# Literature Review on Photogrammetry

Gal Hillel, Noor Agha, Marwan Hreish

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**Abstract**

This comprehensive literature review explores the multifaceted world of Photogrammetry, delving into academic research, paid tools, and open-source technologies in the field. It highlights key studies and innovations in UAV photogrammetry, accuracy of UAV and SfM surveys, and the application in heritage recording and 3D modeling. The review also scrutinizes various commercial and open-source photogrammetry tools, assessing their features, capabilities, and applications. By integrating theoretical insights with practical tool assessments, this review offers a holistic view of the current landscape of Photogrammetry, illuminating its advancements, applications, and potential for future development in various industries.

# 1 Introduction

The science and technology of providing reliable information about the environment and environment through the process of capturing, measuring and interpreting images Photometry has been a hot topic had been intensively studied for decades

This literature review aims to provide a comprehensive overview of advances in imaging, focusing on three main areas: academic research, paid tools, and open source software

The importance of Photogrammetry in various industries cannot be overstated. assist in archaeological reconstruction of ancient sites; Architecture helps preserve and restore historic buildings; and plays an important role in soil research and management in the environmental sciences. Rapidly advancing technologies, especially in image processing and 3D modeling, have further enhanced the versatility of the camera.

Engaging with scholarly discourse, this review will examine the theoretical foundations and methodological developments in the field. Furthermore, it will explore the power limitations of free and open source photogrammetric tools, providing insights into their practical applications and accessibility Through this three-pronged approach, the study aims to not only be a breakthrough in the field but also to identify current knowledge and technological gaps, therefore Providing a roadmap for future research and development in image measurement.

# 2 Research Papers on Photogrammetry

## 2.1 UAV Photogrammetry and Ground Surveys as a Mapping Tool for Quickly Monitoring Shoreline and Beach Changes

Entitled "UAV photogrammetry and ground surveys as mapping tools for monitoring shorelines and rapid shoreline change," the research article launches a comprehensive study to assess the impact of natural phenomena and human-induced activities on coastal morphology so Unmanned aerial vehicle (UAV) survey , Global Navigation Satellite System (GNSS) techniques are also used These state-of-the-art tools support comprehensive three-dimensional modeling that provides important insights into coastal and coastal changes development The broader significance of this research extends beyond academic interests He plays an important role in practical applications such as planning efficient maintenance works, filling sand, designing and operating industrial buildings These are important measures to reduce the impact of coastal erosion, a phenomenon that poses significant challenges to coastal management and preservation.

The experimental part of the study was strategically conducted on the northern Adriatic coast near Ravenna, Italy. This site was chosen because it is representative of broader challenges in coastal areas. The method involved a series of carefully planned steps to ensure proper data collection. Initially, three UAV surveys were conducted using drones equipped with ground control points (GCPs). These surveys were crucial to capturing aerial photographs and the geography of the coastline. This was followed by a Post Processed Kinematic (PPK) analysis. This study is important in providing an accurate three-dimensional model of the study areas, which provides a detailed picture of the coastal landscape In addition to this study, the study incorporated a multi-temporal sampling method. It used data sources including lidar data, field mapping and orthophotos. Such diverse data enabled the study to take a multidimensional approach to shoreline change over time. A key aspect of the study was the digitization of coastal areas. This process allowed researchers to closely monitor and confirm historical coastal changes, providing a clearer picture of how these areas evolved and changed over time.

The findings of the study are revealing and surprising. The findings clearly indicate that the combined use of UAV and GNSS techniques is exceptionally effective in conducting comprehensive coastal monitoring surveys. These technologies offer a unique blend of accuracy, efficiency and cost effectiveness, making them valuable tools in coastal monitoring and research The implications of these findings are far-reaching. By providing detailed and reliable data, these techniques enhance our understanding of coastal erosion and coastal development, two important components of coastal management This understanding is essential greater in order to develop effective strategies to manage and protect coastal areas. Additionally, the study highlights the potential of UAV and GNSS technologies to transform the way coastal areas are managed and conservation efforts are undertaken. By using this advanced technology, researchers and policymakers can gain unprecedented insight into the complex dynamics of the coastal environment, allowing them to make informed decisions and the more efficient management system has been implemented.

### 2.2 Accuracy of Unmanned Aerial Vehicle (UAV) and SfM Photogrammetry Survey as a Function of the Number and Location of Ground Control Points Used

The article from MDPI titled "Accuracy of Unmanned Aerial Vehicle (UAV) and SfM Photogrammetry Surveys as a Function of Number and Location of Ground Control Points Used" examines the complex aspects of georeferenced digital surface model (DTM) imagery derived from micro-UAVs . This analysis is important to understand the geometric accuracy of this model, with many factors such as flight configuration, camera quality, camera calibration, SfM (Structure from Motion) algorithm, ground reference system, and what etc. affect Ground control points (GCPs) on the ground reference stage. The central role of numbers and place is the focus of the paper.

The review begins by highlighting advances in UAV technology and photography that have changed the way we capture the Earth's surface but show that the accuracy of these images is often not fully appreciated. The UAV survey accuracy is affected by a myriad of factors such as flight configuration, camera type, SfM algorithm, ground reference system etc. The paper emphasizes the importance of proper ground reference, a the original arbitrary datum of 3D surface model is transformed into a default coordinate reference system by incorrect ground reference, with Images applying assumptions to visible points.

The study employed a challenging case study involving an area of over 1200 hectares, utilizing more than 100 GCPs and over 2500 photos. A total of 3465 different combinations of control points were introduced in the bundle adjustment. The accuracy of the model was then evaluated using both control points and independent check points. This comprehensive approach allowed for a detailed analysis of how the accuracy improves with the increase in the number of GCP points, the importance of their even distribution, and the relationship between the ground sample distance (GSD) of a project and the maximum achievable accuracy.

The findings of the study are significant. They demonstrate that the accuracy of georeferenced DTMs significantly improves as the number of GCPs increases. Furthermore, the study reveals the importance of an even distribution of GCPs and highlights how

the accuracy is often overestimated when it is quantified only using control points rather than independent check points. This overestimation underscores the necessity of using check points for a more objective quantification of true accuracy in geo-referencing procedures. The research also delves into how the ground sample distance (GSD) of a project relates to the maximum accuracy that can be achieved, providing valuable insights into the limitations and potential of UAV photogrammetry surveys.

### 2.3 Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning

The article titled "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning" from MDPI focuses on the significance of landscape and heritage recording and documentation using optical remote sensing sensors. It reviews the current optical 3D measurement sensors and 3D modeling techniques, discussing their limitations, potentialities, requirements, and specifications. The paper also presents examples of 3D surveying and modeling of heritage sites and objects.

The introduction emphasizes the need for powerful methodologies to capture and digitally model fine geometric and appearance details of heritage and archaeological sites. The digital recording, documentation, and preservation of heritage sites are crucial due to ongoing attritions such as wars, natural disasters, climate changes, and human negligence. The paper highlights the advancements in range sensors and imaging devices that have benefited the recording and preservation of built environment and natural heritage. It also discusses the wide range of applications for 3D data in heritage conservation, including historical documentation, digital preservation, virtual reality, and multimedia museum exhibitions.

The article details the use of various optical sensors and platforms for reality-based recording modeling of large areas and complex objects. It divides optical recording sensors into passive and active systems and explains how passive sensors such as digital cameras infer 3D information from 2D image measurements, while active sensors such as laser scanners provide direct 3D data In the paper The integration of these methods with classical survey techniques is also discussed with the challenges of selecting an appropriate product due to lack of standardized terminology and performance standards. It emphasizes the importance of international collaboration and information sharing to enable digitization of heritage sites.

The study concludes that the continuous development of new sensors and data acquisition techniques is particularly helpful in preserving digital 3D documents, maps and heritage sites. However, it notes that the systematic and targeted application of 3D surveys and models to cultural heritage has not yet developed the format. The paper explores the frequent use of 3D virtual assets due to the benefits offered by remote sensing technologies and third parties and highlights the importance of improving communication between landscape professionals and asset communities and re-adapting in the new recording technology to make it more efficient and useful asset records and documentation.

## 3 Paid Tools Related to Photogrammetry

### 3.1 Agisoft Metashape

Agisoft Metashape, previously named Agisoft Photoscan, is a stand-alone software. This software offers many interesting features like photogrammetric triangulation, point cloud data, measurements for distances, volumes and areas, 3D model generation and textures, for example. Agisoft Metashape appears to be a complete software, useful for various applications such as cultural heritage documentation or visual effects production.

### 3.2 Autodesk ReCap Pro

ReCap Pro is a paid photogrammetry programme developed by American multinational software company Autodesk. The software aids designers and engineers in capturing detailed, high-quality models of actual assets. A designer can produce precise 3D models from photographs using this software.

The software can process laser scans and photographs to generate accurate intelligent models that can be used in a variety of architecture, engineering, and construction (AEC) applications. It can also generate geo-located textured meshes, point clouds, and ortho-photos of existing conditions using data captured by a drone or UAV. It is suitable for both close-range and aerial photogrammetry.

Autodesk ReCap is praised for its advanced editing capabilities, fly features for UAV/drone photos, and superior analytical and teamwork tools.

### 3.3 ContextCapture

ContextCapture is a paid photogrammetry software developed by Bentley Systems subsidiary Acute3D. The software's goal is to eliminate the need for human intervention when creating a 3D model from photographs. ContextCapture is so accurate that it simplifies 3D model reconstruction over 3D scanning. In most cases, no post-processing is required for 3D models. The ContextCapture Editor in this software allows users to edit 3D meshes, generate cross-sections, and extract ground and break-lines.

### 3.4 Pix4Dmapper

Pix4Dmapper is a niche and one of the most popular paid software for drone-based mapping. Because of its advanced digital reconstruction technology, this professional software solution efficiently converts photographs into 2D maps and 3D models.

Pix4Dmapper boasts comprehensive analytical tools with numerous applications in a variety of fields such as agriculture, crop zoning, precise maps, surveying, and so on. It provides a full end-to-end solution package and is suitable for both close-range and aerial photogrammetry.

### 3.5 Reality Capture

Reality Capture is a paid photogrammetry solution developed by Capturing Reality that is user friendly, easy to use, and has a plethora of useful features. According to the company, the software is ten times faster than existing photogrammetry software. It provides high-quality captures, the ability to calculate mesh and textures, and the ability to work with multiple file formats.

The 3D model can be created using both photographs and laser scans. This allows the software to be used for both close-range and aerial projects. It's safe to call it a full-fledged software solution.

### 3.6 3Dsurvey

3Dsurvey is a photogrammetry software solution used for land surveying by professionals. The various tools enables users to digitally recreate any environment using any input, data, or imagery, including aerial, terrestrial, mobile photos, laser scanners, LIDAR, sonar, and more.

Whether it's a brownfield site, a new building, a quarry, a mine, or a natural disaster, this all-in-one photogrammetry tool provides users with everything they need to know about a site. This information is presented to users in the form of digital maps, 3D models, and interactive measurements that can be easily explored.

3Dsurvey is a complete digital surveying suite that includes a state-of-the-art photogrammetry processing engine and two free apps to handle all of your data collection, processing, and sharing needs in one place.

3Dsurvey is designed to help you scale success without any specialised training and is easily accessible to everyone, whether you're a beginner or a seasoned pro.

### 3.7 Coorelator3D

SimActive's Correlator3D software is a patented end-to-end photogrammetry solution for the generation of high-quality geospatial data from satellite and aerial imagery, including UAVs. It supports some advance photogrammetry tools such as GCP Extraction, Point Cloud Colorization, Script Mode and Command Line, NDVI Map Creation, 3D Change Detection, Volume Calculation, DEM Inspection, DEM Contour Extraction, Automatic registration of imagery with LiDAR and also supports distributed processing and scripting and API for automatic processing, customized workflows and adding photogrammetric tools to your software platforms. Python is used to create and execute C3D scripts. It also provides trial license as per the user needs. It has a great knowledge base where they share their wide range of webinar recordings, software tutorials, user guides and manual for each process of photogrammetry.

### 3.8 Trimble Inpho

Trimble Inpho is an leading software for Digital Photogrammetry. This software is designed to precisely transform aerial images into consistent and accurate point clouds and surface models, orthophoto mosaics and digitized 3D features using photogrammetry and remote sensing techniques. Full automatic aerial triangulation including complete camera calibration, robust bundle-adjustment and thorough quality assessment for image blocks of an size, overlap or geometry.

## 4 Open Source Tools Related to Photogrammetry

### 4.1 OpenDroneMap

It is known for its community-driven development. It provides a command-line interface and a web-based user interface. It uses Python scripts for automation and provides REST APIs for integration with other software tools. It allows developers to integrate the software into their workflows and build custom applications. It also provides API to access MICMAC, R package to analyze ortho mosaic images. It runs on all platforms using Docker, but can be also installed natively in Windows. Users can import images captured from any camera with any orientation and in any format with or without EXIFs. It can also process multispectral images. Users can also rebrand the Web based solution with their own logo and theme. User can scale the solution by running multiple jobs in parallel and single jobs distributed on multiple machines. Export in high resolution GeoTIFF, PNG, LAS/LAZ, OBJ and OGC 3D Tiles formats. Also supports to 16+ languages and GPU acceleration with CUDA.

### 4.2 Meshroom

It uses a node-based graphical user interface and supports various camera models and image formats. Meshroom has fully open source nodal workflow so one can create custom pipelines and use it as a default template or can customize some steps without recreating a full pipeline. The software also facilitates integration with other applications like Blender plugin, Maya PhotoGrametryplugin and Houdini plugin. It is available for both Windows and Linux based system.

### 4.3 MicMac

MicMac is a free open-source photogrammetric suite that can be used in a variety of 3D reconstruction scenarios. It has some advanced feature such as multi-view stereo and automatic aerial triangulation. MicMac by default is based on simplified command lines, but for some processes — i.e. image measurements, visualization of the results — a graphical user interface (GUI) is available. Besides this, for multiple commands there exists a GUI that replaces the standard command line. MicMac can also be used as a library, to implement our own algorithms, and share them for the benefit of photogrammetric community. In its documentation there is no example given for the photogrammetric process from the satellite imageries. Hence it might wont support the GeoTIFF or TIFF format.

### 4.4 VisualSFM

It provides a command line interface and a GUI. It uses SIFT (Scale-Invariant Feature Transform), Multicore Bundle Adjustment and other algorithms for feature detection and provides a Python scripting interface for automation. But it has limited functionality for texturing. VisualSFM is only feasible for point cloud generation. It is not completely open source, the GUI is not openly available.

### 4.5 OpenMVG

Photogrammetry library for 3D reconstruction from images/photogrammetry by developing a C++ framework compounded of libraries, binaries, and pipelines and runs on Android, iOS, Linux, macOS, and Windows. It can be used as a standalone software or integrated into other applications. The libraries provide easy access to features like: images manipulation, features description and matching, feature tracking, camera models, multiple-view-geometry, robust-estimation, structure-from-motion algorithms, etc. Its pipelines consist of Python scripts that chain multiple OpenMVG binaries (i.e. Initialization, Image matching and then SfM). Everything they offer is tested, making sure that all the features are 100

### 4.6 Bundler

It is an open-source structure-from-motion (SfM) software written in C and C++. Bundler takes a set of images, image features, and image matches as input, and produces a 3D reconstruction of camera and (sparse) scene geometry as output. Working on Bundler also other application such as ImageMagick installed on you system (for converting jpg files to pgm format, required for David Lowe's SIFT binary) and a feature detector to get the system working.PhotoGrametry

### 4.7 3DF Zephyr

3DF Zephyr is a commercial photogrammetry software by 3DFlow. It also supports Python for automating the workflows. It lets catch on in multiple scenarios, targets and needs by taking advantage of an all-in-one software suite. It allows performing 3D reconstructions automatically by using pictures and video data taken with any sensor and captured using any acquisition techniques and get the most out of aerial and ground photogrammetry by processing videos, spherical pictures, multispectral, LiDAR and thermal + RGB imagery on a single software platform. We can accurately scale and georeferenced your 3D models and calculate distances, volumes and areas. Generate sections, contour lines and track sections. One can also perform CAD drawing directly inside 3DF Zephyr. It has some unique functionalities like Masking, optimized workflow for scanning booths, volume measurements, RTK workflows, and many more. It provides a 30 days free trial license to the user on request. They also provide a free solution with limited capabilities. It also provides plugins to extend its capabilities such as plugin to read native format files from Dot Product (.dp), FARO (.fls,.fws), RIEGL (.rdbx) and Z+F (.zfs) and GEOBIM Revit plugin for 3DF Zephyr Aerial to Revit communication. Leverage many utilities, from 3DF Masquerade and BIM integration to the batch processing and the DEM viewer. FlowEngine SDK completes the whole picture as it allows you to embed their technology into your workflow.

## 5 Comparison of Open Source Photogrammetry Software

### 5.1 OpenDroneMap

**Pros:**

- Community-driven development.
- Command-line and web-based user interfaces.
- Python scripting for automation.
- REST APIs for integration with other software tools.
- Cross-platform compatibility.
- Support for importing images from any camera with any orientation and format.

**Cons:**

- Docker installation may be required on some platforms.
- Limited documentation for photogrammetric processes from satellite imagery.
- Does not use GPU for calculations.

## 5.2 Meshroom

**Pros:**

- Node-based graphical user interface.
- Fully open-source nodal workflow for creating custom pipelines.
- Integration with other applications like Blender, Maya, and Houdini.
- Cross-platform compatibility.
- Open source.
- Completely free.
- Easy to use.
- Supported by an active open-source community.
- Can use GPU for calculations.

**Cons:**

- Limited functionality compared to paid solutions.
- No macOS version.

## 5.3 MicMac

**Pros:**

- Free and open-source photogrammetric suite.
- Advanced features such as multi-view stereo and automatic aerial triangulation.
- Command-line interface with some graphical user interface options.
- Ability to use MicMac as a library for custom algorithms.
- Cross-platform compatibility.
- Active community support.

**Cons:**

- Limited documentation for satellite imagery processes.
- Potential lack of support for GeoTIFF or TIFF formats.
- Steep learning curve for beginners.
- Dependency on external tools.
- High hardware requirements for large datasets.
- Limited integration with other software.

## 5.4 VisualSFM

**Pros:**

- Command-line interface and graphical user interface.
- Utilizes SIFT and Multicore Bundle Adjustment algorithms.
- Python scripting interface for automation.
- 3D generation workflow is quite simple.
- Completely free, no restricted features.
- Well documented.

**Cons:**

- Limited functionality for texturing.
- Not completely open-source.
- GUI not openly available.
- Not a polished UI.
- Requires some knowledge of the command line for greater control.
- Requires additional software to create meshes or clean up the point cloud.

## 5.5 OpenMVG

**Pros:**

- Photogrammetry library for 3D reconstruction.
- Easy access to various features through libraries and pipelines.
- Cross-platform compatibility.
- Integration into other applications.
- Reliable features tested for real situations.

**Cons:**

- No explicit cons mentioned.

## 5.6 Bundler

**Pros:**

- Open-source structure-from-motion (SfM) software.
- Produces 3D reconstructions from image features.
- Cross-platform compatibility.

**Cons:**

- Dependencies on external applications like ImageMagick.
- Limited documentation provided.

### 5.7 3DF Zephyr

**Pros:**

- Commercial photogrammetry software with Python support.
- All-in-one suite for various needs, including CAD drawing and volume measurements.
- Automatic 3D reconstructions with accurate scaling and georeferencing.
- User-friendly interface with extensive support and training materials.
- Supports CAD drawing, polyline extraction, and generation of sections and contour lines.
- Utilizes data from LiDAR, TIs, cameras, videos, and more.

**Cons:**

- Only available on Windows.
- Limited capabilities in the free version.
- Documentation may lack completeness.
- FlowEngine SDK integration may require specialized knowledge.

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## 6 Analysis and Conclusion

In the previous section, we have compared several popular open source photogrammetry software options, including OpenDroneMap, Meshroom, MicMac, VisualSFM, OpenMVG, Bundler, and 3DF Zephyr. Each software has its own set of pros and cons, making them suitable for different types of projects and users.

## 6.1 Analysis

**OpenDroneMap** stands out for its community-driven development, multiple user interfaces, scalability, and support for various image formats. However, it may require Docker installation on some platforms, and its documentation for photogrammetric processes from satellite imagery is limited.

**Meshroom** offers advanced algorithms for accurate reconstruction, a user-friendly graphical interface, flexibility for customization, seamless integration with other applications, strong community support, and cost-effectiveness. These features make it a top choice for many users, despite some potential limitations in texturing functionality.

**MicMac** provides advanced photogrammetric features like multi-view stereo and automatic aerial triangulation, along with a simplified command-line interface. However, it may lack comprehensive documentation for satellite imagery processes and support for certain image formats.

**VisualSFM** offers both command-line and graphical user interfaces, along with scripting capabilities. While it utilizes advanced algorithms like SIFT and Multicore Bundle Adjustment, it may have limitations in texturing and lacks complete open-source availability.

**OpenMVG** serves as a photogrammetry library with easy access to various features and integration into other applications.

**Bundler** is an open-source structure-from-motion software that produces 3D reconstructions from image features, but it requires dependencies on external applications like ImageMagick and may lack comprehensive documentation.

**3DF Zephyr** is a commercial photogrammetry software offering Python support, automatic 3D reconstructions, accurate scaling and georeferencing, CAD drawing capabilities, and a free trial license. However, its free version may have limited capabilities, and its FlowEngine SDK may require specialized knowledge for integration.

In conclusion, Meshroom emerges as a strong contender for the best option among the open-source photogrammetry software. Its combination of accuracy, ease of use, flexibility, interoperability, community support, and cost-effectiveness makes it suitable for various industries and applications.

## 6.2 Conclusion - Why Meshroom Stands Out?

When choosing photogrammetry software, several important factors need to be considered to ensure that the selected tool aligns with project requirements and objectives. Meshroom stands out as a compelling choice due to various reasons:

- **Accuracy and Quality of Results:** Accurate reconstruction of 3D models from images is crucial in photogrammetry. Meshroom utilizes advanced algorithms for feature detection, matching, and reconstruction, leading to high-quality outputs. Its robust processing pipeline ensures reliable results, which is essential for applications such as archaeological reconstruction, heritage preservation, and precision agriculture.

- **Ease of Use:** User-friendliness is a critical factor, especially for beginners or those with limited technical expertise. Meshroom's node-based graphical user interface (GUI) simplifies the creation of photogrammetric workflows. Users can intuitively drag and drop nodes to define processing steps, making it accessible even to individuals with minimal programming knowledge.

- **Flexibility and Customization:** Every project has unique requirements, and flexibility is essential to adapt the photogrammetry software accordingly. Meshroom's fully open-source nature allows users to customize and extend its functionality to suit specific needs. Whether it's modifying existing nodes, integrating external tools, or creating custom processing pipelines, Meshroom offers ample flexibility for tailored solutions.

- **Interoperability:** Seamless integration with other software applications enhances productivity and workflow efficiency. Meshroom supports integration with popular tools such as Blender, Maya, and Houdini, enabling users to leverage their existing workflows and pipelines. This interoperability streamlines data exchange and collaboration across different platforms.

- **Community Support and Documentation:** A strong user community and comprehensive documentation are invaluable resources for learning, troubleshooting, and sharing knowledge. Meshroom benefits from an active community of users and developers who contribute tutorials, forums, and resources. This support network fosters collaboration, accelerates learning curves, and provides assistance in resolving issues or challenges encountered during projects.

- **Cost:** While commercial photogrammetry software often comes with hefty price tags, open-source solutions like Meshroom offer cost-effective alternatives without sacrificing quality or functionality. This affordability makes photogrammetry accessible to a broader audience, including academic researchers, students, hobbyists, and small businesses.

In summary, Meshroom stands out as an excellent choice for photogrammetry projects due to its accuracy, ease of use, flexibility, interoperability, community support, and cost-effectiveness. By prioritizing these essential factors, Meshroom addresses the diverse needs of users across various industries and applications, making it a versatile and reliable solution for 3D reconstruction from images.

# 7 Tools Developed for Efficient Photogrammetry Processing

In our photogrammetry project, we developed three essential tools that automate the workflow from extracting video frames to producing and merging high-quality point clouds. Each tool is tailored to address specific requirements of the photogrammetric process, optimizing both efficiency and output quality.

## 7.1 Tool 1: `video2Images.py`

This tool is responsible for extracting the best frames from a video, with a focus on minimizing blur and maximizing frame overlap. It uses sharpness and motion calculations to select frames that meet specific photogrammetric criteria.

The script's core functions include:

- `calculate_sharpness`: Uses the Laplacian method to determine frame clarity.
- `estimate_motion`: Leverages optical flow to measure motion between frames.
- `capture_best_frames`: Iterates through frames, captures high-quality frames based on the set thresholds, and saves them to the specified output folder.

## 7.2 Tool 2: `images2PointCloud.py`

Following frame extraction, the `images2PointCloud.py` tool takes the filtered images and creates a 3D point cloud. This tool acts as a bridge between image data and 3D modeling by leveraging Meshroom, a robust open-source photogrammetry software, to reconstruct the scene in three dimensions.

The tool operates Meshroom in batch mode, automating the typically manual process of photogrammetry. During execution, it ensures the input and output folders are correctly set up, checking for any issues with directory paths or permissions. The output folder is then populated with the 3D data generated by Meshroom, including dense point clouds and mesh files that represent the geometry of the scene.

Additionally, the tool manages the interaction with Meshroom's real-time output, displaying logs and error messages directly within the terminal. This setup allows users to monitor the progress and ensures that any processing errors are identified and handled without user intervention, making the workflow both robust and user-friendly.

## 7.3 Tool 3: `combinePointCloud.py`

The final tool, `combinePointCloud.py`, is dedicated to merging two point clouds. This is essential when combining scans from different perspectives or when aligning different sections of a larger scene. The merging process uses CloudCompare, a powerful 3D point cloud processing software, to execute an alignment method known as Iterative Closest Point (ICP).

ICP works by iteratively adjusting the position of one point cloud relative to the other to minimize the distance between them. The tool automates this process, selecting optimal parameters to ensure an accurate and smooth merge. Once the two point clouds are aligned, the tool merges them into a single, cohesive file. It then relocates the output to a specified directory, where the resulting merged point cloud can be easily accessed.

This tool simplifies what is otherwise a complex alignment process by automating the CloudCompare commands, making the ICP alignment accessible without requiring deep technical knowledge. The end result is a unified, high-resolution 3D model that incorporates data from multiple perspectives, providing a more complete representation of the scanned environment.

Each tool plays a unique role in ensuring that the photogrammetry process remains efficient and that the resulting models meet the high standards required for detailed 3D reconstruction. By chaining these tools, we have created a streamlined pipeline from raw video data to accurate 3D point clouds, suitable for diverse applications in photogrammetry.

# 8 Results

This section presents the various point clouds generated and merged throughout the photogrammetry project. Each file represents a stage in the process, starting from the initial individual point clouds to the final comprehensive merged point cloud. The progression of these files demonstrates the effectiveness of the tools developed in this project.

## 8.1 Individual Point Clouds from Video Frames

The initial point clouds were generated from individual videos using the `video2Images.py` and `images2PointCloud.py` tools. These files capture distinct perspectives and details, forming the foundation of the final model:

- `video1.ply`: Point cloud derived from the first video dataset, containing fine details captured from the initial perspective.
- `video2.ply`: Point cloud generated from the second video dataset, providing a complementary view for merging.

## 8.2 Point Clouds from Selected Image Sets

Following video extraction, selective frames from the videos were used to generate additional point clouds, providing more refined input for merging:

- `v1.ply` and `v2.ply`: Point clouds generated from selected frames of the first video.
- `v3.ply` and `v4.ply`: Point clouds generated from selected frames of the second video.

## 8.3 Intermediate Merged Point Clouds

Using `combinePointCloud.py`, we combined the initial point clouds to create intermediate models. These files demonstrate progressive alignment and merging of individual scans:

- `v1+v2.bin`: Merged point cloud from `v1.ply` and `v2.ply`, showing the combined data from both perspectives of the first video.
- `v3+v4.bin`: Merged point cloud from `v3.ply` and `v4.ply`, combining the perspectives captured in the second video.
- `v1+v2+v3+v4.bin`: Further merged point cloud, integrating both sets of perspectives from the first and second videos. This file represents a nearly complete model.

## 8.4 Visualization and Analysis

Figures 1 through 6 showcase each point cloud's structure, highlighting the increasing level of detail and completeness at each stage of merging. The final merged point cloud (Figure 6) demonstrates the successful consolidation of all input data, resulting in a high-resolution, cohesive 3D model.

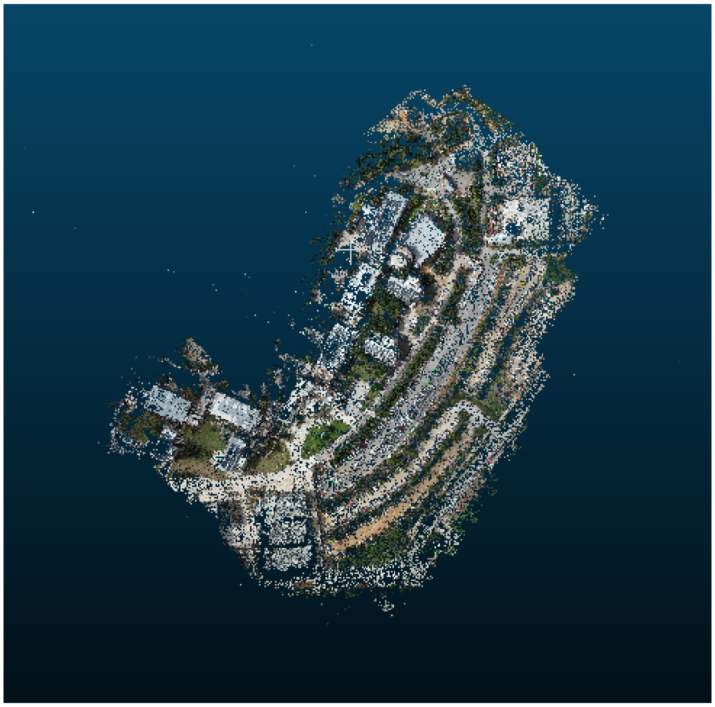

Figure 1: Point cloud from the v1 dataset (`v1.ply`).

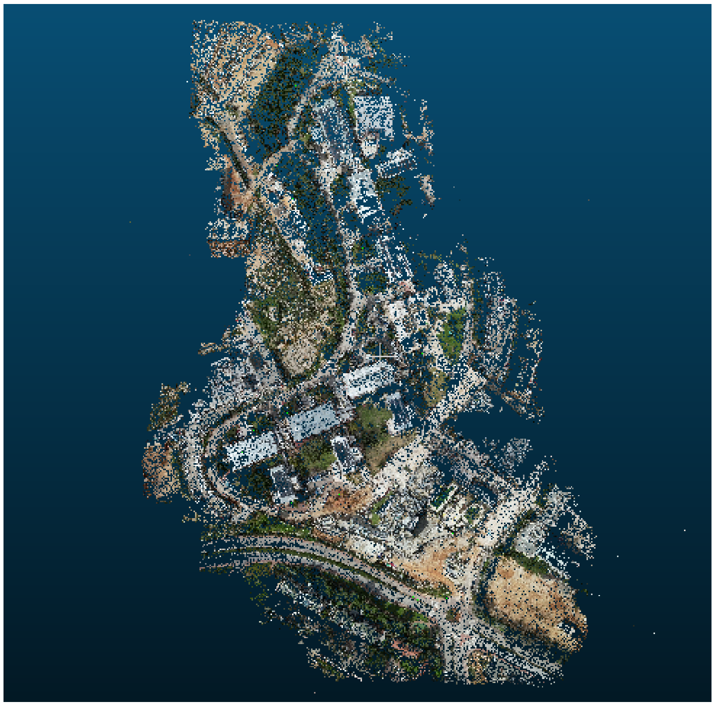

Figure 2: Point cloud from the v2 dataset (`v2.ply`).

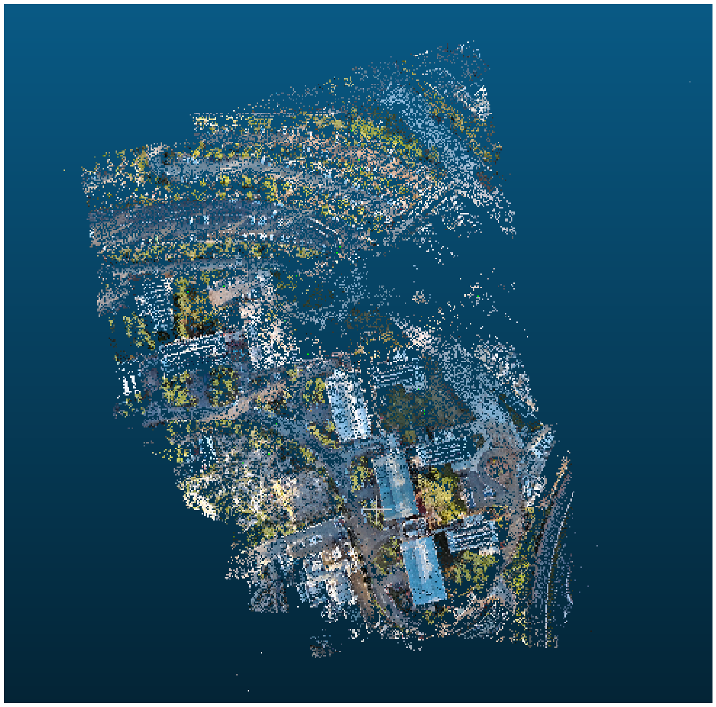

Figure 3: Point cloud from the v3 dataset (`v3.ply`).

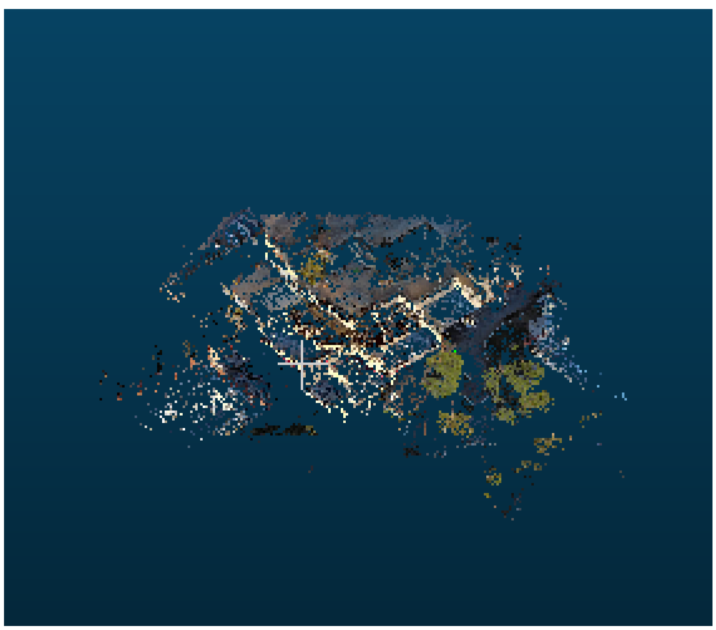

Figure 4: Point cloud from the v4 dataset (`v4.ply`).

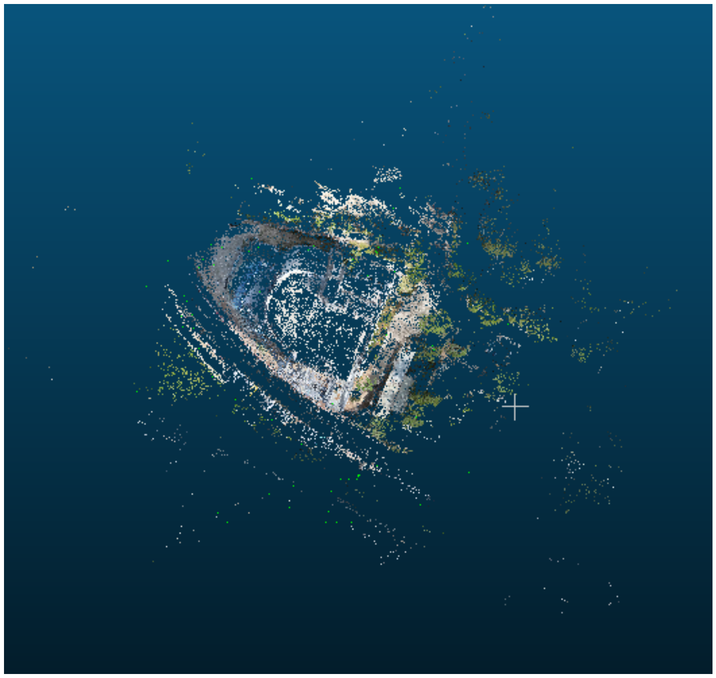

Figure 5: Final merged point cloud (`video2.ply`).

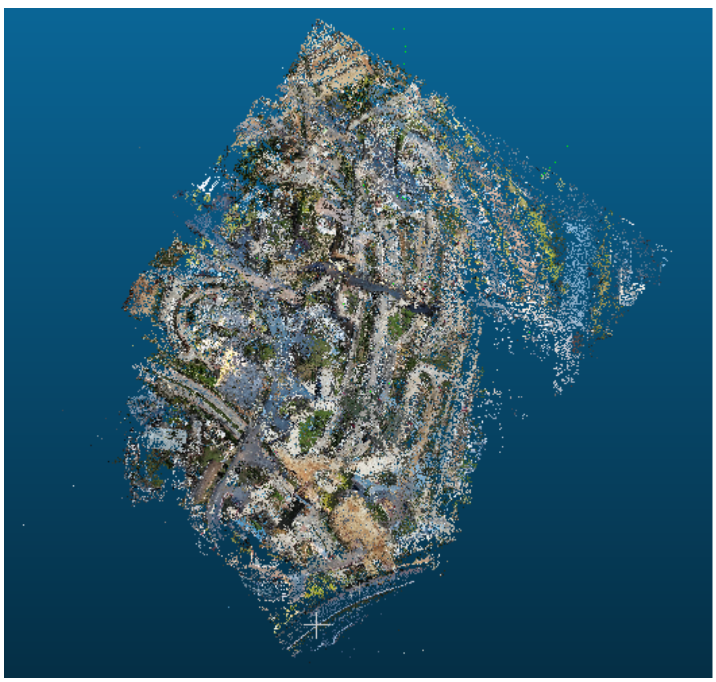

Figure 6: Final merged point cloud (`v1+v2+v3+v4+video1+video2.bin`).

# 9 Discussion and Future Work

The tools developed allowed us to refine our approach to photogrammetry, effectively creating a pipeline from video to high-quality 3D models. However, further enhancements could include:

- Improved frame selection criteria in `video2Images.py`, potentially using machine learning for automatic quality assessment.

- Optimized Meshroom settings in `images2PointCloud.py` for faster processing and higher detail resolution.
- Support for additional file formats and merging methods in `combinePointCloud.py`.

# 10 Appendix

For additional details, source code, and updates, refer to our GitHub repository: https://github.com/GalHillel/Final-Project-PhotoGrammetry

# References

[1] L. Vittuari, "UAV Photogrammetry and Ground Surveys as a Mapping Tool for Quickly Monitoring Shoreline and Beach Changes," *Journal of Marine Science and Engineering*, vol. 8, no. 1, p. 52, 2020. [Online]. Available: https://www.mdpi.com/2077-1312/8/1/52

[2] C. Ordóñez, "Accuracy of Unmanned Aerial Vehicle (UAV) and SfM Photogrammetry Survey as a Function of the Number and Location of Ground Control Points Used," *Remote Sensing*, vol. 10, no. 10, p. 1606, 2018. [Online]. Available: https://www.mdpi.com/2072-4292/10/10/1606

[3] F. Remondino, "Heritage Recording and 3D Modeling with Photogrammetry and 3D Scanning," *Remote Sensing*, vol. 3, no. 6, p. 1104, 2011. [Online]. Available: https://www.mdpi.com/2072-4292/3/6/1104