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ADVANCED 3D MODELING SYSTEM UTILIZING PHOTOGRAMMETRIC TECHNIQUES

This paper considers approaches and principles of building the 3D modeling system based on photogrammetry principles. It also describes integration with Object Capture, developed by Apple, as an example of technology that allows creating 3D models of real-world objects using a set of photos. Additionally, the article describes the approach to creating client-server applications, which will provide potential users with a convenient interface for interacting with the system.

Keywords: *3D modelling, photogrammetry, Object Capture.*

Introduction

Creating 3D models of historical and archaeological objects and the current state of sites requires powerful methodologies that can capture and digitally model fine geometric and exterior details of such sites. Our heritage (natural, cultural and mixed heritage) suffers from continuous wear and tear, war, natural disasters, climate change and human neglect, requiring digital records, documentation and preservation. In particular, built environments and natural sites have received much attention and benefit from recent advances in range sensors and imaging devices. 3D data is an important component for permanently recording the geometry of important objects and sites and passing them on to future generations, at least in digital form.

Also the availability and use of 3D data opens a wide spectrum of further applications and allows new analyses, studies, interpretations, conservation policies or digital restoration. Thus 3D virtual heritages should be more frequently used due to the great advantages that remote sensing technologies and the third dimension offer to the heritage world and to recognize the digital documentation and preservation needs stated in numerous international charters and resolutions. Unfortunately, there are still some difficulties of communications between the geomatics people and the heritage community. New technology and new hardware improve the quality of 3D models with the aim of attracting new people to the 3D world [1].

Many companies have entered this market, developing and using well-featured software and survey systems, often with very impressive results. So the number of 3D products is huge and on the one hand the cost of these technologies is slowly

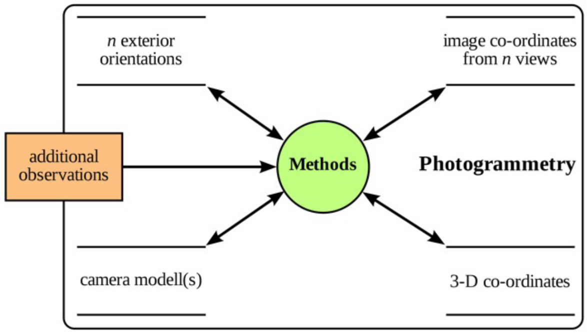

Fig. 1. Photogrammetry data model

declining, on the other hand especially for non-professionals choosing the right product due to the lack of standard terminology It's hard to beat specs and performance benchmarks. Moreover, new technologies can be powerful tools for improving classical standards of cultural heritage recording and documentation and for creating new methodologies. However, even standard two-dimensional representations are not without problems.

Although digitally recorded and modeled, our heritages require also more international collaboration and information sharing to make them accessible in all the possible forms and to all the possible users and clients. Nowadays, the digital documentation and 3D modeling of Cultural Heritage should always consist of [2]:

• Recording and processing of a large amount of 3D (possibly 4D) multi-source, multi-resolution, and multi-content information;

• Management and conservation of the achieved 3D (4D) models for further applications;

• Visualization and presentation of the results to distribute the information to other users allowing data retrieval through the Internet or advanced online databases;

• Digital inventories and sharing for education, research, conservation, entertainment, walk-through, or tourism purposes.

Theoretical Fundamentals

Photogrammetry uses methods from many fields, such as optics and projective geometry. Digital image acquisition and photogrammetric processing involve several well-defined stages that allow the production of his 2D or 3D digital model of an object as the final product. The data model on the right shows the types of information that can flow in and out of the photogrammetry process [3].

3D coordinates define the position of an object point in 3D space. Image coordinates define the image location of an object point on a film or electronic imaging device. The camera's external orientation defines the position in space and the orientation of the view. The medial orientation defines the geometric parameters of the imaging process [4]. This is primarily the focal length of the lens, but it can also account for lens distortion. Other complementary observations play an important role. A scale is essentially a known distance between two points in space, or a known fixed point, that establishes a connection to a base unit of measurement. Each of the four main variables is the input or output of the photogrammetric method.

Photogrammetry algorithms usually try to minimize the sum of the squared errors of the coordinates of the reference point and the relative displacement. This minimization is called bundle adjustment and is often performed using the Leven berg-Marquardt algorithm.

Stereophotogrammetry

A special case, called stereophotogrammetry, uses measurements made on two or more photographic images taken from different positions to estimate the three-dimensional coordinates of points on an object (stereoscopic reference). Commonalities are identified in each image. A line of sight (or ray) can be constructed from the camera position to a point on the object. It is the intersection of these rays (triangulation) that determines the 3D position of the point. More sophisticated algorithms can use other information known a priori about the scene, such as symmetry. This allows us to reconstruct his 3D coordinates from a single camera position in some cases. Stereo photogrammetry is emerging as a robust non-contact measurement technique for determining the dynamic properties and mode shapes of non-rotating [5, 6] and rota ting [7, 8] structures. According to Pierre Seguin, the collection of images to create photogrammetric models can be better described as polyoscopy [9].

The task of converting multiple 2D images into a 3D model consists of several processing steps.

Camera calibration consists of intrinsic and extrinsic parameters, without which the set of algorithms cannot function at some level. The dotted line between calibration and depth determination usually represents the need for camera calibration to determine depth.

Depth determination is the hardest part of the whole process, as it computes depth, which is the missing 3D component in certain images. The key problem here is the correspondence problem of finding matches between two images so that the positions of matching elements can be triangulated in 3D space.

Once we have multiple depth maps, we need to combine them, calculate the depth and project from the camera to create the final mesh registration. Camera calibration is used to identify where many meshes created by depth maps can be combined to create a larger mesh that provides multiple views for observation.

A full 3D mesh is completed when the material is applied. This may be the ultimate goal, but usually the color of the original photo is applied to the grid. This ranges from randomly projecting an image onto a mesh, to approaches that combine textures for super-resolution, to segmenting meshes by materials such as specular and diffuse properties.

Photogrammetric data can be supplemented with distance data from other techniques. Photogrammetry is more accurate in the x and y directions, but distance data is generally more accurate in the z direction. This range data can be provided by techniques such as *LiDAR*, laser scanners (using time-of-flight, triangulation, or interferometry), white-light digitizers, and other techniques that scan an area and return *x*, *y*, and *z* coordinates, increase. A set of discrete points (commonly called a "point cloud").

Even if the point cloud footprint does not clearly define the building edge, the photograph can clearly define the building edge. There are advantages to taking the best of both systems and integrating them into a better product. A 3D visualization can

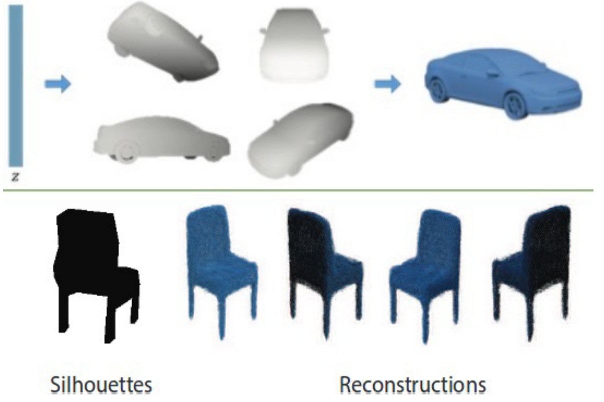

Fig. 2. Generating and reconstruction 3D shapes from depth maps

be created by georeferencing aerial imagery and *LiDAR* data in the same reference frame, orthorectifying the aerial imagery, and draping the orthorectified imagery onto the *LiDAR* grid. Digital terrain models could be used to create 3D visualizations from pairs (or multiples) of aerial or satellite images (such as SPOT satellite imagery). Then, using techniques such as least-squares adaptive stereo matching to generate a dense array of matches. This produces a dense array of *x, y, z* data that can be transformed by the camera model and used to generate digital terrain models and orthoimagery products. Systems that use these technologies as ITG systems were developed in the 1980s and 1990s, but have since been superseded by *LiDAR* and radar-based approaches.

Object Capture

Object Capture is a technology developed by Apple that allows users to create high-quality 3D models of real-world objects using a set of photos taken from various angles. It uses photogrammetry principles and advanced algorithms to create accurate 3D models that can be used in a variety of applications, such as augmented reality, gaming, and visual effects [10].

The process of creating a 3D model with Object Capture involves taking a series of photos of the object from different angles using an iPhone, iPad, or any other digital camera. The Object Capture software then analyzes the photos and creates a 3D

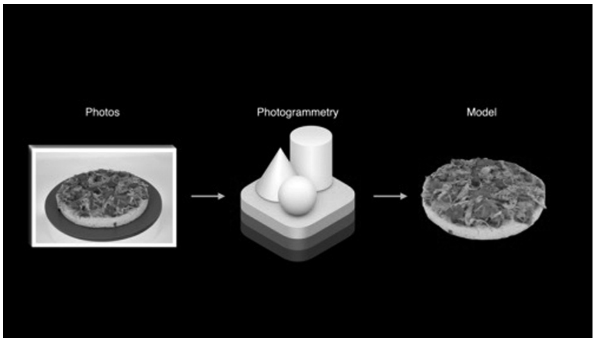

Fig. 3. Object Capture workflow

mesh of the object, along with a texture map that captures the color and details of the object's surface.

Object Capture is designed to be easy to use, with a user-friendly interface that guides users through the process of capturing and creating 3D models. It is also highly customizable, allowing users to adjust the level of detail and accuracy of the model to fit their specific needs.

Overall, Object Capture is a powerful and versatile tool that makes it easy for users to create high-quality 3D models of real-world objects, and is particularly useful for applications such as augmented reality, where realistic and accurate 3D models are essential.

System Application Lifecycle

The architecture of the system is crucial to its success. A well-designed architecture not only ensures the smooth functioning of the system but also makes it easier to maintain and modify over time. This is especially true for iOS and macOS applications, where user experience is paramount. An efficient architecture can significantly enhance the performance of an application, reduce the likelihood of errors, and improve its scalability. Moreover, the architectural design is not limited to application development but is also crucial for software in general.

During the complex of software development, it was decided to create three separate applications (in the future ScanAR):

1. A standalone program for macOS that allows generating models on the computer where the program is running. To work correctly, it is necessary to specify the path to the folder with the object's photos to be modeled.

2. A self-hosted server application that runs on a macOS computer and serves as a kind of backend. It allows accepting a selection of object photos, starting the scanning process, and, in case of success, allowing the client to download the generated model. Also, if necessary, the system allows tracking the model creation progress in real-time. This is implemented using websockets.

3. A client application for iOS that provides a convenient interface for taking photos of the object to be modeled. The application also allows sending photos to the aforementioned backend and creating a 3D model remotely without the computational power of an iOS device.

The design of each program has its own approaches and peculiarities. Overall, modern approaches to software development were used, with modularity and low coupling of software being a priority.

Below is a general life cycle for the applications.

Detailed description of the Object Capture-based application lifecycle and workflow [11]:

1. Planning: The first step in creating an object capture based application is to plan what object or scene to capture. This involves selecting the object or scene and determining how it should be captured. Factors such as lighting, camera angles, and the size and shape of the object may need to be considered.

2. Image Capture: Once capture have planned, the next step is to capture images of the object or scene. Object Capture uses photogrammetry to create 3D models of real-world objects, so user will need to capture images from multiple angles using iPhone or iPad. The ScanAR iOS/ScanAR macOS app will guide user through the image capture process, and let user know when he has captured enough images.

3. Processing: After user have captured the ima-ges, the ScanAR app will process them using computer vision algorithms and machine learning. This process involves generating a depth map for each image and using these depth maps to create a 3D model of the object. The app will also refine the model by removing any unwanted artifacts or imperfections.

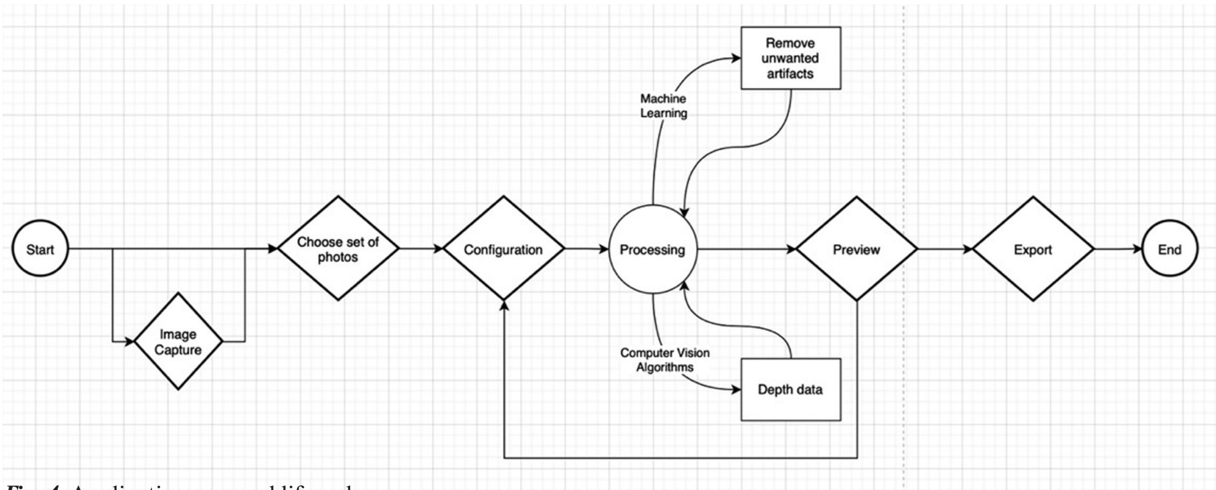

Fig. 4. Applications general lifecycle

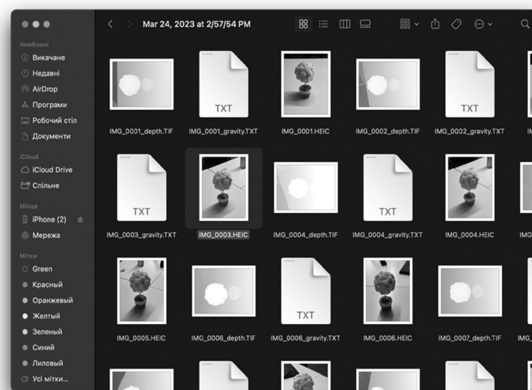

Fig. 5. Set of photos with depth and gravity data

4. Preview: Once the processing is complete, user can preview the 3D model in the ScanAR app. User can rotate and zoom in on the model to see the details and check for any errors. User can also adjust the level of detail and texture mapping to improve the quality of the model.

5. Export: Once user are happy with the 3D model, he can export it in various formats, such as USDZ, OBJ, or STL. These formats can be used in various applications, such as 3D printing, AR/VR experiences, or digital content creation.

6. Integration: The exported 3D model can then be integrated into other application or workflow. For example, user could use the model in an AR app to place the object in a real-world environment or use it in a digital content creation tool to create a scene or animation.

Overall, the object capture based application lifecycle and workflow involves planning, image capture, processing, preview, export, and integration. The ScanAR app simplifies the process of creating accurate and detailed 3D models of real-world objects, making it accessible to anyone with an iPhone or iPad [12].

Creating First 3D Model

To begin the generation process, it is necessary to have a pre-prepared set of photographs of the selected object. If the photos are taken on a device with iOS/iPadOS operating system, there is an additional option to use depth files and/or metadata from the *LiDAR* sensor (if available).

During the generation process, the program will automatically try to find the aforementioned files in the folder and, if possible, use them during the generation process.

After selecting the set of photos and the desired quality for the future model, the user can start the generation process. The generation process is accompanied by the updating of the progress bar in the main window. Additionally, the program outputs the generation process to the console.

If the program does not find depth files and/or metadata from the LiDAR sensor, it will signal each photo without such information.

The user has the optional ability to generate a preview for the future model. The preview is a 3D model without detailing and in low quality, which

Fig. 6. Generated 3D model

allows understanding what the future model will look like. If the preview is generated, the .usdz file is saved in the Temporary Directory of the macOS operating system.

After full generation, the output .usdz file is saved in the directory where the initial files are stored with the name "model.usdz". Also, the model is immediately output to the view (SCNView of the SceneKit framework) for models. The user can rotate, zoom in, zoom out, and fully examine the selected model.

Conclusion

Using the mentioned tools and technologies, software has been developed that enables the creation of 3D models. The feature of the developed system is that it does not require 3D modeling skills from the potential user for correct operation. The user only needs to take photographs of the selected object correctly. Also, a significant advantage of the created system is that it does not require the user's computer to have high computational power. With the help of the iOS client connection (or any other REST API client) and the macOS backend, modeling is performed remotely on the server's power.

During development and testing, various objects were scanned: from a cup to a car. Given the availability of snapshots that correspond to input conditions and quality, the system can generate objects of almost any size. The quality of the input photos has an undeniable impact on the result.

Further research can be developed in several directions simultaneously: increasing the speed of model generation, adding the ability to edit object's geometric frames (Bounding box), improving modeling quality by increasing the system's sensitivity during object creation, and so on.

At this stage, the system is built flexibly and can be applied in any subject area (commercial modeling of goods for stores, modeling sculptures for further preservation in digital form, etc.). An important step for the system will be expanding and deploying it on powerful servers to provide parallel modeling capabilities without loss of productivity.

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СИСТЕМА 3D МОДЕЛЮВАННЯ З ВИКОРИСТАННЯМ ФОТОГРАММЕТРИЧНИХ МЕТОДІВ

Вступ. Створення 3D-моделей історичних, археологічних та інших об'єктів потребує потужних методологій, що можуть точно зафіксувати та відтворити їхні зовнішні деталі. Наші природні, культурні та змішані спадщини постійно зазнають зужиток від воєнних дій, природних катаклізмів, змін клімату та недбалості людей, тому потрібні цифрові записи, документація та збереження. Цифрові дані є важливою складовою для вічного збереження геометрії важливих об'єктів та місць і передачі їх майбутнім поколінням, принаймні у цифровій формі. Також доступність і використання 3*D*-даних відкриває широкий спектр подальших застосувань та уможливлює нові аналізи, дослідження, тлумачення, політики збереження або цифрового відновлення. Нові технології можуть бути потужними інструментами для поліпшення класичних стандартів документації та збереження культурної спадщини.

Мета статті: Оцінити можливості сучасних методів фотограмметрії для створення моделей об’єктів реального світу у цифровому вигляді; описати принципи реалізації системи, її можливості, перспективи тощо.

Методи. Системний підхід, аналітичний метод, експериментальний метод.

Результати. Було створено систему з використанням різноманітних інструментів та технологій для створення 3*D*-моделей. Особливістю цієї системи є те, що вона не вимагає від користувача знань із 3*D*-моделювання для правильної роботи. Достатньо правильно зробити фотографії обраного об'єкта. Крім того, система не вимагає від комп'ютера користувача високої обчислювальної потужності. Моделювання виконується на сервері завдяки з'єднанню клієнта на *iOS* (або будь-якого іншого *REST API*-клієнта) та бекенда на *macOS*. У процесі розробки та тестування було проскановано різні об'єкти: від келиха до автомобіля. Система може створювати об'єкти практично будь-якого розміру за наявності якісних фотографій. Якість вхідних фото має значний вплив на результат.

Висновки. Результати роботи показують, що сучасні засоби (зокрема засоби фотограмметрії) дають змогу створювати системи, що уможливлюють успішне відтворення об’єктів з реального світу у цифровому вигляді. Для подальшого розвитку системи можуть бути розглянуті такі напрямки, як підвищення швидкості генерації моделей, можливість редагування геометричних рамок об'єктів, покращення якості моделювання та розширення можливостей системи. На даному етапі система має гнучку архітектуру й може бути застосована в будь-якій сфері діяльності (комерційне моделювання товарів для магазинів, моделювання скульптур для збереження у цифровій формі тощо). Одним із важливих кроків для системи буде розширення та впровадження її на потужних серверах для забезпечення паралельних можливостей моделювання без втрат продуктивності.

Ключові слова: *3D моделювання, фотограмметрія, Objects Capture.*