ЗАСТОСУВАННЯ 3D ФОТОГРАММЕТРІЇ ДЛЯ ОБСТЕЖЕННЯ ОБ’ЄКТІВ КУЛЬТУРНОЇ СПАДЩИНИ

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Анотація. Пам’ятки архітектури вимагають періодичного обстеження і реставрації. Існують численні методики, що дозволяють детальну обстеження будівель і споруд. Однак, для рішення цієї задачі зазвичай потребується велика кількість знімків і, отже, використання спеціалістів з фотограмметрії. Науковою новизною можна вважати розробку алгоритму для програмування польоту БПЛА з метою отримання детального зображення будівлі або споруди з ефективним кількісним аналізом текстур і структур. Методика будується на здатності цифрових фотоапаратів здобувати велику кількість інформації, що дозволяє здійснити детальну обстеження будівель.

Keywords: building inspection; 3D modeling; 3D photogrammetry; 3D scanning; landmarked buildings preservation; heritage objects capturing

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3D PHOTOGRAMMETRY APPLICATION FOR BUILDING INSPECTION OF CULTURAL HERITAGE OBJECTS

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Abstract. Landmarked buildings require periodic inspection and restoration. Numerous techniques are known that allow engineers to perform detailed inspection of buildings and structures. However, for solving this task, it is usually necessary to use a large number of images and, therefore, the services of photogrammetry specialists. The methodology is based on the ability of digital cameras to capture a large amount of information, which allows to perform detailed inspection of buildings.

Keywords: building inspection; 3D modeling; 3D photogrammetry; 3D scanning; landmarked buildings preservation; heritage objects capturing

Установлено, що наведена методика значно зменшує трудомісткість і підвищує ефективність робіт з обстеження конструкцій.
**Ключові слова:** обстеження; 3D моделювання; 3D фотограммії; 3D сканування; пам'ятки архітектури

**ПРИМЕНЕНИЕ 3D ФОТОГРАММЕТРИИ ДЛЯ ОБСЛЕДОВАНИЯ ОБЪЕКТОВ КУЛЬТУРНОГО НАСЛЕДИЯ**

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**Аннотация.** Памятники архитектуры требуют периодического обследования и реставрации. Известны многочисленные методики, позволяющие детально обследовать здания и сооружения. В последние десятилетия большое распространение получил способ обследования с применением 3D сканирования и фотограмметрии. Целью исследования является разработка наиболее эффективного подхода к аэрофотосъемке с применением UAV для построения наиболее точной модели здания. Методика основывается на построении из двумерных фотоснимков при помощи специального программного обеспечения трехмерной модели. Научной новизной можно считать разработку алгоритма для программирования полета БПЛА по наиболее оптимальной траектории с целью получения достаточного количества снимков, и, следовательно, построения модели с наименьшим количеством искаженных участков. Результатом работы является трехмерная модель здания или сооружения с сохранением всех фактических размеров и текстур, которая впоследствии может быть применена как для детального исследования дефектов существующих конструкций и элементов здания, так и в качестве подложки для разработки чертежей для проекта реконструкции или реставрации в зависимости от целей исследования. Практическое значение данной методики продемонстрировано при обследовании реального объекта культурного наследия: менонитской школы в г. Запорожье. Обследуемое здание построено в конце XIX века и до сегодняшних дней не поменяло функционального назначения. Здание является одним из немногих хорошо сохранившихся образцов аутентичной менонитской архитектуры в этом регионе, поэтому было удалено большое внимание обследованию и разработке мероприятий по его восстановлению. Выполнено комплексное обследование с применением фотограмметрической съемки и построением трехмерной модели. С использованием модели точно установлены места, требующие восстановления, определены дефекты, требующие устранения. Оценено состояние конструкций даже в труднодоступных местах. Таким образом наглядно показано, что представленная методика обследования существенно снижает трудоемкость и повышает эффективность работ по обследованию конструкций.

Ключевые слова: обследование; 3D моделирование; 3D фотограммії; 3D сканування; архітектурні пам'ятки; об'єкти культурного наслідництва

**Introduction.** There are not many land-marked buildings preserved in Zaporizhia region, Ukraine. Therefore, they especially need preservation and, consequently, periodic inspection and restoration.

Detailed measurements of buildings and structures - an integral part of the building inspection. Landmarked buildings often have a complex geometric shape, complex architectural forms of facades, complex crack and damage patterns that requires capturing as well in order to analyze their potential causes. Furthermore, a detailed survey is required to determine the technical state of all structural and architectural elements of the building for the restoration of the landmarked building.

It could be challenging to perform detailed measurements manually in practice, especially at height and in hard-to-reach elements of roofs, towers, etc. In addition, manual collecting of geometrical dimensions of elements are labor-intensive and the human factors error could occur which increases the cost and duration of surveys especially when big projects are concerned.

In comparison to a traditional manual approach, modern digital methods of 3D capturing provide very accurate representations of building’s properties including the following: surface, structure, realistic visual presentation (textures). As far as landmarked building inspection is concerned, 3D capturing of building’s elements using different methods has its wide practical use.

Currently, there are two main approaches to 3D virtual modeling that are used to create digital models of different subjects: 3D scanning and photogrammetry. 3D scanning based on using highly specialized equipment that measures and reconstructs the surface of an object using technology based on stereo vision, light wave, or sound wave distance measurement. Alternatively, photogrammetry
methods extract information from 2D photographs to reconstruct objects in 3D.

Recently, low altitude unmanned aerial vehicles (UAV) expanded its practical application area in the construction industry. These vehicles fully meet the needs of 3D photogrammetry capturing of building-sized objects.

During the last decade, many studies concerning the use of 3D photogrammetry for building inspection were carried out. Practical use of 3D photogrammetry and 3D laser scanning combination is described in the case study of ancient theatre inspection [1]. Decreasing the time needed for documentation was shown. Comparison of two terrestrial photogrammetric methods - semiautomatic and automatic was provided in [2] - the case study of old military building capturing. In [3] the accuracy of the UAV-derived 3D models was assessed. The experiment showed that besides the Laser Scanner Systems, even the lowest cost systems based on UAV image processing and photogrammetric analysis with Structure from Motion algorithms are able to produce 3D models, with a good level of accuracy. In [4] practical use of Photogrammetry and aerial photography in the field of building inspection, as well as disaster assessment, is considered. Automated masonry crack detection using pictures taken by UAV is described in [5].

In this study, practical use of 3D photogrammetry capturing in the field of heritage objects inspection using an example of the monument of Mennonite architecture in Zaporizhia city is described.

To reconstruct a 3D model Autodesk ReCap Photo software was used. The main features of the obtained three-dimensional model are high geometrical accuracy, the presence of the textures, which allowed us to analyze in detail the technical state of structural elements, as well as various architectural details and assemblies. Such an analysis makes it possible to identify damage and structural defects that cannot be captured by visual inspection due to the inaccessibility and complexity of particular elements.

2. The methodology of a building inspection: the case study of the monument of Mennonite architecture

In order to illustrate the inspection methodology an example of a monument of Mennonite architecture is given. Mennonites appeared in Ukraine in the last decades of the XVIII century and made a significant contribution to the development of the region [6]. They developed highly productive agriculture, contributed to the development of industry, trade, and finance of the region. One of the few buildings that have retained their functional purpose is the building of the women's school (now Zaporozhia Comprehensive School No. 81) in the village of Rosenthal. The village was founded in 1790, had one main street, which ran parallel to the river Khortitsa. Currently, Rosenthal is part of the of Zaporozhia city and is informally known as Verhnya Khortytsya.

The building was built in 1895 and at the time of the inspection, it fully functions as a school (Fig. 1). Since its construction, a minor architectural replanning, replacement of roofing materials, replacement of the heating system have been implemented. Basement, in general, remained unchanged. In this case, structural elements of the building were not affected. However, over a long period of time, destruction occurred: the structures underwent some damage and deformation, the finishing layers were dilapidated.

![Fig. 1. Aerial overview of the building](image-url)

A complex of inspection works was carried out, including a detailed visual inspection [7], determination of the strength of the material of some load-bearing structures, geodetic
measurements, and model building using photogrammetric methods.

3. 3D Photogrammetry process

Photogrammetry methods extract information from 2D photographs to reconstruct objects in 3D. This technique, also known as image-based 3D modeling, uses structure-from-motion and stereo reconstruction algorithms to identify and match shared points from overlapping photographs to create point clouds and meshes representing the surface of an object.

Depending on the position (point of view) of a camera, photogrammetry can be classified as a terrestrial or areal.

Each part of the building should be photographed from at least three distinct – but not radically different – viewpoints. The overlap between consecutive photographs should typically exceed two thirds. For aerial photography, a longitudinal overlap of 80% and lateral overlap of 50% or more are recommended. Preparing a flight plan by preprogramming flight trajectory helps to achieve capturing pictures with sufficient and systematic overlap [8].

There are two major phases while acquiring a 3D model out of 2D pictures:

- **Aerotriangulation** that represents the mathematical process of establishing precise and accurate relationships between the individual image coordinate systems and a defined datum and projection (Fig. 2) [9]. One of the most fundamental processes in photogrammetry is to identify and measure tie points in several photographs, which is a part of the aerotriangulation process. The camera positions coordinates are determined during this process as well.

- **Reconstruction of a 3D model.** Through this phase, a 3D model (polygonal mesh or point cloud) is constructed using data acquired during aerotriangulation (tie points coordinates, camera positions).

The end-product of 3D photogrammetry is a precise 3D virtual model of a particular subject. An output model could be represented in different variations such as textured polygon mesh or point cloud depending on the purposes for the further use.

For school capturing the combination of aerial and terrestrial photogrammetry was chosen. Because of a high density of buildings, trees, power lines in surrounding area application of aerial capturing only would not have provided sufficient amount of pictures and overlap required for accurate result model.

The aerial images were taken with the UAV DJI Phantom, a compact sized quadcopter equipped with a built-in digital camera and active stabilizer (3-axis gimbal).

Camera has a resolution of 20 megapixels; pictures taken with it contain metadata of GPS coordinates and altitude value from the built-in barometer.

Quadcopter was piloted in the polar coordinate system with the origin in the center of the building (Fig. 3). This made it possible to achieve consistency in picture capturing and sufficient overlap. In total, during the entire flight session, 141 photographic shots were taken.

To provide capturing of the lower part of the building as well as to capture architectural elements of the building with geometrically complex form, that is difficult to view from above, terrestrial pictures were taken. Eighty-five pictures were taken with action camera Xiaomi YI 4K.
Fig. 4. 3D Point cloud result model. Prospective view

Fig. 5. – Textured and untextured result models

3D model was created with Autodesk Recap Photo software (ex- Autodesk Remake) in two variations – dense point cloud and high accurate polygonal textured mesh (Fig. 4, 5).

The workflow of ReCap photo is completely automated for image orientation, aerotriangulation and for generating and reconstructing the model. All operations that require computing power of computer are performed at cloud service. During this process, the human factor is minimized, i.e. limited on image and control points entering. The entire process of photogrammetry and modeling is automated, and no other human interference is necessary.

4. Results of the inspection

Based on the results of the inspection and capturing, defects were determined for individual structural and architectural elements, a cracking pattern, and technical measures for eliminating defects were elaborated.

Fig. 6. Front elevation view

Damaged areas of the roof coating have been precisely identified through studying 3D textured mesh model in terms of both quantity and quality, which is challenging to do with traditional methods of inspection.

The obtained model was successfully used for documentation of structural and architectural elements and the building itself. Main drawings of existing building were semi-automatically created in Autodesk Revit BIM software with the help of background 3D point cloud model (Fig. 6-7). Creation such documentation with traditional methods of inspection would take a great deal of time and human resources with lack of detail and accuracy.

5. Conclusion

Today, the preservation of monuments, the renewal and the restoration of historical buildings and structures is an integral part of the national culture. However, such work requires serious efforts of many specialists to perform proper diagnosis of the causes of destruction and the application of effective repair and finishing materials, as well as the valuation of financial investments.
The application of photogrammetry allowed providing full documentation of the building in a short time with minimum amount of human resources as well as assessing the technical condition of its elements including in hard-to-reach places.

The combined photogrammetry method including aerial and terrestrial capturing has shown its effectiveness, especially for an inspection of landmarked buildings due to their complexity in form and density of obstacles around.

Thus, it is clearly shown that the presented inspection technique significantly reduces labor intensity and raises the efficiency of building and structures inspection.

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