НАУКИ ПРО ЗЕМЛЮ. ГЕОІНФОРМАЦІЙНІ ТЕХНОЛОГІЇ МОДЕЛЮВАННЯ СТАНУ ГЕОСИСТЕМ

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METHODOLOGY AND RESULTS OF CREATION 3D MODELS OF HISTORICAL AND CULTURAL OBJECTS USING A SMARTPHONE EQUIPPED WITH A LIDAR SCANNER

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Annotation. *The article describes the methodology and results of creating 3D models of objects of the historical, cultural and scientific heritage of Ukraine using the technology of shooting the investigated objects using a smartphone equipped with a LiDAR scanner. The Museum of Soils, named after Prof. M. M. Godlin, of the National University of Life and Environmental Sciences of Ukraine, which is located in auditorium No. 53 and in the foyer of educational building No. 2. The exposition includes more than 200 monoliths of soils, selected from various natural zones of Ukraine over more than 100-year period of the museum's operation. Considering the high scientific and didactic value of this object, it was decided to create a digital 3D model of it. In order to implement this task, a principal scheme (algorithm) was first developed for performing shooting works using a smartphone with a LiDAR scanner and processing the resulting points cloud that reflects the contours of the scanned objects. This algorithm is the basis of a methodology for creating 3D models of objects of historical, cultural and scientific heritage of Ukraine. In the construction of mobile devices, LiDAR technology first appeared on rear cameras in 2020 with the release of the iPad Pro and iPhone 12 Pro/iPhone 12 Pro Max. LiDAR is used in them to determine the distance from the camera to the objects under study using laser radiation. Using a smartphone equipped with a LiDAR scanner, the main exposition of the Museum of Soils was shot using the program Polycam. In the course of further work, based on the cloud of points created by lidar 3D scanning of the Museum of Soils, a cloud of points was constructed (using such software tools as Auto CAD, PIX 4D, 3DMAX,*

Blender) digital 3D model of the exposure of soil monoliths of this object. The result of the completed works is a 3D model of the exposition of the soil monoliths of the Museum of Soils, located in the auditorium of educational building No.2 of NUBiP of Ukraine. At the final stage of the research, the results were verified by comparing the linear dimensions of the stands, determined by using a tape measure directly in the Museum, and the same indicators displayed on the 3D model. The error of measurement of linear exposure parameters using LiDAR did not exceed 3.10%, that considered acceptable. The created version of the 3D model of the exposition of soil monoliths of the Museum of Soils of NUBiP of Ukraine can be used for both educational and popularization purposes.

Keywords: *LiDAR scanner, program Polycam, 3D shooting with a smartphone, 3D model, 3D scanning, point cloud*

Relevance of the research

Mobile 3D scanners at the current stage of technical and informational equipment of society find new areas of application in solving both geodetic and land management and construction and reconstruction tasks. This is facilitated by both the improvement of their technological component and the introduction of restrictions on the use of UAVs when performing filming under the conditions of martial law introduced in Ukraine in connection with Russia's military aggression. The need for 3D scanning of valuable historical-cultural and historical-architectural objects and the creation of their 3D models is due to the existing high risk of damage and destruction during Russian terrorist attacks on objects of energy, civil and cultural and scientific and educational infrastructure in various regions of Ukraine. From these positions, the application of 3D scanning of various objects, the formation of a cloud of points that reflect their contours and structure, and its processing and creation of digital 3D models is an extremely urgent task of geodesy.

Terrestrial laser 3D scanning can be performed using a wide range of geodetic equipment, the choice of which depends on the dimensions of the scanned object, the purpose and purpose of the created digital 3D model [1]. Laser scanning is widely used in solving the problems of conservation of damage and restoration of ancient architectural monuments due to its ability to accurately record both the shape and dimensions and the external and internal structure of the object. In the order of solved tasks, the most important are: documenting the state of the object through the creation of accurate 3D models of architectural monuments, museums, monuments, etc.; creation of information and analytical prerequisites for the restoration and conservation of damaged architectural monuments or valuable objects of another type, for which there are threats of destruction or destruction; solving the problems of increasing the level of accessibility and popularizing information about architectural monuments, museums and even their exhibits. Thanks to the use of 3D models, it is possible to create virtual exhibitions, disseminate information about cultural heritage among the broad masses of the population, store it in digital form as a historical memory, use 3D models for research, analysis and monitoring of changes that occur in the state or structure of one or another object [1; 5].

Starting 2020, researchers have obtained new relatively inexpensive tools that can be used to perform laser 3D scanning of various objects: iPad Pro and iPhone 12 Pro/iPhone 12 Pro Max [1; 5]. We tried to test this technology to create a 3- D model of the Museum of Soils named after Prof. M. M. Godlin, located in educational building No. 2 of NUBiP of Ukraine (Kyiv).

Thus, laser scanning using a smartphone can serve as an important tool for ensuring the preservation and research of architectural heritage, because it produces detailed and accurate information about objects, which can later be used to solve a wide range of tasks - from educational and popularization to conservation and reconstruction to the preservation of historical memory of important historical-architectural, museum and scientific objects.

Analysis of recent research and publications

Many studies of both domestic and foreign scientists are devoted to issues related to the creation of 3D models of objects in the surrounding world with the help of LIDAR scanners. They reflect the variety of ways and techniques of using this technology when scanning various small structures and objects using iPhone and iPad [1], during the reconstruction and reproduction of objects of historical cities and various structures [2, 3] and creating phantom models of architectural components [7], obtaining digital versions of cultural objects [8], improving methods of creating 3D models using drawings and photographs [9], solving similar problems with a complex of geodetic methods [10 - 12].

In Ukraine, there are several teams and companies that carry out specialized scanning and creation of 3D models of objects of historical and cultural heritage located in different regions of our country. They include [6]:

- SKEIRON. This team has been digitizing Ukrainian heritage for over eight years. During this time, the company digitized the Palace of Culture "Energetik" in Pripyat, St. Sophia Cathedral, Golden Gate, St. Nicholas Church, Chernivtsi University, a series of architectural monuments of Lviv and most UNESCO monuments located in Ukraine. Of these, more than 100 objects have been digitized in high detail;
- NGO "Pixelity Realities". Specialists of this organization launched the military-documentary project "Museum of Ukrainian Victory", the main task of which is to preserve the cultural and historical heritage in the form of 3-D models and to demonstrate to the world the struggle and aspirations of the Ukrainian people through the display of objects affected by russia's war against Ukraine. in the form of virtual 3- D models. "Pixelity Realities" has already scanned more than 85 objects, created 2 scans of cities and 175 scans of monuments and statues;
- AERO3D is a Ukrainian engineering company that specializes in 3D modeling, laser scanning, performing geodetic and photogrammetric work, creating virtual 3D tours, and taking photos and videos of valuable objects. The company has already created models of 25 objects of cultural significance and 16 models of military and civilian objects destroyed by russia, such as, for example, churches;
- “My Future Heritage” is a project dealing with digitization of material cultural heritage, creation of tactile exhibits for blind and partially sighted people, 3D scanning and printing, as well as

photogrammetry. At the initiative of the team, a project was created, within the framework of which it is planned to digitize more than 1,100 works of the B.G. Voznytskyi Lviv National Art Gallery.

In addition to the described organizations in the field of creation of 3D objects and models valuable for Ukraine, such companies as Town Image Studio, Hemo, MEMORYSAVERS and others also work. This industry has significant potential and value for our country, so the development of such initiatives is an urgent task.

Scanning and creating 3D monuments of cultural heritage is important for Ukraine in view of the possibility of preserving unique objects that are under threat of destruction by natural and man-made processes and the russian aggressor. In addition, these technologies make it possible to make cultural heritage more accessible to the public, even for those who cannot visit these objects physically. The technology of creating 3D models of objects allows you to virtually explore and study cultural monuments, which opens up new opportunities for education, tourism and popularization of the cultural heritage of Ukraine both within the country and beyond. The brief analysis carried out shows the significant prospects of laser scanning of historical and cultural objects, including h using a LIDAR scanner.

The purpose of the article is to study the methodological principles of shooting and creating 3D models of valuable historical, cultural and scientific objects using a smartphone equipped with a LiDAR scanner.

Materials and methods of scientific research

The following methods were used during the scientific research: field shooting with the use of a smartphone equipped with a LiDAR scanner [1]; processing of shooting results using the Polycam software [4] and Auto CAD, PIX4D, 3DMAX, Blender; verification of the obtained 3D model of the museum exposition, the method of summarizing the obtained results and their display in the form of a 3D model.

Research results and their discussion

The essence of LiDAR technology - scanning of objects using a smartphone. The LiDAR sensor in the smartphone is represented by a small module located on the back of the device. It consists of a laser emitter, a light receiver and a processor for processing the data received (Fig. 1).

Lidar allows measuring distances to objects with high accuracy and speed [1; 4; 8]. This is achieved using infrared light rays that are not absorbed by the atmosphere. LiDAR works as follows (Fig. 2):

- the LiDAR sensor emits short pulses of infrared light rays;
- infrared rays of light are reflected from the objects we shoot and

Fig. 1. Location of the LIDAR scanner on the smartphone panel [1].

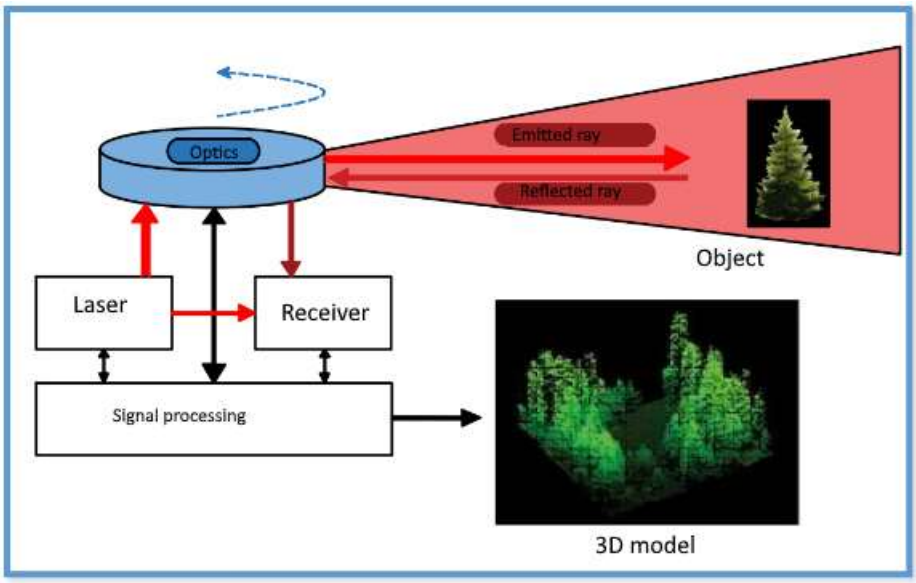

Figure 2. Schematic diagram of filming operations using a smartphone with LiDAR (according to [12])

fall into the field of view of the sensor in the smartphone;

- the sensor measures the time it takes for the light to return;
- based on this time, the sensor calculates the distance to the object;
- an image (3- D model) of the object is formed on the basis of the cloud of points.

The basic principle of operation of this shooting technology is that the sensor emits light rays and detects the time required for these rays to move to the shooting object, reflect from it and return. This process takes into account the influence factor of the dispersion of the environment, which allows us to achieve high accuracy in determining distances to objects.

Among mobile devices, LiDAR technology first appeared on rear cameras in 2020 with the release of the iPad Pro and iPhone 12 Pro/iPhone 12 Pro Max [1; 8]. LiDAR is a method of determining distances from the camera to the objects under study using laser radiation. As a result of the shooting, a cloud of points is obtained, with the help of which the contours of the object under study are outlined. Further processing of this cloud of points allows creating 3D models of the studied objects.

Creating 3 D models of the object of historical and cultural heritage from using the Polycam software in a smartphone. LiDAR can be used to create accurate 3D models of historical and architectural objects and museum spaces. This technology can be useful for solving various tasks, such as: architectural design, shooting valuable architectural monuments and creating their three-dimensional images, supporting repair works, creating virtual and augmented reality, etc. The implementation of these tasks is especially important during the period of martial law, when there is a danger of destruction of valuable historical and cultural objects, therefore the early creation of their 3D models is extremely important for the preservation of our historical, architectural, museum, and cultural heritage.

The general principle of creating a 3D model of one of these objects (namely, the Museum of Soils in educational

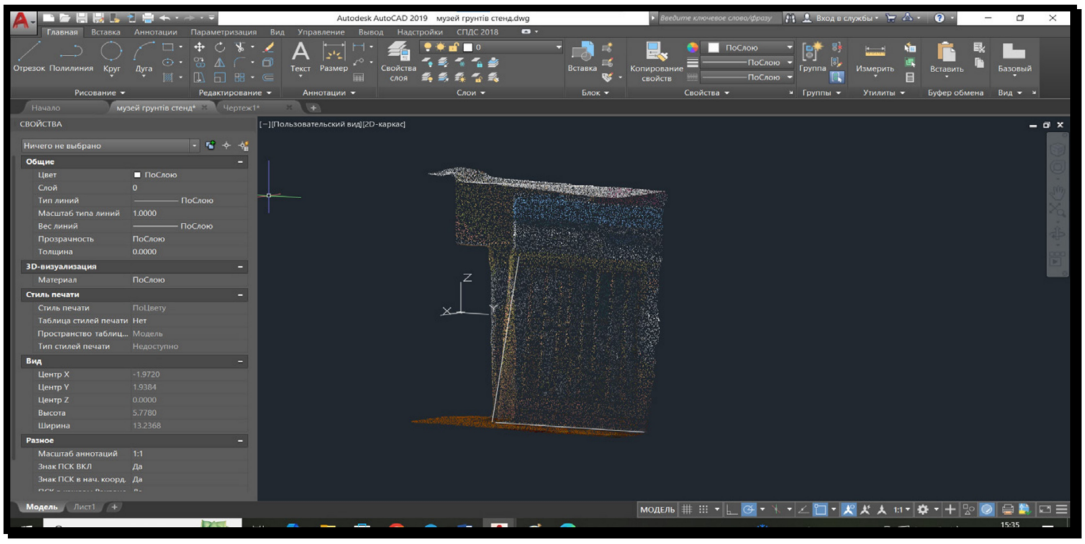

Figure 3. A cloud of points representing the elements of the Museum's exposition and their export to a file with the DXF extension

building No. 2 of NUBiP of Ukraine) is described below.

1. Open the Polycam program [4] and click "create a new project".

2. Select the LiDAR function and we begin to scan the surface of the researched object.

3. After the scanning is completed, we receive a ready to use polygonometric model, which can later be exported to various extensions that are suitable for further processing in additional software, such as Auto CAD, PIX 4D, 3DMAX, Blender.

4. After exporting the project to a file with the DXF extension, open it in AutoCAD (Fig. 3) and determine the accuracy of the transmission of the exposure parameters on the created point cloud, which displays the exhibits of the Museum of Soils of the NUBiP of Ukraine - soil sections from various natural zones of Ukraine.

5. The cloud of points loaded into the program has a density sufficient to determine the display of the dimensions of soil monoliths on the 3- D model of the Museum of Soils exposition being created with sufficient accuracy (Fig.6).

Figure 4. A fragment of the exposition of soil sections in the Museum of Soils of NUBiP of Ukraine with a display of their linear dimensions determined by a tape measure.

For the reference value of the length of the exhibition stand, we chose the value measured with a tape measure, which was 258 cm. (Fig. 4, 5, 6).

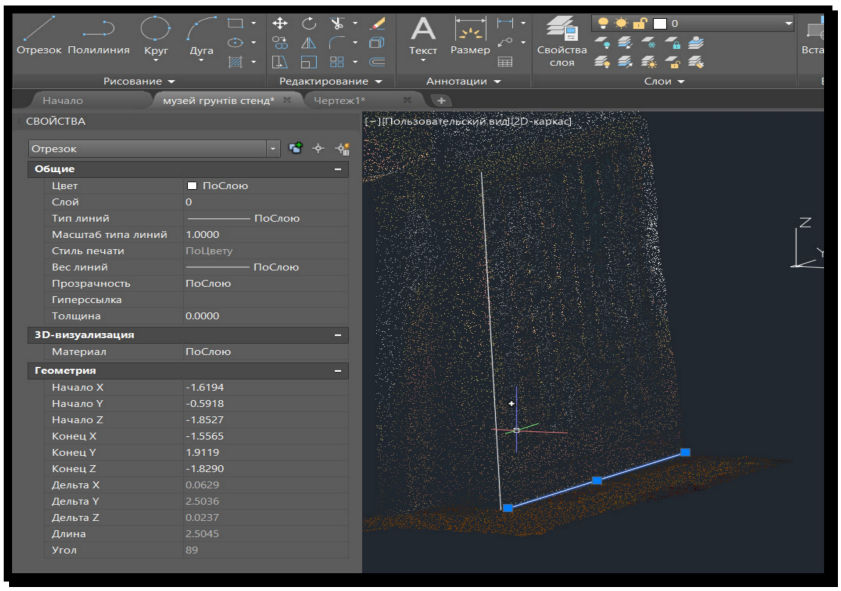

Figure 5. Assessment of the accuracy of the created 3- D model of the Museum of soil exposition.

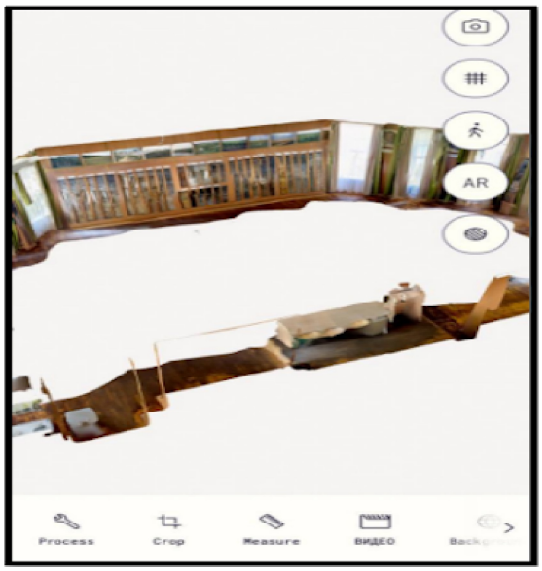

Figure 6. A 3-D model of the Museum of soil exposition was created

6. To determine the accuracy of measuring the length of the stand of soil monoliths, you can use the relative error, which is calculated as the ratio of the difference between the average (measured thrice) reference and average measured values to the average reference value expressed as a percentage. The data we measured were: reference average length value measured with a tape: 258 cm; value average measured with LiDAR scanner: 250 cm. Calculated as follows, the relative error was 3.1%.

Therefore, the error in measuring linear exposure parameters of the model (Fig.6) using LiDAR scanner does not exceed 3.1%, i.e., it is acceptable.

Conclusions

At the current stage of the development of our country, when russia has been waging a war of aggression on the territory of Ukraine for almost three years, destroying cities and villages, destroying historical, cultural, architectural, scientific values, buildings, components of the engineering and technical infrastructure, there is a need to conduct filming for creation of 3D models of the most valuable objects of national heritage. In solving this task, geodesy has great potential, in particular, its research technologies, such as laser scanning and shooting with the help of a LiDAR scanner in a smartphone. To implement the task of creating a 3D model of the Museum of Soils of NUBiP of Ukraine as an object of scientific heritage, a schematic

diagram (algorithm) of filming works using a smartphone with a LiDAR scanner and processing the obtained cloud of points that reflect the contours of scanned objects was first developed. This algorithm is based on a well-founded method of creating 3D models of objects of historical, cultural and scientific heritage of Ukraine using laser scanning technologies of the objects under study.

The article describes the results of using a LiDAR scanner to create a 3D exposure model of soil sections (monoliths) collected over a 100-year period in the Museum of Soils of NUBiP of Ukraine. The obtained 3D model of the Museum of Soils exposition (Fig.6) accurately conveys the real dimensions and properties of its exhibits.

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МЕТОДИКА І РЕЗУЛЬТАТИ СТВОРЕННЯ 3D МОДЕЛЕЙ ІСТОРИКО-КУЛЬТУРНИХ ОБ'ЄКТІВ З ВИКОРИСТАННЯМ СМАРТФОНА, ОСНАЩЕНОГО LIDAR-СКАНЕРОМ

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Анотація. *У статті висвітлена методика і результати створення 3D моделей об'єктів історико-культурної і наукової спадщини України з використанням технології знімання досліджуваних об'єктів за допомогою смартфона, оснащеного LiDAR-сканером. В якості об'єкта дослідження, на прикладі якого апробовувалася придатність даного LiDAR-сканера, для виконання знімальних робіт, опрацювання хмари точок отриманої інформації про об'єкт дослідження та створення 3D моделей історико-культурної і наукової спадщини України, обрано Музей ґрунтів ім. проф. М. М. Годліна, Національного університету біоресурсів і природокористування України, який розташований в аудиторії №53 та в фойє навчального корпусу № 2. Експозиція нараховує понад 200 монолітів ґрунтів, відібраних у різних природних зонах України за більш як 100-річний період функціонування музею. Враховуючи високу наукову та дидактичну цінність цього об'єкта, було вирішено створити його цифрову 3D модель. Для реалізації цього завдання спочатку була розроблена принципова схема (алгоритм) виконання знімальних робіт за допомогою смартфону з LiDAR-сканером та опрацювання отриманої хмари точок, які відображають контури сканованих об'єктів. Цей алгоритм покладений в основу обґрунтованої методики створення 3D моделей об'єктів історико-культурної та наукової спадщини України. В будові мобільних пристроїв вперше технологія LiDAR з'явилася на задніх камерах у 2020 році з випуском iPad Pro та iPhone 12 Pro/iPhone 12 Pro Max. LiDAR в них використовується для визначення віддалей від камери до досліджуваних об'єктів за допомогою лазерного випромінювання. Використовуючи смартфон, оснащений LiDAR-сканером, було виконано знімання основної експозиції Музею ґрунтів з задіянням програми Polycam. У процесі подальших робіт, базуючись на створеній при лідарному 3D скануванні Музею ґрунтів хмарі точок, була побудована (з використанням таких програмних засобів, як Auto CAD, PIX4D, 3D MAX, Blender) цифрова 3D модель експозиції ґрунтових монолітів цього об'єкта. Результатом виконаних робіт виступає 3D модель експозиції ґрунтових монолітів Музею ґрунтів, розміщених в аудиторії 53 другого навчального корпусу НУБіП України. На завершальному етапі досліджень проведено верифікацію отриманих результатів через порівняння лінійних розмірів стендів, визначених з застосуванням рулетки безпосередньо в Музеї та цих же показників, відображених на 3D моделі. Похибка вимірювання лінійних параметрів експозиції за допомогою LiDAR не перевищила 3,10%, тобто є прийнятною. Створений варіант 3D моделі експозиції ґрунтових монолітів Музею ґрунтів НУБіП України може використовуватися як з навчальною, так і популяризаційною метою.*

Ключові слова: *LiDAR-сканер, програма Polycam, 3D знімання смартфоном, 3D модель, 3D сканування, хмара точок.*