household level, 3D models can be used, for example, for printing objects on a 3D printer. All these cases require specialized software that allows working with 3D models.

Thus, a 3D model is necessary for conducting research. When such an object does not exist yet and is still in the design stage, the model is created from scratch using software tools. However, there are cases in which we deal with existing objects and need to reproduce their accurate models; this is especially relevant when using images taken from close range [3, 5, 9, 10]. In this case, it is necessary to measure the given object. Such measurements can be performed in various ways, for example, by geodetic surveying if the object is large enough (performing GNSS surveying with subsequent processing [8]). For smaller objects, laser scanning or photography can be used to identify common points, and a 3D model of the object can be reconstructed. There are also methods that allow mobile imaging or the use of multiple cameras [12]. For certain tasks, territory imaging can be performed using unmanned aerial vehicles (UAVs) [1] or for agricultural tasks [4]. Sometimes, combinations of different methods are used to increase the accuracy of the expected result [7]. All these methods have their advantages and disadvantages and can be applied in various situations. However, in this paper, we will focus on a method for obtaining a 3D model from photographs of the object taken from different angles.

Thus, this work considers the construction of a 3D model using photographs, as this is one of the most accessible methods that does not require expensive equipment and can be performed with an ordinary camera. The result of such processing is a 3D model saved in a popular format, which can later be imported into various software applications for further work.

The purpose of the research

The purpose of this work is to create a 3D model of an object using ordinary photographs, so that this approach is accessible to a regular user without deep knowledge of photogrammetry or expensive equipment.

Presentation of the main research material

One of the fundamental concepts of photogrammetry is central projection. When an object is photographed, its image is always distorted, regardless of the angle of view, making it impossible to use unprocessed photographs for any kind of measurement. Therefore, for images to be used as cartographic materials, they must first be processed. Such distortions occur because the device used for photography is usually located at a single point, and consequently, the resulting image is formed by central projection.

Let us consider in more detail the main properties of central projection as shown in Figure 1. The gray plane represents the object plane on which the photographed object is located. The blue plane represents the image (or projection) plane onto which the object is projected. This plane is called the picture plane.

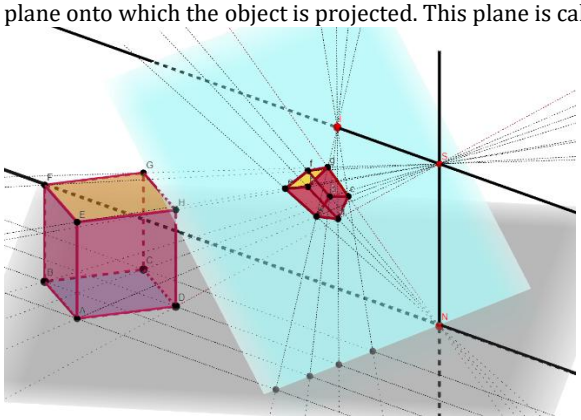

Fig. 1. Central projection

Point S is called the center of projection (or principal projection point). It is the point at which all rays coming from the object on the object plane converge. Two important points are the vanishing point (I) and the nadir point (N), which are used to correctly represent the object on the picture plane.

The vanishing point lies on the line parallel to the object plane that passes through the projection center S. The position of point I can be found as the intersection of this line with the picture plane. Meanwhile, the nadir point (N) lies on the line perpendicular to the object plane and passing through the projection center S. The position of the nadir point can be determined as the intersection of this line with the picture plane.

Thus, knowing the positions of points S, I, and N, it is possible to project the object onto the picture plane. However, for this purpose, three additional facts must be considered:

- All rays that originate from the object and pass through the picture plane converge at point S.
- All projections of lines that lie on the object plane and are parallel to the line SI are arranged on the picture plane in such a way that they converge at the vanishing point I.
- All projections of lines that are perpendicular to the object plane are arranged on the picture plane in such a way that they converge at the nadir point N.

The input data for constructing a 3D model is photographs of the object taken from different angles, with at least 60% overlap between adjacent images. Figure 2 shows three photographs of a shell, which serves as our object for 3D model reconstruction. In total, 40 photographs of the object were taken.

Fig. 2. Example of the initial photographs of the object

Various software can be used to process photographs. For our purposes, the software 3DF Zephyr was chosen.

The first step is to create a new project and upload the photographs. After this, procedures are performed to produce a sparse point cloud of matching points. To achieve this, corresponding points on adjacent photographs are first identified. This can be implemented using a variety of algorithms, such as SIFT, SURF, BRIEF, and others [6].

It is also important to note that several approaches can be used to orient and rotate the obtained points. For example, a classical method involves transforming coordinates using well-known rotation matrices around each axis. However, when computational load needs to be reduced, approaches based on quaternions [11] or computer processing methods [2] can be applied.

After performing this procedure, the positions of the photographs are determined, and a sparse point cloud is obtained (Figure 3).

It should be noted that at this stage not only are common points between images identified, but the position of the camera now of image acquisition is also determined. This result can be obtained by processing the displacements of the image of the same object across different photographs.

Briefly, popular methods for finding corresponding points include the SIFT (Scale-Invariant Feature Transform) method, which has been in use for more than two decades and was developed by David Lowe at the University of British Columbia. This method comprises two main stages. The first stage involves detecting keypoints, while the second stage focuses on extracting keypoint descriptors. The core idea of the first stage is to approximate the Laplacian of a Gaussian function. This method requires substantial computational resources and is not recommended for processing large datasets.

In contrast to SIFT, the SURF (Speeded-Up Robust Features) method performs significantly better on large datasets, as it uses box filters that enable parallel, independent processing of individual regions of the data array. This method was developed approximately at the same time as SIFT. There is also the BRIEF (Binary Robust Independent Elementary Features) method, which can be used as a keypoint descriptor. This method performs significantly worse than others when rotation of points is required.

Thus, when comparing the two main methods, SIFT and SURF, the following differences can be identified: SURF is faster because it performs simpler computations than SIFT. From the standpoint of accuracy, SIFT has the advantage, achieved through more complex computations. Taking these two factors into account, it can be concluded that SIFT is a more suitable choice when accuracy is a priority, whereas SURF is better suited for real-time processing of large volumes of data.

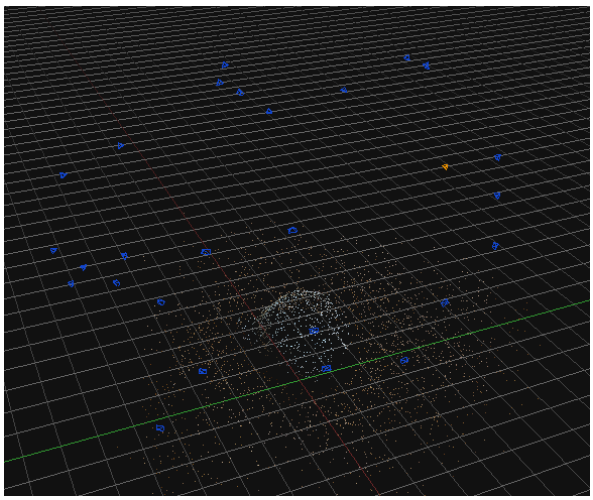

Fig. 3. Sparse point cloud and the positions of the photographs

The next step is densifying the point cloud. To do this, spatial interpolation is performed using the existing points. As a result, a dense point cloud is obtained. Figure 4 shows the sparse point cloud (on the left) and the dense point cloud (on the right).

After obtaining the dense point cloud, a surface can be constructed using the finite element method based on the set of dense points. Interpolation is an important stage that allows significantly increasing the number of points when the number of available points is insufficient, by finding corresponding points. The identified corresponding points can be considered characteristic points of the surface, defining the locations of the object's main bends or transitions. This allows one to assume that the intermediate points lie on a smoother surface and can therefore be interpolated.

For small distances, in certain cases, linear interpolation may be sufficient; it is relatively simple but ineffective when the surface deviates significantly from a plane. In such cases, one possible interpolation approach is spline interpolation. Although it requires third-order polynomials, which significantly increase computational costs compared to linear interpolation, this approach can yield much better results for curved surfaces.

After the point cloud has been densified and enough points have been obtained, it is necessary to construct a surface that incorporates these points. From a mathematical point of view, this task is quite complex if all points are processed in a single step. To simplify and accelerate the construction of such a surface, the finite element method is used. The essence of this method is to divide the set of input points into many small regions, so that separate surface constructions can be performed for each region.

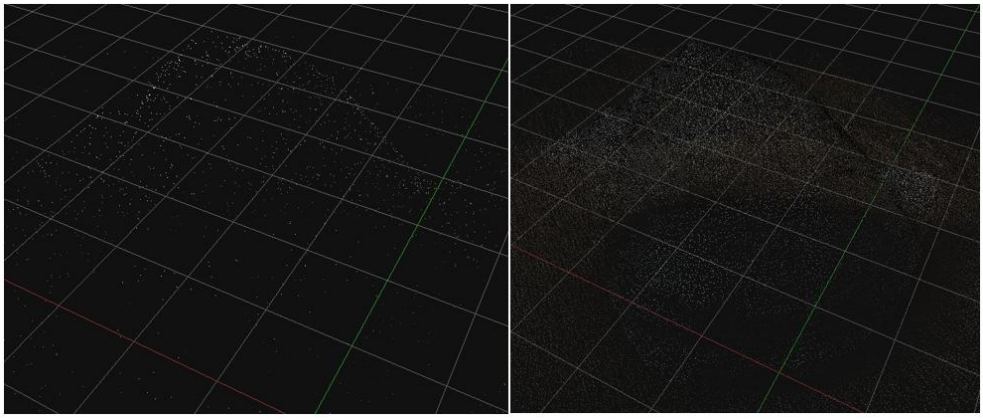

Fig. 4. Point cloud (sparse – left, dense – right)

This approach makes the surface reconstruction process much more flexible. In particular, the size of each region can be adjusted, thereby determining the number of computational resources required for the procedure. As a result, the work can be divided into separate independent parts, allowing it to be performed sequentially with greater time expenditure or in parallel (if computational resources permit) within a significantly shorter time interval.

The final step is to apply textures from the original photographs onto the constructed 3D model. Figure 5 shows the final 3D model from three different angles

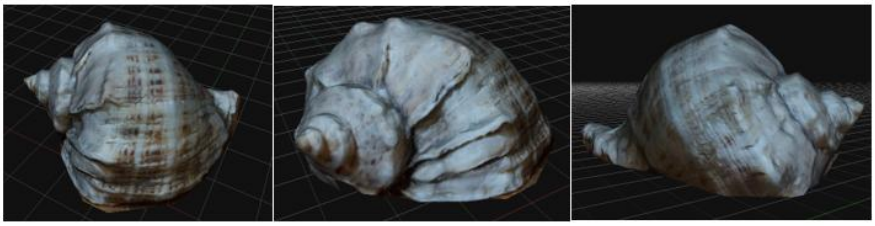

Fig. 5. Reconstructed 3D model of the object

Texture mapping is an essential and irreplaceable stage, without which a realistic 3D model cannot be created. At this stage, the model's corresponding regions are compared with the original photographs, after which texture information for a particular region of the model is extracted from the images and applied to it. As a result of these operations, the model acquires a realistic appearance, which is especially important when reconstructing historical artifacts whose appearance and shape must be reproduced with the highest possible level of realism.

Conclusions and prospects for further research

This work presents a method for constructing a 3D model of a shell from photographs taken from different angles. During model construction, matching points were identified, and a sparse point cloud was generated. Subsequently, interpolation was used to generate a dense point cloud, which served as the basis for constructing the three-dimensional object. In the final stage, textures from the original photographs were applied to the model, and the 3D object was exported. This approach enables rapid reconstruction of a 3D model of a small object without expensive equipment. Such a method can be used to create three-dimensional models of instruments, which can in turn be used for remote training on how to operate them.

It should be noted that this method performs well when reconstructing small objects. Equally important are the conditions present during image acquisition. For example, poor lighting can significantly degrade the result, not only in texture and color reproduction but also in the accuracy of shape and dimensions. This effect is particularly noticeable when reconstructing sharp edges of a model, which may appear unclear or blurred. Such artifacts can arise from the interpolation of

points that were not determined with sufficient accuracy during the matching process. However, excessively bright lighting can also cause significant problems, especially if the object's surface is glossy and highly reflective. In such cases, reflected images of other objects may appear on the surface, greatly complicating the detection of corresponding points and distorting the shape of the resulting model. This distortion may manifest itself as a lack of clearly defined contours. This effect must be considered, especially when working with objects with well-defined geometric shapes and flat, planar surfaces. For objects with less distinct shapes, such as a soft toy, this effect is not as critical.

It is also important to consider the background against which the object is photographed. It is preferable to choose an empty, uniform background, as this significantly reduces the computational load during the search for corresponding points and accelerates the generation of the final model, since no time is spent removing unnecessary parts of the model that may have been created during background processing. Thus, an empty, uniform room would be a better background than shooting in an environment with many extraneous objects, such as an outdoor scene with many buildings and trees.

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Стаття надійшла до редакції / Received 18.10.2025 Прийнята до друку / Accepted 03.11.2025