Digital Object Identifier

Photogrammetry

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ABSTRACT Photogrammetry is a technique used to obtain precise measurements and three-dimensional information about objects and landscapes through the analysis of photographs. It involves the process of capturing, measuring, and interpreting data from images to create detailed and realistic three-dimensional models.

I. INTRODUCTION

The evolution of photogrammetry is closely linked to advancements in science and technology. There are four main stages in its development, each corresponding to key technological innovations: photography, aircraft, computers, and electronics. The first generation, in the mid-19th century, was characterized by pioneering efforts in terrestrial photography and balloons. The second generation, analog photogrammetry, emerged with the invention of stereophotogrammetry and laid the foundation for aerial survey techniques. The third generation, analytical photogrammetry, began with the introduction of computers in the 1950s, leading to improved accuracy in aerial triangulation. The fourth generation, digital photogrammetry, is now emerging, utilizing digital images instead of aerial photographs. While still in its infancy, digital photogrammetry is advancing rapidly with the availability of specialized microprocessor chips and storage devices. Over the past decade, photogrammetry has been increasingly applied as a precise three-dimensional measurement tool in industrial and engineering projects. Analytical photogrammetry is routinely used in diverse measurement tasks such as machine tool inspection, fixture verification, monitoring structural deformations, providing data for controlling industrial robots, and surveying Earth's surface structures. Traditional photogrammetric techniques and equipment are generally not suitable for industrial work, and the recent development of complete and integrated photogrammetric systems has seen significant progress.

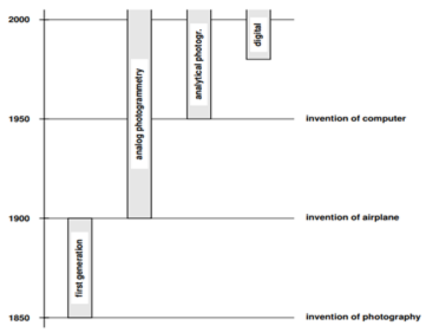


FIGURE 1: Major photogrammetric phase as a result of technological innovations.

II. KEY POINTS ABOUT PHOTOGRAMMETRY

PhotoGrammetry Collection: Photogrammetry begins with a collection of photos from aerial or terrestrial sources. These photos should have sufficient overlap and coverage for accurate reconstruction. Triangulation: The fundamental principle in photogrammetry is triangulation, where the positions of points in three-dimensional space are determined by analyzing the angles formed by lines of sight from multiple camera positions to those points. Bundle Adjustment: This is an optimization process used to refine the parameters of the camera and the 3D points, ensuring a more accurate reconstruction by minimizing errors in triangulation. Digital Elevation Models (DEM): Photogrammetry can be employed to create digital models of elevation, representing the surface height at different points. These models are useful in geospatial applications. Applications: Photogrammetry finds applications in various fields, including cartography, archaeology, surveying, urban planning, and virtual reality. It is widely used in industries such as construction, agriculture, and environmental monitoring. Software and Tools: Specialized software and tools, ranging from commercial solutions to open-source options, are used for processing and analyzing images, performing necessary calculations, and creating three-dimensional models. Advancements: With technological advancements, such as unmanned aerial vehicles (UAVs or drones) and high-resolution cameras, photogrammetry has become more accessible and efficient. It allows for the creation of detailed and accurate three-dimensional models for various applications.

III. HOW THE FINDINGS AFFECT ABOUT PHOTOGRAMMETRY

Flight altitude and distance from the object can alter the final outcome. To explain the relationship between flight altitude or, more generally, the distance between the camera and objects, and the length of the object, let's consider an example. First, let's look at Figure 2: Our goal is to capture the entire house and fill the entire image area. We have several options to achieve this: we can take the picture from a short distance with a wide-angle lens (like Camera Position 1 in the illustration) or from a greater distance using a lens with a smaller angle (like Camera Position 2 in the illustration) or from any external position. The question is, will we get the same result each time? Figure 3 illustrates the differences: As the distance between the camera and the object becomes smaller and the lens angle widens, a deeper image of the object is obtained due to a central perspective point. Conversely, as the distance between the camera and the object becomes greater and the lens angle is smaller, a flatter image of the object is obtained.

:Figure 3

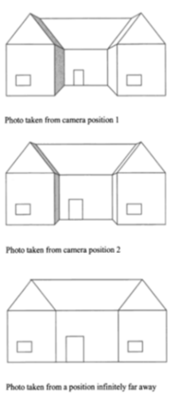


Figure 2:

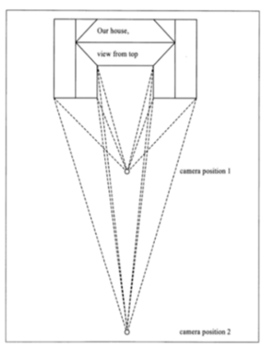


Fig. 2: Different positions and lens angles. The situation, view from above.

IV. TOP PHOTOGRAMMETRY COMPANIES

A. BLACKSHARK.AI

Type: Private Company
Founded: 2020
Location: Austria
Information: Blackshark.ai is the platform creating an authentic 3D map of our planet. Blackshark.ai developed a unique solution that uses the Microsoft Azure Cloud and Artificial Intelligence to gain insights about our planet based on aerial data.

B. MOD TECH LABS

Type: Private Company
Founded: 2020
Location: USA
Information: Create digital content automatically with AI. Our AI-powered photogrammetry tools automatically bring your 3D models to life at scale and in mind-blowing time. Generate meshes, transform point clouds, optimize textures, and so much more.

C. CYBERHAWK

Type: Private Company
Founded: 2008
Location: United Kingdom
Information: Cyberhawk is the world's leading engineering company using Unmanned Aerial Vehicles (UAV or UAS) for aerial inspection and surveying, and a pioneer in the development of innovative visual asset management and maintenance software.

D. CLICK-INS

Type: Private Company
Founded: 2014
Location: Israel
Information: Click-Ins has developed a mobile-first platform that uses behavioral analytics technology to promote more personalized insurance products and to detect potential fraud at the point of sale.

V. RESEARCH PAPERS

ACCURACY OF UNMANNED AERIAL SYSTEMS PHOTOGRAMMETRY AND STRUCTURE FROM MOTION IN SURVEYING AND MAPPING: A REVIEW BY SAYED ISHAQ DELIRY AND UGUR AVDAN

INTRODUCTION

The article highlights a modern method of creating detailed maps using drones, known as Unmanned Aerial Systems (UAS), and a special technique called Structure from Motion (SfM). UAS are drones that fly without a pilot, and SfM is a technique that transforms multiple photographs taken from various angles into three-dimensional models. This method is gaining popularity in surveying and mapping for its cost-effectiveness and efficiency compared to traditional survey methods.

WIDE RANGE OF USES

Drones with SfM technology find use in a variety of fields beyond just map-making. They are instrumental in urban planning, environmental monitoring, historical site studies, geological mapping, and agriculture. The ability of this technology to produce detailed 3D surveys and maps proves invaluable across these diverse applications.

HOW SFM WORKS

SfM is a complex yet efficient method of creating 3D structures from 2D images. Imagine a drone capturing multiple pictures of an area from different angles. SfM processes these images to build a detailed 3D model of the area. The process involves capturing overlapping photographs, detecting distinctive features, matching these features across images, estimating the motion and structure, creating a 3D point cloud, refining it using Multi-View Stereo (MVS), and finally generating a detailed 3D model. This method is increasingly popular due to its affordability and ability to create detailed point clouds, elevation models, and maps. Structure from Motion (SfM) is a fascinating and complex technique that has transformed the way we create detailed 3D models from 2D images. It's a process that marries the principles of photogrammetry (the science of making measurements from photographs) with computer vision.

CAPTURING IMAGES
The first step in SfM is capturing a series of overlapping photographs of the target area or object. In the context of drone surveys, this means that the drone flies over the area and takes many pictures from different angles. Each photo captures the same area from a slightly different perspective, which is crucial for the next steps.

FEATURE DETECTION
Once the images are captured, the SfM algorithm begins by detecting distinctive features in each image. These features are specific points or patterns in the image that can be easily identified and matched across the different photographs. Common features include corners, edges, or unique color patterns.

FEATURE MATCHING AND TRACKING
The next step is one of the most critical parts of SfM—matching these features across multiple images. The algorithm looks for the same feature in different images and tracks how it moves from one image to another. This process is akin to how your eye might follow a particular landmark while moving around it.

ESTIMATING MOTION AND STRUCTURE
Using the movement of these features across images, the SfM algorithm starts to make calculations. It estimates the 3D position of each feature and the position and orientation of the camera when each photo was taken. This is where the "motion" in Structure from Motion comes into play—the algorithm essentially 'figures out' how the camera moved, based on the movement of features in the images.

CREATING A 3D POINT CLOUD
All these calculations lead to the creation of a 3D point cloud. Each point in this cloud represents a feature in the real world, mapped in three-dimensional space. The point cloud is a rough 3D model of the surveyed area, showing its contours, shapes, and different features.

REFINEMENT WITH MULTI-VIEW STEREO (MVS)
To make the 3D model more detailed and realistic, SfM often uses a technique called Multi-View Stereo (MVS). This step refines the point cloud by adding more points, thereby increasing the resolution and detail of the model. The MVS process uses the texture and color information from the photographs to make the model as accurate and lifelike as possible.

FINAL 3D MODEL CREATION
Finally, the point cloud is processed into a full 3D model. This model can be used in various applications like surveying, mapping, 3D printing, or even in virtual reality environments. The final model is a detailed and accurate representation of the original survey area, all created from a series of 2D images.

EVALUATING THE ACCURACY
The article extensively discusses the accuracy of these drone-based mapping methods. It involves comparing drone survey results with traditional ground-based methods like laser scanners and GPS surveys. The results indicate high accuracy in drone mapping, with error margins ranging from a few centimeters to about a meter. The article also delves into potential error sources in drone surveying, highlighting the importance of careful assessment.

STUDY OF DIFFERENT CASES
The authors compiled data from 50 different studies that used drones for mapping to assess their accuracy under various conditions. This synthesis aimed to evaluate the efficacy of drones and SfM in different survey scenarios, highlighting the strengths and limitations of this technology in diverse environments.

PERFORMANCE IN DIFFERENT TERRAINS
The performance of drone mapping with SfM varies based on the terrain being surveyed. This variability signifies the importance of understanding how the technology operates in different environments, aiding in better planning and execution of surveys.

CONCLUSION
In summary, drones combined with the SfM technique represent a significant advancement in surveying and mapping. This innovative approach offers an efficient and cost-effective solution for creating high-quality maps and 3D models. However, its accuracy varies based on several factors, including terrain type. Ongoing research and evaluation are essential to maximize the capabilities and applications of this groundbreaking surveying method.

ABOUT THE AUTHORS
Sayed Ishaq Deliry - received his BSc degree in geodesy & geomatics engineering from Kabul Polytechnic University in 2010, and his MSc degree in remote sensing and GIS from Anadolu University, Turkey, in 2020. He is currently pursuing his PhD at Eskisehir Technical University, where he is conducting research in surveying, mapping, and environmental earth sciences, including remote sensing, photogrammetry, structure from motion, unmanned aerial systems, image processing, and machine learning. **Ugur Avdan** - was born in Ankara, Turkey. He received a B.Sc. degree in Geomatic Engineering from the YTU, Istanbul, Turkey, in 2000. He received the M.Sc. and Ph.D. degrees in remote sensing and

GIS from YTU, in 2004 and 2011, respectively. He worked as an Assoc. Prof. from the Institute of Earth and Space Sciences, Eskisehir Technical University, Eskisehir, Turkey. His research interests include remote sensing, photogrammetry, UAVs, digital image processing, and deep learning.

TECHNIQUES, TOOLS, PLATFORMS AND ALGORITHMS IN CLOSE RANGE PHOTOGRAMMETRY IN BUILDING 3D MODEL AND 2D REPRESENTATION OF OBJECTS AND COMPLEX ARCHITECTURES. DICATECH, POLITECNICO DI BARI, VIA E. ORABONA 4, BARI, ITALY, DICATECH, POLITECNICO DI BARI, VIA E. ORABONA 4, BARI, ITALY CORRESPONDING AUTHOR: MASSIMILIANO PEPE.

ABSTRACT
The article discusses a suitable pipeline for building high-resolution 3D models and 2D orthophotos of objects and architectural structures of historical and cultural importance using the photogrammetric method. The paper presents results obtained with an imagery acquisition tool mounted on a drone, specifically developed to acquire images, for example, of the base of high bridges that cannot be achieved through terrestrial surveys.

INTRODUCTION
The introduction explores the use of Close Range Photogrammetry and UAVs in Cultural Heritage digital documentation, termed "UAV photogrammetry," employing Structure from Motion (SfM)/Multi-View Stereo (MVS) for 3D reconstructions. The selection of UAV platforms considers specific application needs and drone characteristics, leading to the development of sensors and algorithms to address challenges in building 3D models, especially with shiny or transparent objects. The study proposes a Lisp script for intuitive orthophoto generation on complex surfaces and evaluates 3D reconstruction performance with low-cost cameras.

ARTICLE STRUCTURE
The article is divided into two main parts. First, it provides a brief summary of the photogrammetric pipeline used for obtaining 3D models and orthophotos. The second part introduces a fast procedure developed to determine planes for orthophoto generation, tested on various case studies. These studies include 3D reconstruction of a small object using a smartphone camera, survey and modeling of an architectural element with a compact camera and an extensible pole for detailed reconstruction, and UAV photogrammetry for a Roman masonry bridge survey. The paper concludes with a summary of findings and insights.

PHOTOGRAMMETRIC PIPELINE
Agisoft Metashape is the software used for 3D data processing in the presented case studies. The process involves several key steps:

- **SfM (Structure from Motion) Image Alignment:** Detects and matches key-points on overlapping images to estimate external camera parameters. Object separation from the background using masks is recommended to reduce computational effort and matching errors. Options for accuracy settings (High, Medium, Low, Lowest) and limits for feature and matching points can be adjusted.
- **MVS (Multi-View Stereo) Building Dense Cloud:** Utilizes a dense image matching algorithm to generate a point cloud. Cardinality of the final point cloud depends on settings such as image downsizing (Ultra high, High, Medium, Low, Lowest).
- **Building Mesh:** Obtains textured triangulated meshes from the dense point cloud. Interpolation mode options (Enabled/Disabled) affect the reconstruction results, with manual hole filling often needed in the latter case.
- **Building Orthomosaic:** Textures the entire object surface in an orthographic projection. Enables orthomosaic seam-line editing for improved visual results. The software provides flexibility in adjusting settings such as accuracy, downsizing, and interpolation to tailor the 3D reconstruction process to specific requirements.

SFM APPROACH

$$\begin{bmatrix} x - x_P + \Delta x \\ y - y_P + \Delta y \\ -c \end{bmatrix} = \lambda R \begin{bmatrix} X - X_C \\ Y - Y_C \\ Z - Z_C \end{bmatrix}$$

Object point coordinates: X, Y, Z
Perspective centre: X_C, Y_C, Z_C
Principal point offsets: x_P, y_P
Image coordinates perturbation: $\Delta x, \Delta y$
Rotation matrix: R
Image space coordinates: x, y
Focal length (or principal distance): c
Scale factor for the image radius: λ

The additional parameters Δx,Δy can be calculated by the following equations:

$$\Delta x = -\Delta x_0 + \frac{\Delta c}{c}\bar{x} + \bar{x}SX + \bar{y}A + \left(k_1 r^2 + k_2 r^4 + k_3 r^6\right)\bar{x} + p_1$$
$$\Delta y = -\Delta y_0 + \frac{\Delta c}{c}\bar{y} + \bar{y}A + \bar{x}SX + \left(k_1 r^2 + k_2 r^4 + k_3 r^6\right)\bar{y} + 2p_1$$

The analytical process of rotating points in a three-dimensional space from one coordinate system to another. It introduces a rotation matrix denoted as R, consisting of nine parameters derived from three non-linear variables. The matrix ensures that each row and column are unitary and orthonormal, forming an orthonormal basis.

The transformed coordinates (X, Y, Z) are obtained through cosines of angles between the coordinate axes. The passage also mentions the application of this process in 3D photogrammetry, specifically in Agisoft Metashape software, for generating orthophotos and CAD representations by exporting and importing Ground Control Points (GCPs) in a specific file format. This approach can be adapted to other 3D photogrammetric software with the consideration of their ability to handle GCPs in a compatible format.

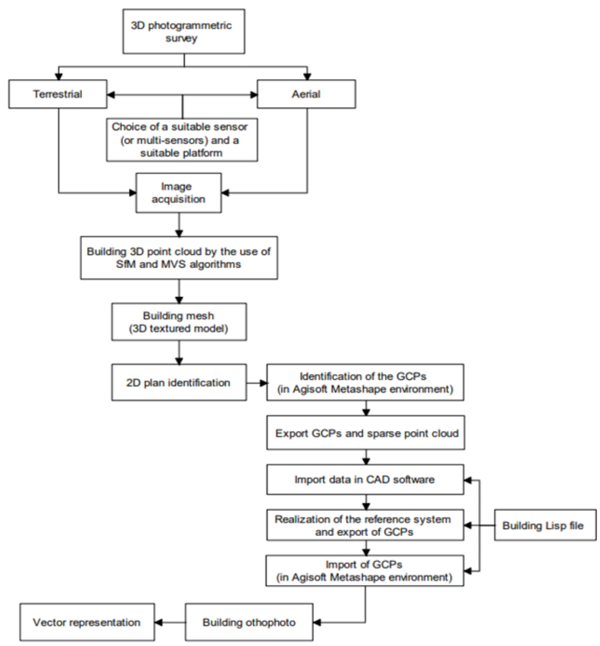


Figure 2: Pipeline to obtain 3D model and 2D orthophoto-Vector representation.

UAV PHOTOGRAMMETRY IN BUILDING 3D MODEL OF A MASONRY BRIDGE

The paper addresses limitations in traditional UAV camera angles (0° to 90°), preventing observation of objects higher than the UAV. It proposes a low-cost system with a specially chosen light camera for zenith-oriented photos. The system is designed to minimize weight impact on UAV performance, allow remote control, and ensure sharp image capture despite potential drone movements. The hardware includes shock mounts for stability. The goal is to provide a cost-effective solution for capturing detailed images of structures from below, overcoming traditional method limitations.

Figure 8: Architecture of the system: design (a) and realization (b).

The study involves experimentation with the GoPro Hero3 Silver camera, chosen for its lightness and features such as a wide-angle sensor and the ability to capture high-resolution images. The wide-angle sensor introduces distortions in the image, impacting photogrammetric accuracy. To mitigate this, tests were conducted, considering pre-calibration and pre-correction of lenses in different scenarios. A 3D test field with coded targets was used to evaluate the Level of Accuracy (LoA) using the Structure-from-Motion/Multi-View Stereo (SFM/MVS) approach. The 3D test field consisted of 20 circular coded targets at varying heights from the ground. Four scenarios were assessed: self-calibration, self-calibration with radial distortion correction, pre-calibration, and pre-calibration with radial distortion correction using Adobe Photoshop software. The study aimed to determine the impact of these scenarios on accuracy, emphasizing the importance of addressing distortions in photogrammetric processes. The radial distortion of the GoPro Hero3 Silver lens was analyzed using Agisoft Lens software, revealing barrel distortion characteristics.

	DATASET	*Total Error (m)*	*Total Error (pixel)*	*Matching time*	*Alignment time*
1	Self-calibration	0.0009	2.796	11m 11s	3m 14s
2	Self-calibration with lens correction	0.0008	2.613	13m 14s	1m 53s
3	Pre-calibrated	0.0009	2.583	13m 21s	1m 32s
4	Pre-calibrated with lens correction	0.0007	1.163	12m 13s	1m 29s

Table 4: Time and accuracy achievable in the different scenarios.

As shown in Table 4, the images corrected by radial distortions and using the calibration values obtained through the procedure described in the scenario n.4 showed a higher level of accuracy than the other scenarios and, at the same time, tight alignment times.

THE MASONRY BRIDGE USED FOR A UAV PHOTOGRAMMETRY

The test is located in southern Italy, specifically in the Platano river, with approximate coordinates of 40.643978, 15.483073. Known as Annibale's bridge, it is kept in fairly good condition but has undergone interventions over time. The bridge has a donkey-back profile with two arches, one larger (12.65 m) and one smaller (4.60 m). Its total length is approximately 30 m with a width of 3.40 m. The survey was conducted using a Xiaomi Mi Drone 4K, a rotary-wing UAV with a digital camera capable of capturing images at 8.2Mpixel resolution with a pixel size of 4.54 m. The mission planning involved nadir-oblique and zenith directions, utilizing the Mission Planner software. Flight lines along the longitudinal direction of the bridge were created, incorporating variations in tilt angle to cover the entire structure based on the survey technique principles using the Structure from Motion (SfM) approach. For the upper part of the bridge, zenithal photos were taken in manual mode, adjusting flight heights to achieve approximately the same Ground Sample Distance (GSD). This approach involved planning flight lines to survey the intrados of the masonry bridge.

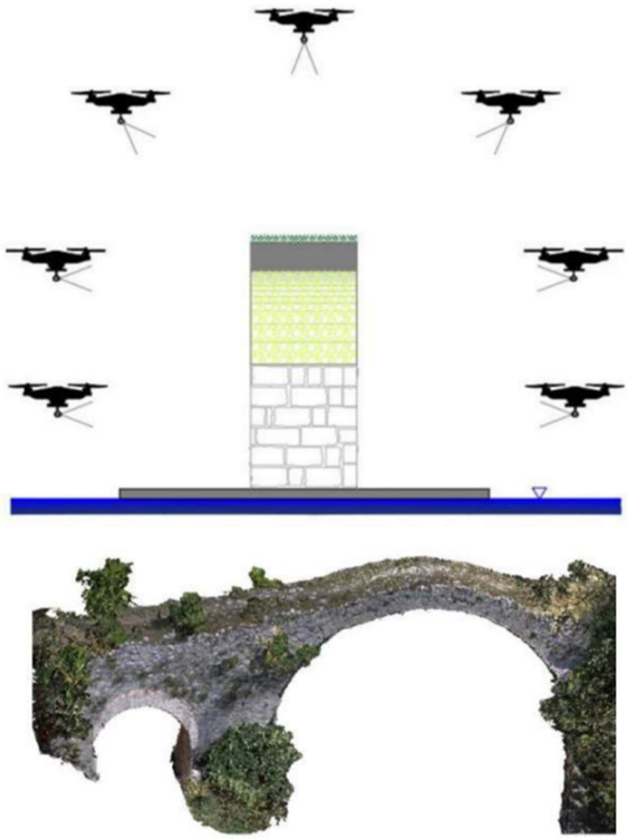


Figure 12: 3D model of the Roman masonry bridge.

The survey resulted in the acquisition of 132 photos in NADIR mode, 93 photos in zenith mode, and 114 photos in manual zenith mode for the extrados. The Structure from Motion/Multi-View Stereo (SfM/MVS) process was applied to orient the images, optimize the alignment, and construct a dense cloud with 17,028,009 points. The 3D model was created using 3DF Zephyr software, and the dense cloud was filtered to eliminate isolated points while retaining the necessary data for subsequent operations. The 3D mesh was generated from the dense cloud, resulting in 2,514,078 triangles.

CONCLUSIONS

The presented study demonstrates the successful integration of UAV photogrammetry with Structure from Motion/Multi-View Stereo (SfM/MVS) techniques for accurate 3D model generation and orthophoto production of historical and cultural structures. By addressing limitations in traditional UAV photogrammetry, such as capturing zenith-oriented images and mitigating lens distortions, the proposed approach enhances the quality and accuracy of 3D reconstructions. The use of low-cost cameras, innovative mounting systems, and precise calibration techniques further contribute to the effectiveness of the method. In particular, the development of a fast and intuitive procedure for determining orthophoto planes and its successful application in various case studies highlights the potential for widespread adoption of this approach in cultural heritage documentation. The ability to create detailed and accurate 3D models and orthophotos provides valuable tools for preservation, analysis, and dissemination of historical and cultural assets. Future work will focus on further refining the methodology, exploring the use of advanced sensors and imaging techniques, and expanding the application of UAV photogrammetry to a broader range of structures and environments. By continuing to innovate and improve upon existing techniques, this research aims to contribute to the ongoing efforts in preserving and documenting cultural heritage for future generations.

DEVELOPMENT AND STATUS OF IMAGE MATCHING IN PHOTOGRAMMETRY

CONTEXT OF PHOTOGRAMMETRY AND IMAGE MATCHING

Image and template matching are critical in digital photogrammetry, with a significant impact on automated modeling and mapping. The field has evolved over 50 years, yet many challenges remain unsolved.

IMPORTANCE IN VARIOUS DOMAINS

Image matching is essential in numerous applications, such as navigation, surveillance, robot vision, medical image analysis, and mapping sciences. Despite extensive research, there's still a gap between the quality of automated approaches and human capabilities.

EARLY YEARS (1950S - 1970S)

INITIAL DEVELOPMENTS

Began as an analogue process using electrical circuits. Dominated by equipment manufacturers, with systems like Gestalt Photomapper and GPM I & II.

DIGITAL EVOLUTION

Shifted to digital processing in the 1970s. Notable developments included auto- and cross-correlation based on linear system theory.

CHALLENGES AND LIMITATIONS

Early digital efforts showed optimism but faced significant challenges. Cross-correlation techniques had limitations like geometrical distortions and radiometric issues.

NEW APPROACHES (1980S)

SHIFT TO MORE SOPHISTICATED METHODS

A shift from cross-correlation to more complex techniques like derivative matching, relaxation methods, and edge-based analysis. Epipolar line matching emerged as a critical concept.

LEAST SQUARES MATCHING (LSM)

Developed in the early 1980s, LSM brought flexibility and accuracy. It combined area-based and edge-based matching, offering a statistical estimation model.

COMMERCIAL INTEGRATION

Integration of these techniques into photogrammetric equipment like analytical plotters and digital stations.

TIME OF CONSOLIDATION AND EXTENSIONS (1990S)

ADVANCEMENTS IN LSM

LSM techniques were refined, with improvements in accuracy and reliability. Extensions like multi-image matching and adaptive computation evolved.

COMMERCIAL SYSTEMS AND CHALLENGES

Automated DTM generation became a major function of digital photogrammetric stations. Systems faced issues with texture, occlusions, and shadow areas.

CURRENT STATUS AND FUTURE PROSPECTS

AUTOMATED DTM/DSM GENERATION

Gained significant attention in recent years. Commercial systems available, but challenges with accuracy and quality persist.

ONGOING CHALLENGES

Lack of texture, repetitive patterns, and surface discontinuities remain problematic. Need for more robust algorithms and multi-sensor data integration.

FUTURE DIRECTIONS

Emphasis on improving image matching quality and reliability. Integration of image understanding algorithms and advancements in multi-sensor approaches.

DEVELOPMENT AND STATUS OF IMAGE MATCHING IN PHOTOGRAMMETRY (PART 2)

DETAILED OVERVIEW OF MATCHING TECHNIQUES

INTENSITY-BASED MATCHING

Utilizes the original or enhanced image data in a matrix of grey values. Predominant methods include cross-correlation and least squares matching (LSM), capable of sub-pixel accuracy.

FEATURE-BASED MATCHING

Involves extraction of basic image features like corners, edges, and then matching between these features. Methods include relaxation, dynamic programming, and cross-correlation. It's somewhat stable but loses information during feature extraction.

RELATIONAL MATCHING

Employs geometric or other relations between features and structures. Not very accurate, but robust and doesn't require good approximations.

CHRONOLOGICAL REVIEW OF IMAGE MATCHING DEVELOPMENT

EARLY YEARS (1960S - 1970S)

Focus on analog procedures and initial digital correlation efforts. Systems like Gestalt Photomapper showcased early optimism but faced limitations.

NEW APPROACHES (1980S)

Introduction of more sophisticated techniques and the pivotal LSM. Shift from area-based to edge-based analysis, with LSM being a significant contribution.

TIME OF CONSOLIDATION AND EXTENSIONS (1990S)

Refinement and extension of LSM techniques. Integration into commercial systems, with a focus on DSM and DTM generation.

TIME OF ACCEPTANCE (2000S TO PRESENT)

Automated DTM/DSM generation gained prominence. Persistent challenges with accuracy and quality in commercial systems.

APPLICATIONS IN VARIOUS FIELDS

LSM and other image matching techniques have found applications in numerous domains, including industrial quality control, mapping, and surveillance. The need for integration with other technologies and multi-sensor data is emphasized for future advancements.

CHALLENGES AND LIMITATIONS

One of the main challenges in photogrammetry and image matching is the gap between automated methods and human-level quality. Issues like texture, occlusions, and repetitive patterns are significant obstacles. The complexity and diverse requirements of photogrammetric applications add to the challenge.

FUTURE PROSPECTS

The field is moving towards integrating more advanced image understanding algorithms. There is a strong emphasis on improving the quality and reliability of image matching techniques. Future developments may include more powerful multi-sensor approaches and further advancements in LSM and other methodologies.

CONCLUSION

This summary provides a comprehensive overview of the document, focusing on the key aspects of photogrammetry and image matching. The summary has been structured to cover historical developments, techniques, applications, challenges, and future prospects in the field.

INTRODUCTION TO OUR PROJECT

This project focuses on the integration of various open-source tools to streamline the photogrammetric pipeline, optimize image processing, and enhance 3D reconstruction. Our approach leverages the strengths of BoofCV, CloudCompare, and COLMAP to achieve high-quality results efficiently.

OPEN SOURCE

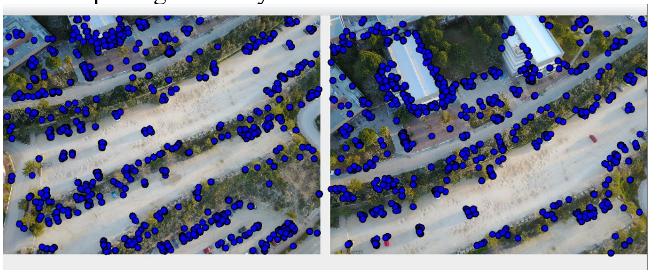
BoofCV by java is excellent for image processing and feature extraction within the photogrammetric pipeline, thanks to its robust algorithms and ease of integration. CloudCompare shines in processing, analyzing, and visualizing 3D point clouds and meshes, making it ideal for post-processing and analysis of photogrammetric data. COLMAP by c++ stands out as a powerful tool for structure-from-motion and multi-view stereo reconstruction, which we use to achieve higher quality 3D models from images.

OPTIMIZED IMAGES

The code processes the video by first importing it and then analyzing each frame sequentially. It starts by capturing the initial frame and placing it into an array. It then proceeds to the next frame, jumping at regular intervals to balance efficiency and coverage. Direct frame-by-frame comparison isn't effective due to potential overlap issues.

For each frame, the code compares it with all frames in the array to evaluate the degree of overlap. If the overlap percentage is below a defined threshold, the frame is added to the collection. Conversely, if any frame has an overlap exceeding the threshold, it is excluded to minimize redundancy.

To assess overlap, the code utilizes the SSIM (Structural Similarity Index) library. Once the video has been fully processed, the algorithm completes its run. The number of resulting images is not fixed, as it varies depending on the video's length. For instance, a one-minute video will yield a different number of images compared to a fifteen-minute video, with the code determining the optimal number of frames for photogrammetry.



STITCHING TWO CLOUD POINTS

Initially, we attempted to merge the two point clouds using the CloudCompare tool-CLOUDCOMPARE is an open-source software for visualizing, editing, and comparing 3D point clouds and meshes. It supports various formats and provides tools for detailed analysis and manipulation of 3D data. However, we encountered an issue where the point clouds could not be aligned along the same Y-axis and scale. After consulting with our mentors, we implemented the ICP (Iterative Closest Point) algorithm by adding a specific flag. This adjustment allowed us to correct the alignment problem and successfully merge the point clouds.

BENEFITS OF USING A COMMAND-LINE PROJECT FOR PHOTOGRAMMETRY

Using a command-line (cmd) project for photogrammetry is beneficial due to its flexibility, efficiency, and automation capabilities. It allows for easy scripting and customization of workflows, which is essential for handling large datasets and repetitive tasks. Cmd projects are resource-efficient, integrate well with other tools, and excel in batch processing. They offer direct user control, making them ideal for precise and repeatable photogrammetric operations. Overall, cmd projects provide a powerful and streamlined approach to managing photogrammetric data.

COMMAND-LINE OPTIONS

FIGURE 2: The CMD of the project

-h or –help: Displays help information.
-t or –tutorial:Displays a tutorial.
create:Prompts for a folder path and creates a photogrammetry proj
-func:Executes the example_function.
-mergecloud:Prompts for two cloud paths and merges them.
-framesfromvideo:Prompts for a video path and extracts frames bas
-examplesvideo:Opens a URL to example videos.
-cloudview:Opens the CloudCompare software.
-research: Opens a research PDF file.

RESULTS

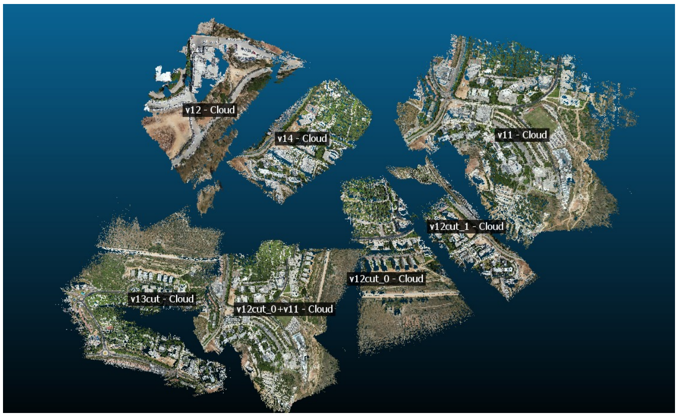


FIGURE 3: The clouds results for each video after we've done -framesfromvideo and -create

FIGURE 4: Final cloud after do -mergecloud

In our project's results, we addressed the challenge of make point clouds from each video. Initially, we organized the videos and isolated the segments where the drone changed altitudes, which affected the quality of the model. We utilized our CMD tool to automatically merge most of the clouds. However, there were instances where the overlap between clouds was insufficient, requiring manual intervention to achieve a more accurate result. As a final outcome, we successfully mapped the entire university area optimally and demonstrated an effective and efficient use of our system for generating photogrammetric point clouds.

VI. DISCUSION

This project demonstrated the successful integration of various open-source tools to streamline the photogrammetric pipeline, optimize image processing, and enhance 3D reconstruction. By leveraging the strengths of BoofCV, CloudCompare, and COLMAP, we achieved high-quality results efficiently. BoofCV was particularly effective for image processing and feature extraction, CloudCompare excelled in processing and analyzing 3D point clouds, and COLMAP provided robust structure-from-motion and multi-view stereo reconstruction capabilities.

One key aspect of our approach was the optimization of image selection from video frames. The use of the Structural Similarity Index (SSIM) library allowed us to assess the overlap between frames and minimize redundancy, ensuring that only unique and relevant images were included in the photogrammetric process. This method balanced efficiency and coverage, significantly reducing the computational load without compromising the quality of the resulting 3D models.

The process of merging point clouds using CloudCompare and the Iterative Closest Point (ICP) algorithm proved to be effective in aligning and scaling the point clouds accurately. This step was crucial for creating coherent and detailed 3D models, especially when dealing with large datasets and complex structures.

Our findings highlight the benefits of using command-line projects for photogrammetry, including flexibility, efficiency, and automation capabilities. The ability to script and customize workflows allowed us to handle large datasets and repetitive tasks effectively, making the entire photogrammetric process more streamlined and manageable.

FUTURE WORK

Future work will focus on further refining the methodology and exploring the use of advanced sensors and imaging techniques. Specifically, we aim to:

1) **Improve Image Matching Quality and Reliability:** Enhance the quality and reliability of image matching techniques by integrating more advanced image understanding algorithms. This will address ongoing challenges such as texture, occlusions, and repetitive patterns, which currently limit the accuracy and quality of automated methods.
2) **Multi-Sensor Approaches:** Investigate the integration of multi-sensor data to provide more robust and comprehensive photogrammetric solutions. Combining data from different sensors can help overcome the limitations of individual systems and improve the overall accuracy of 3D reconstructions.
3) **Advanced Sensors and Imaging Techniques:** Explore the use of cutting-edge sensors and imaging technologies to capture higher-quality data. This includes experimenting with innovative camera systems, improved calibration techniques, and novel imaging methods that can enhance the precision and detail of the photogrammetric outputs.
4) **Broader Applications:** Expand the application of UAV photogrammetry to a wider range of structures and environments. By adapting our methods to different types of cultural heritage sites and other complex environments, we can demonstrate the versatility and effectiveness of our approach in various contexts.

5) **Automation and User Interface:** Develop more user-friendly interfaces and automation features to make the photogrammetric tools accessible to a broader audience. This includes creating intuitive software solutions that can be easily operated by non-experts, thereby facilitating the adoption of photogrammetric techniques in diverse fields.

By addressing these areas, we aim to contribute to the ongoing efforts in preserving and documenting cultural heritage, enhancing the capabilities of photogrammetric systems, and pushing the boundaries of what can be achieved with modern image processing and 3D reconstruction technologies.

VII. BIOGRAPHY

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