Project Report

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1 Part 1: Introduction to Photogrammetry

The science and technique of collecting, measuring, and analyzing photographic pictures, patterns of electromagnetic radiation imaging, and other occurrences to gather trustworthy data on real-world objects and their surroundings is known as photogrammetry[1]. Photogrammetry was notably applied in the survey of Fazenda do Pinhal's headquarters in Sao Carlos, SP, Brazil. Albrecht Meydenbauer, a Prussian architect, is credited with coining the word "photogrammetry," which first appeared in his 1867 paper "Die Photometrographie," even though the method's creator is Aimé Laussedat[2].

1.1 Research Papers

The following are some of the key research papers that have significantly contributed to the field of photogrammetry:

1.2 Research Papers

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- **Forstner, W. (2016)**: *A future for learning semantic models of man-made environments*. In 2016 23rd International Conference on Pattern Recognition (ICPR) (pp. 2475-2485). IEEE.
  This paper discusses the development of semantic 3D representations of man-made environments. Despite the increasing relevance of such environments in fields like navigation, urban planning, and disaster relief, semantic modeling still faces challenges. These include inconsistencies

in signal analysis models, the interaction between discrete and continuous geometric representations, and the complexity of integrating crisp and probabilistic models. The paper advocates for creating generative models to improve the understanding and rationalization of artificial environments.

- **Westoby, M. J., Brasington, J., Glasser, N. F., Hambrey, M. J., & Reynolds, J. M. (2012)**: *Structure-from-Motion photogrammetry: A low-cost, effective tool for geoscience applications.* Geomorphology, 179, 300-314.
  This paper introduces Structure-from-Motion (SfM) as a cost-effective photogrammetric method for acquiring high-resolution datasets. SfM uses overlapping images to reconstruct 3D geometry, offering high precision and versatility. The authors compare SfM results to terrestrial laser scanning data and demonstrate its effectiveness for geoscientific applications.

- **Pepe, M., Fregonese, L., & Scaioni, M. (2018)**: *Planning airborne photogrammetry and remote-sensing missions with modern platforms and sensors.* European Journal of Remote Sensing, 51(1), 412-436.
  This paper presents an overview of mission planning strategies for airborne photogrammetry and remote sensing, focusing on passive optical sensors. The discussion includes modern aerial platforms, such as manned and unmanned aircraft, and the role of sensor technologies in successful survey missions.

- **Remondino, F., Nocerino, E., Toschi, I., & Menna, F. (2017)**: *A critical review of automated photogrammetric processing of large datasets.* The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 42, 591-599.
  This review highlights the automation of photogrammetry, emphasizing the accessibility of 3D modeling through common digital cameras. The paper discusses the potential and limitations of automated image-based methods in creating high-quality 3D models, particularly for heritage projects, while calling for standard quality assessment techniques.

- **Everaerts, J. (2008)**: *The use of unmanned aerial vehicles (UAVs) for remote sensing and mapping.* The International Archives of Pho-

togrammetry, Remote Sensing and Spatial Information Sciences, 37(2008), 1187-1192.
This paper explores the use of UAVs in remote sensing and mapping, noting their potential to lower costs and increase accessibility. Everaerts predicts that UAVs will play an increasingly important role as airspace regulations evolve to allow their widespread use alongside manned aircraft.

1.3 Leading Companies in Photogrammetry

Several companies are at the forefront of photogrammetry, offering cutting-edge solutions and tools:

- **Pix4D**: Pix4D leads the industry in photogrammetry software. Their tools allow users to measure and digitize reality from images captured by phones, drones, aircraft, or any type of camera. They are revolutionizing photogrammetry, enabling users to scale and enhance the impact of their images.

- **Agisoft Metashape (formerly PhotoScan)**: Agisoft Metashape is a stand-alone software that processes digital images photogrammetrically, producing 3D spatial data for various applications such as GIS, cultural heritage documentation, visual effects production, and indirect measurements of objects at different scales.

- **Bentley Systems (ContextCapture)**: ContextCapture is a desktop program that generates high-resolution 3D models from photographs taken at different angles. It allows users to import XML or Excel files containing all the necessary information for creating a block.

- **DroneDeploy**: DroneDeploy is an easy-to-use tool for creating 3D models and aerial maps. It offers mobile software compatible with both Android and iOS devices, transforming a variety of DJI drones into reliable and efficient mapping tools.

1.4 Main Open-Source Tools

Open-source tools have played a crucial role in making photogrammetry accessible to a broader audience. Some of the main open-source tools include:

- **OpenDroneMap**: The open-source photogrammetry toolbox OpenDroneMap converts aerial imagery—typically taken by drones—into maps and three-dimensional (3D) models. The software is hosted and distributed on GitHub free of charge. Compared to traditional survey methods, drone mapping produces high-resolution airborne data that is more accurate and detailed. This increased precision can lead to better decision-making, planning, and analysis.
- **COLMAP**: With both graphical and command-line interfaces, COLMAP is a versatile Structure-from-Motion (SfM) and Multi-View Stereo (MVS) pipeline. It offers a variety of tools for reconstructing unordered and ordered image collections.
- **VisualSFM**: VisualSFM is a graphical user interface tool that utilizes the SfM system to reconstruct objects in 3D from images. Created by Changchang Wu, it is an improved version of his earlier works, enhanced with SiftGPU and Multicore Bundle Adjustment methods.
- **Meshroom**: Meshroom is an open-source, free 3D reconstruction software based on the AliceVision framework for photogrammetric computer vision. For more information about the pipeline, visit the AliceVision website. The output of the pipeline can be viewed on Sketchfab.

2 Tool Selection and Justification

We carefully considered several open-source technologies before deciding on COLMAP as the main tool for the photogrammetry project's implementation. The following standards were used to make the selection:

2.1 Evaluation Criteria

- **Compatibility with Video Input**: To create 3D models for the project, video data must be processed. COLMAP is primarily meant for image-based reconstruction, but it can also be easily integrated into our process by enabling frame extraction from movies using third-party programs like FFmpeg.
- **Feature Extraction and Matching**: Strong feature extraction and matching capabilities are essential for precise 3D reconstruction, and

COLMAP is well known for these. The tool is quite appropriate for our research since it offers cutting-edge Structure-from-Motion (SfM) and Multi-View Stereo (MVS) algorithms.

- **Flexibility and Customization**: COLMAP's broad modification possibilities and adaptable architecture make it easy to adjust to meet our unique requirements. It also supports command-line operations, allowing for automation of certain aspects of our workflow.
- **Documentation and Community Support**: COLMAP is characterized by a strong user community, plenty of online training resources, and well-documented software. This support is crucial throughout the process for debugging and optimizing the tool's performance.
- **Cross-Platform Availability**: COLMAP is available on multiple operating systems, including Linux, macOS, and Windows. This cross-platform availability enhances collaboration, ensuring that team members can work on the project regardless of their operating system.

2.2 Supporting Tools

We incorporated FFmpeg into our process to handle video input effectively. FFmpeg, a robust open-source multimedia framework, allows frames from videos to be extracted and used as input for COLMAP. The command utilized to retrieve frames from the video was as follows:

```
ffmpeg -i input_video.mp4 -vf "fps=1" ./output/output.png
```

This command extracts one frame per second from the video file, which is then processed by COLMAP for 3D reconstruction.

3 Initial Performance Evaluation

After deciding to utilize COLMAP as our primary photogrammetric tool, we evaluated its initial performance to determine how well it could generate 3D models and interpret video data. The following is a description of the key stages in the review process, along with our conclusions and the challenges we encountered.

3.1 Steps Taken for Evaluation

3.1.1 Frame Extraction from Video

Using FFmpeg, the initial step involved extracting frames from the supplied video. To extract one frame every second, we utilized the following command:

```
ffmpeg -i E:\PHOTO_PROJECT\DJI_0449.mp4 -vf "fps=1" ./output/output.png
```

This command was effective in retrieving high-quality frames from the video, which COLMAP could utilize as input. A frame-per-second extraction rate was employed to balance the amount of data with the necessary level of detail.

3.1.2 Importing Frames into COLMAP

The retrieved frames were then loaded into COLMAP. This required establishing the image directory, creating a new project, and adjusting the camera settings. Before starting the feature extraction process, it was simple to arrange and preview the imported frames using COLMAP's user interface.

3.1.3 Feature Extraction and Matching

We began the feature extraction process by locating key points within the extracted frames, using the default parameters of COLMAP. Feature matching was then performed to find correspondences between different frames. Numerous matching points were successfully identified across the frames due to COLMAP's robust feature matching algorithms.

3.1.4 Sparse and Dense Reconstruction

Following a successful feature matching process, we generated a sparse point cloud using the Structure-from-Motion (SfM) phase. The resulting sparse reconstruction captured the main structural components and provided a good initial representation of the area. The Multi-View Stereo (MVS) process was then applied to create a dense point cloud, which significantly enhanced the level of detail in the 3D model.

3.2 Findings and Challenges

3.2.1 Findings

- **Accuracy**: COLMAP produced a dense point cloud that was highly accurate, with well-defined structures and minimal noise. The technology successfully captured the three-dimensional geometry of the scene, enabling further analysis and refinement.

- **Performance**: COLMAP handled the dataset efficiently, completing the reconstruction process in a reasonable time frame. The tool's performance was optimized for our hardware setup, allowing it to handle larger datasets with ease.

- **Ease of Use**: COLMAP's graphical user interface made it simple to navigate between the different phases of the reconstruction process. Detailed logs and visual feedback throughout processing made it easier to track progress and troubleshoot issues.

3.2.2 Challenges

- **Handling Large Frame Sets**: One of the challenges encountered was managing the large number of frames extracted from the video. Although COLMAP processed these frames effectively, their sheer volume required careful system resource management to avoid delays in the reconstruction process.

- **Feature Matching in Complex Scenes**: Feature matching proved challenging in scenes with low texture or repeating patterns, sometimes resulting in fewer matched points and less accurate reconstructions. This required manual adjustment of feature extraction parameters to improve matching results.

- **Sparse Point Cloud Artifacts**: Artifacts were observed in the sparse point cloud, particularly in regions with few visual features. While these artifacts were reduced during the dense reconstruction phase, they highlighted the importance of selecting appropriate keyframes for processing.

4 Part 2: Image Extraction and Point Cloud Merging

4.1 Objective

In the second part of the project, we focused on two main objectives:

1. Computing a set of images from video files optimized for photogrammetry.
2. Implementing a software tool that allows the stitching of two-point clouds into a single point cloud using CloudCompare's Command Line Interface (CLI).

4.2 Video2Images Tool Design and Implementation

4.2.1 Objective

To extract frames from video for photogrammetry, we created a tool called `video2Images`. The tool is highly efficient, extracting frames optimized for 3D point cloud creation.

4.2.2 Tool Design

We utilized the OpenCV library in Python for handling video input. The tool is designed with simplicity and flexibility, allowing the user to input any video file, choose the frame extraction interval, and specify the output directory for storing the extracted frames.

4.2.3 Implementation Details

The main functionalities of the tool are as follows:

- **Frame Extraction**: The frames are extracted based on the interval specified by the user through the command-line interface (CLI) using the `--step` parameter. The extracted frames are stored in the specified output directory.
- **Directory Management**: The tool ensures that frames are extracted in the correct order and verifies whether the output folder already exists, preventing overwriting of files.

Below is an overview of the code for the tool:

```
import cv2
import os
import argparse

def extract_frames(video_path, output_dir, step=30):
    if not os.path.exists(output_dir):
        os.makedirs(output_dir)

    cap = cv2.VideoCapture(video_path)
    count = 0

    while cap.isOpened():
        ret, frame = cap.read()
        if not ret:
            break

        if count % step == 0:
            filename = os.path.join(output_dir, f’frame_{count}.jpg’)
            cv2.imwrite(filename, frame)

        count += 1

    cap.release()
    print(f"Frames saved to {output_dir}")

if __name__ == "__main__":
    parser = argparse.ArgumentParser(description="Extract frames from video")
    parser.add_argument("video_path", help="Path to the video file")
    parser.add_argument("output_dir", help="Directory to save extracted frames")
    parser.add_argument("--step", type=int, default=30, help="Frame extraction ste
    args = parser.parse_args()

    extract_frames(args.video_path, args.output_dir, args.step)
```

4.2.4 Usage Instructions

In order to run the code we created, the following command line is used:

```
python video2Images.py ./input/video.mp4 ./output/image.jpg --step 50
```

Where:

- `<video path>`: The path to the video file from which frames are to be extracted.
- `<output dir>`: The directory where the extracted frames will be saved.
- `<frame step>`: The interval between extracted frames (e.g., every 50th frame).

4.2.5 Testing and Validation

The `video2Images` tool was tested using two video files: `DJI_0055.mp4` and `DJI_0056.mp4`. After being properly retrieved, the frames were stored into the directories `s1` and `s2`, respectively, with a 50-frame extraction interval. The output folders contained enough images for additional photogrammetric processing.

4.3 Creating Point Clouds from Sets of Images

To create point clouds from `s1` and `s2`, we ran the image sets through COLMAP and received point clouds `p1` and `p2`. Our point clouds were saved as `p1.ply` and `p2.ply`.

4.4 Merging Point Clouds Using CloudCompare CLI

4.4.1 Objective

The objective was to merge two-point clouds (generated from the image sets `s1` and `s2`) into a single unified point cloud. This task was performed using the CloudCompare CLI, which allows for automated processing of point clouds.

4.4.2 Procedure

The following steps were followed to merge the point clouds using CloudCompare CLI:

1. **Loading Point Clouds**: The point clouds corresponding to the image sets `s1` and `s2` were loaded into CloudCompare using the `-O` option.

2. **Applying ICP for Alignment**: The Iterative Closest Point (ICP) algorithm was applied to align the two-point clouds using the `-ICP` option.

3. **Merging Point Clouds**: The aligned point clouds were merged using the `-MERGE CLOUDS` option.

4. **Saving the Merged Cloud**: After the merging was completed, the final file was saved with the merged clouds using the `-SAVE CLOUDS` option.

4.4.3 Example Command

The following command was used to merge the point clouds from `p1` and `p2`:

```
CloudCompare -O p1.ply -O p2.ply -ICP -MERGE_CLOUDS -C_EXPORT_FMT PLY -PLY_EXPORT_
```

4.4.4 Results

The point clouds from the files `s1` and `s2` were successfully merged into the file named `merged cloud.ply`. After analyzing the datasets, the merged point cloud file was ready for further visualization.

5 Part 3: Finalizing the Photogrammetry Project

5.1 Review and Completion of the Merging Process

5.1.1 Final Check

As mentioned earlier, the second part of the project was crucial for ensuring that the point clouds were created and successfully merged into a new file. The following checks were made:

- Using the CloudCompare GUI, we were able to visualize the merged point clouds and confirm that there were no misalignments.

- Outliers were identified and removed where necessary.

- The final point cloud was saved in the required `.ply` format for further analysis and documentation.

5.1.2 Visualization of Merged Point Cloud

The final merged point cloud is shown in Figure 4. This visualization demonstrates the successful integration of the point clouds from different datasets.

5.2 Designing Photogrammetry Missions with FlyLitchi

5.2.1 Creating an Account on FlyLitchi

A free account was created on FlyLitchi (`https://flylitchi.com/hub`), which allowed us to prepare and implement photogrammetry missions. The FlyLitchi Hub provides a reliable platform, well-suited for designing complex drone missions for photogrammetry applications.

6 Mission Planning for Ariel University Region

6.1 Introduction

This section describes how the FlyLitchi platform was used to create photogrammetry missions for the Ariel University area. These flights were essential for gathering aerial video to be used in the later stages for producing accurate 3D models and point clouds.

6.2 Mission Objectives

The primary objectives of these missions were:

- To cover the Ariel University area, including the the upper and campus and it's surroundings.
- To ensure that each mission lasted no more than fifteen minutes, adhering to typical drone battery limitations.

- To comply with local regulations and maintain a maximum flight altitude of 120 meters above the launch site. The flight routes were planned to avoid obstacles such as police buildings, powerlines, and antennae.

6.3 Mission Planning Process

Three drone missions were created using the FlyLitchi platform. Every mission was meticulously planned to achieve the project goals, ensuring thorough coverage of the target region while abiding by all operational limitations.

6.4 Mission 1: Upper Campus and Surroundings

The main goal of Mission 1 is to cover the upper campus and its immediate surroundings. The trajectory of the intended flight is shown in Figure 1, displaying altitude settings, waypoint distances, and waypoint locations.

6.5 Mission 2: Upper Campus Advanced

Mission 2 focuses on gathering data from the university's upper elevation locations and covers the upper campus more precisely. In Figure 2, the flight path is displayed. The purpose of this advanced mission was to obtain a better understanding of distance coverage and to create a more precise reconstruction map of the upper campus.

6.6 Mission 3: Comprehensive Campus Coverage

Mission 3 aims to provide comprehensive coverage of the entire Ariel University region. As seen in Figure 3, the objective is to ensure that no significant areas are overlooked.

6.6.1 Mission Execution and Data Collection (Planned)

After the missions are completed, the previously created tools will be used to process the video footage. This will include extracting frames from the video, creating point clouds, and potentially combining the newly created clouds with the existing dataset to enhance the final model.

7 Summary and Next Steps

This section has outlined the process of completing the merged point cloud and scheduling FlyLitchi photogrammetry flights. The planned missions will be carried out, the collected data will be processed, and the information will be integrated into the existing photogrammetry model. The concluding sections of the project report will provide documentation of these tasks.

8 Mission Execution and Data Processing

8.1 Execution of Planned Missions

Drones were used to carry out the three missions according to the FlyLitchi mission plans. The drone was closely monitored during each mission to ensure it followed the predetermined flying routes and heights. The following actions were taken during the execution:

- The drone was launched from a predetermined safe location within Ariel University.
- Real-time monitoring was performed using the FlyLitchi interface, ensuring that the drone followed the planned waypoints and maintained the correct altitude.
- The missions were completed within the set time limit of 15 minutes, ensuring that the drone's battery was not depleted.

8.2 Data Collection and Preliminary Analysis

After each mission was completed, the video footage captured by the drone was downloaded and securely stored for further processing. The preliminary analysis involved:

- Examining the video to ensure it was steady, clear, and devoid of any significant distortions or errors.
- Using the `video2Images` tool to extract essential frames from the video recording at regular intervals for optimal photogrammetry processing.
- Sorting the retrieved images into the relevant folders for each mission.

9 Part 4: Photogrammetry Model Creation

9.1 Generating Point Clouds from Video Frames

An open-source photogrammetry program, COLMAP, was used to analyze the extracted frames and create intricate point clouds. The steps taken included:

- Importing the extracted frames into COLMAP and configuring the settings for optimal point cloud generation.
- Running the photogrammetry pipeline to reconstruct the 3D models and point clouds from the images.
- Exporting the resulting point clouds in PLY format for further processing and merging.

9.2 Merging New Point Clouds with Existing Data

The new point clouds generated from the mission footage were merged with the previously merged point cloud (from Part 2) using CloudCompare. The merging process involved:

- Employing the ICP (Iterative Closest Point) approach to align the newly created point clouds with the existing merged cloud.
- Combining the aligned clouds to produce a single, comprehensive point cloud covering the Ariel University area.
- Saving the combined final cloud for further study and visualization.

9.3 Visualization of the Final Photogrammetry Model

CloudCompare was used to visualize the final combined point cloud. The model provided a detailed three-dimensional representation of the entire Ariel University Upper campus as well as the surrounding landscape.

10 Summary of Results

10.1 Key Findings

With the successful completion of the photogrammetry project, a comprehensive three-dimensional model of the Ariel University area was produced. Key findings include:

- Using CloudCompare's CLI, automating the process of combining point clouds from various sources resulted in a highly accurate and comprehensive final model.
- The FlyLitchi missions were executed smoothly, providing high-quality footage for photogrammetry processing.
- The final photogrammetry model serves as a valuable tool for further analysis and visualization, capturing the architectural and topographical features of Ariel University with high fidelity.

10.2 Challenges and Solutions

Several challenges were encountered during the project, including:

- Verifying the precision of point cloud alignments acquired from multiple sources. The ICP technique in CloudCompare enabled precise alignment and merging of the point clouds.
- Maintaining consistent visual quality across all missions. Careful planning and on-the-spot monitoring ensured high-quality imagery suitable for photogrammetry during the drone missions.

11 Discussion and Future Work

11.1 Discussion

The project demonstrated the effectiveness of photogrammetry techniques when combined with automated mission planning tools like CloudCompare and FlyLitchi. The resulting 3D models provided detailed and accurate representations of the university campus.

11.2 Future Work

Future work could involve:

- Enhancing the clarity and detail of the photogrammetry models by incorporating more footage taken from ground level.
- Experimenting with photogrammetry in larger or more challenging terrains.
- Exploring the creation of 3D models with detailed textures using texture mapping.
- Applying the models to campus planning, virtual tours, and augmented reality projects.

12 Conclusion

This report documents the successful completion of a photogrammetry project aimed at producing a three-dimensional representation of Ariel University. The project's careful planning, execution, and data processing resulted in an accurate and detailed model of the campus, demonstrating the potential applications of photogrammetry.

13 References

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2. "Photogrammetry history and modern uses". 8 June 2022.
3. "Photogrammetry and Remote Sensing" (PDF). Archived from the original (PDF) on 2017-08-30.
4. Albrecht Meydenbauer: Die Photometrographie. In: Wochenblatt des Architektenvereins zu Berlin Jg. 1, 1867, Nr. 14, S. 125–126 (Digitalisat); Nr. 15, S. 139–140 (Digitalisat); Nr. 16, S. 149–150 (Digitalisat).

Figure 1: FlyLitchi Mission Plan for the Upper Campus and Surroundings.

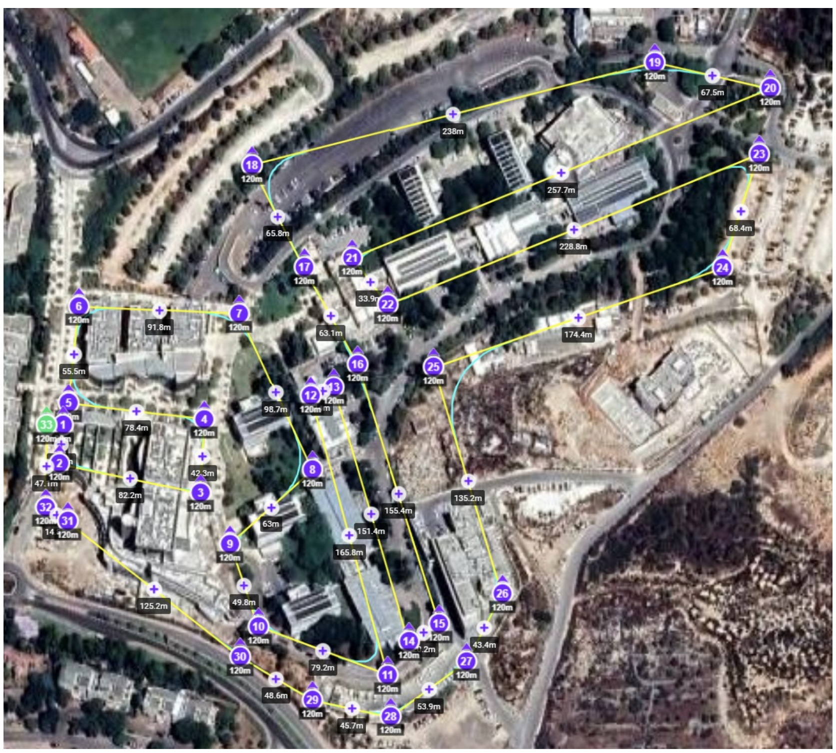

Figure 2: FlyLitchi Mission Plan for the Advance Upper Campus and Surroundings.

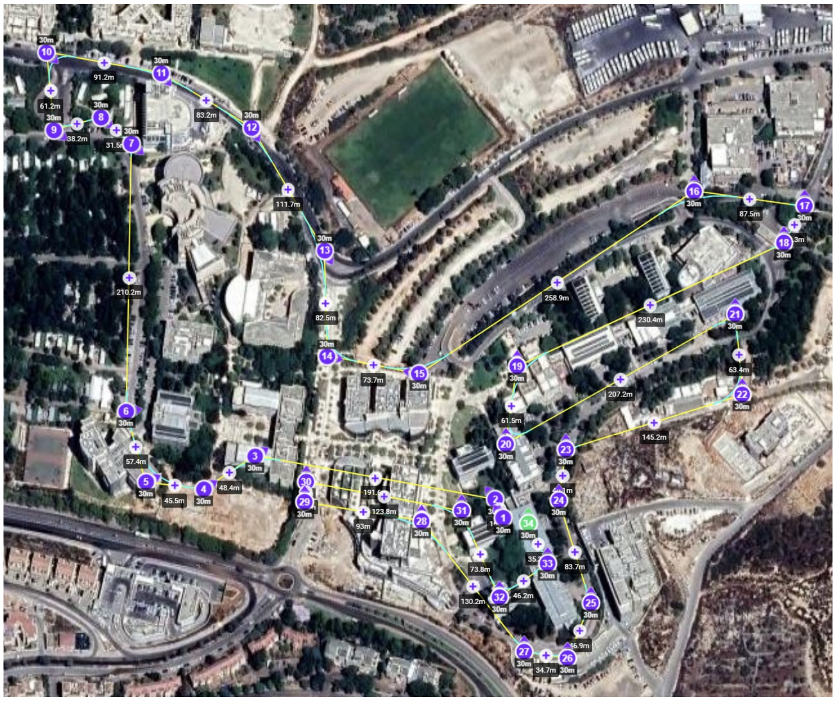

Figure 3: FlyLitchi Mission Plan for Comprehensive Campus Coverage.

Figure 4: Visualizations of the final merged point cloud.