# Lab 1. Creating an Orthomosaic and Digital Surface Model (DSM)in Pix4DMapper Using JPEG Imagery and Ground Control Points

GEOG 314: Intro to Uncrewed Aerial Systems

## Objective

This lab guides you through processing raw aerial imagery (.jpeg format) into an orthomosaic and DSM using **Pix4DMapper**. You will import imagery, set up coordinate systems, process basic outputs, and refine the results using Ground Control Points (GCPs).

## Learning Outcomes

By the end of this lab, students will be able to:

- Import and organize aerial imagery in Pix4DMapper.
- Define input and output coordinate systems.
- Run basic photogrammetric processing (Step 1: Initial Processing).
- Integrate and optimize Ground Control Points for improved spatial accuracy.

## Part 1: Imagery Processing

### 0. Create a Workspace

- Do not save to OneDrive for processing. Pix4D has trouble with the cloud file system. **Create a folder** on the local machine and name it **GEOG314_Lab01**
    - At the end of the lab exercise you will back up your project to OneDrive
- IMPORTANT – These lab computers function just like other lab computers on campus and will delete any files stored locally when you log out. There is no way to retrieve these files. Complete the lab in one sitting and then back up your project and deliverables to OneDrive

### 1. Starting Data

- Download zip folder containing **333 JPEG images** (or similar dataset) and extract files to your working directory.

    - This data set is over 2 GB in size and will take several minutes to download and extract
- Download the CSV file that contains the ground control point data to the same working directory
- Download the text file titled EXIF_Update.txt

**2. Create a New Project**

1. Open **Pix4DMapper**. If Pix4D does not appear in the list of applications, follow these steps (pdf)
2. If prompted, accept the end user license agreement
3. Select Pix4dMapper Educational #/25 option and enter the username and password given by the instructor
4. Select **New Project** → choose a project name and save it to your working directory.
    1. Choose a meaningful name like "GEOG314_Lab01_Pix4D_Project"
5. Click **Next**.

**3. Import Imagery**

1. Select "Add Directory..." and browse to your folder containing the JPEG files.
2. Once you have selected the folder, select **Next**.
3. Pix4D will automatically detect image metadata (EXIF GPS information).
4. Long story, but early DJI drones don't actually use GPS to calculate their elevation. Instead, they use barometric pressure which can be off by hundreds of feet. Because of that, we need to manually adjust the height of the photos in the EXIF metadata or the images will not line up correctly. In our specific case, the drone thought it was flying at 175 meters above sea level...but the ground is at about 258 meters above sea level...meaning the drone thought it was flying underground.
    1. Click on "From File..."
    2. Navigate to the data folder you downloaded earlier and find the EXIF_Update.txt file.
    3. Click on Next – Pix4D will automatically adjust the height using the new value of 287 meters (258 meters + 29 meters (95 feet) AGL)

```
DJI_0265.JPG,35.920322,-83.9901500277778,287,1.34116,-24.4655,-86.7645,5,10
DJI_0266.JPG,35.9202984166667,-83.9901105555556,287,-13.0495,-21.3948,-122.431,5,10
DJI_0267.JPG,35.9202773611111,-83.9900732777778,287,-14.5986,-20.521,-126.612,5,10
DJI_0268.JPG,35.92025325,-83.9900306944444,287,-14.8508,-20.3431,-127.334,5,10
DJI_0269.JPG,35.9202311944444,-83.9899891666667,287,-14.8866,-20.3175,-127.437,5,10
DJI_0270.JPG,35.9202073333333,-83.9899448888889,287,-14.958,-20.266,-127.643,5,10
DJI_0271.JPG,35.920183,-83.9899006111111,287,-15.0648,-20.1883,-127.952,5,10
```

**4. Coordinate System**

- **Image Coordinate System:** WGS 84 - EGM 96
    - This should be detected automatically.
        - If your data were collected in a different coordinate system, you would change it accordingly.
    - Click on Next

**5. Output Coordinate System**

An important part of what a client pays for when hiring a UAV survey is the specific knowledge needed to convert the images into an accurate 2D and 3D map. People spend entire careers studying this field, called geodesy, and if you work as a mapping professional, you will certainly need to know more about it. But this is not a GIS class, so I'll keep it short. Because the earth is not a perfect sphere, we use a mathematical model of the earth to help figure out where everything is located. That mathematical model is called a datum. In this scenario, we are using the World Geodetic System of 1984 as our datum (abbreviated WGS 1984). In order to define the horizontal location of our data, we need to transform the original 3D location of the data using latitude and longitude to a flat map surface using x, y coordinates using something called a projection. There are literally hundreds of different projections. For this scenario we will be using one called the Universal Transverse Mercator that is specifically tied to our area (Zone 17 North) abbreviated as UTM Zone 17N. That takes care of the horizontal part of our data, but not the vertical part. Since the elevation of the earth varies constantly, and even sea level is constantly changing due to tides, we need a way to set up a zero, or starting point, for our elevation values. For our scenario today we are using the Earth Gravitational Model 1996 (abbreviated EGM96) to define a local value for sea level.

- **Output:** UTM Zone 17N
    - Units: **Meters**
    - This should be the default for your study area.

- Click on Next

**6. Template and Processing Options**

1. Under **Rapid**, Select **3D Maps – Rapid/Low Res** as the processing template.
    1. Note that using the Rapid workflow provides faster results but they will not be full quality.
2. **Uncheck** “Start Processing Now.”
3. Click **Finish** to create the project.
    1. Pix4D will import your image files (along with the updated EXIF metadata you provided)
    2. The dots you see are the locations where each photo was taken
    3. You may see a green line that represents the flight path of the UAV

**7. Configure Processing Steps**

1. Open **Processing Options**.
    1. Icon in lower left corner of screen or under Process menu
        1. Next we will make an initial pass at the images so that we can add our ground control points. If you were not adding ground control points you could skip this step.
2. Disable **Point Cloud and Mesh** and **DSM and Orthomosaic**.
3. Leave only **Step 1: Initial Processing** checked.
4. Click **OK**.
5. Run **Step 1** to generate image alignment, keypoints, and initial tie points by clicking Start.
    1. As Pix4D works through its processing steps, you will see the dots change color.
6. Pix4D will generate a quality report about the images and resulting analysis
    1. Find a full explanation of the quality report here. Take a moment and scroll through the report if this is your first time using Pix4D.

2. For now, just note that under Quality Check, green is good. All of our values are good except for georeferencing. We will fix that by tying the drone images to our ground control points in the next step.

7. TAKE A SCREENSHOT OF PIX4D AFTER STEP 1 FINISHES FOR YOUR DELIVERABLES – save this somewhere you can find it later.

**Step 1 Results**

So what are you looking at? These are the results of the initial processing step. Start by turning off (unchecking the boxes) for everything in the Layers section. Turn Cameras on. The spheres are the estimated location of the drone at the time it took the image. Below each sphere you will see a thumbnail of the image the drone took at that location. And the green and blue lines show the angle (these are called Rays) from the drone camera to the image on the ground. It helps to zoom in to see this easier. Nothing happens when you turn on Rays. That data is included in the Cameras layer above. Next turn on Tie Points. These are the specific parts of each image that Pix4D is using to tie the different images together.

**Save your project**

**Part 2: Ground Control Point (GCP) Processing**

When attempting to create the best maps possible, many people will collect ground control points at the same time as their UAV imagery. To accomplish this, typically, we use a survey grade GNSS receiver that has much better positional accuracy than the built in GNSS unit on the UAV (More expensive UAVs may come with survey grade GNSS units built in). Our goal is to find features on the ground that will be easily visible from the drone imagery and collect the GNSS coordinates for that exact same location. Then in Pix4D, we can “nudge” the images into the more accurate location.

**1. GCP Data Preparation**

- Ensure GCPs are collected in **NAD83**.
    - The csv has been cleaned up for you and contains 7 GCPs.

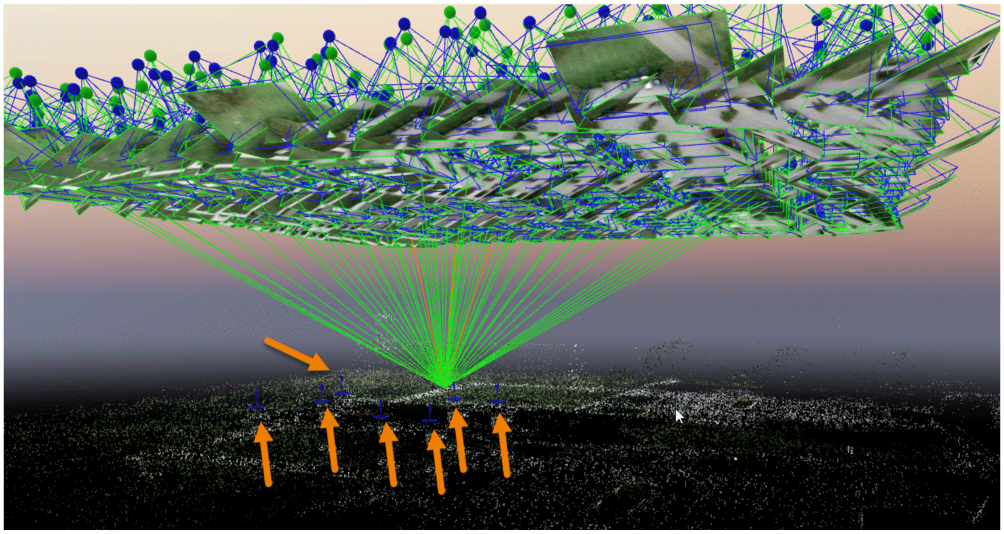
**2. Import GCPs**

1. In Pix4DMapper, open the **GCP/MTP Manager** (Project > GCP/MTP Manager).
2. Click **Import GCPs**.
3. Load your **7 cleaned GCPs** file.

4. Verify the **datum** and **coordinate system** are correct (should match your transformed coordinates).

5. Click on OK

If you adjust the View so you are looking parallel to the ground, you will see blue symbols representing the locations of the ground control points underneath the drone images.



4. **Refine GCP Locations in Images**

At this point, Pix4D has done its best to mark where it thinks the GCP are located in each image, but it needs some help. This is where you will manually define the location for each ground control point.

- You will need to download this map of the control point locations (pdf) before you begin this step. Take a moment to familiarize yourself with the location of the ground control points relative to the building. Each GCP is located at the intersection of four pieces of concrete.

- In Layers, expand Tie Points and GCPs/MTPs

    1. Note that there are 7 GCPs with names that match the GCPs in the map from above. You will select each GCP and manually mark the location of the GCP on the image.

- Click once on GCP CH3 in the Layers section. The right side of your screen will update and you will see images with a blue circle and dot showing where Pix4D thinks the GCP is located. It clearly isn't perfectly lined up at a concrete intersection, so we need to fix it.

1. If necessary, adjust the image size until you see only one or two images side by side.
2. Use the Zoom Level to zoom out of all the images until you can see the roof of the building, especially the steeple. If you can't see the roof or steeple, scroll through the images until you find one where you can.
3. On our PDF map, CH3 is on the left side of the building, furthest away from the steeple. Note that depending on the location and angle of the drone, the orientation of the image may not match the map.
4. Zoom into the image until you find the correct concrete intersection. Zoom into the intersection until the image begins to get grainy. Find the exact center of the intersection. Click once on the intersection.
5. Scroll to a second image and repeat this process.
    - Now if you scroll to a third image, you will see a bright green "x" marking the spot where you indicated the GCP is in the image.
6. Once you have correctly marked two images, click on Automatic Marking This will rescan the images and adjust the GCP in all the images to the refined location you specified.
7. Finalize these corrections by clicking on Apply.

- Click once on GCP CH5 in the Layers section. Note on our map that this GCP is next to a brass-colored circle on the ground. That should make it easier to find. Repeat the steps above to mark the location of the GCP in two images. Then click on Automatic Marking and Apply.
- Repeat these steps for the remaining 5 GCPs.
- Once you have finished the last GCP, adjust the Image Size slider so you can see about 4 pictures at once with a green "x". TAKE A SCREENSHOT OF THESE FOUR IMAGES TO INCLUDE IN YOUR DELIVERABLES.

**Save your project**

### 4. Define Checkpoints

When creating accurate 2D orthomosaics and digital surface models (DSMs), it's important to reserve some ground control points (GCPs) as checkpoints rather than using them all for model calibration. While GCPs are used to georeference and improve the spatial accuracy of the model, checkpoints provide an independent means of validation - they are measured points on the ground that are not included in the processing workflow. By comparing the model's predicted coordinates for these checkpoints with their surveyed locations, we can quantify the model's absolute accuracy through statistical metrics such as root mean square error (RMSE). This independent accuracy assessment helps ensure that the final products are both precise and reliable, not just internally consistent.

- Designate **2 of the 7 GCPs** as **checkpoints** (to validate accuracy later).
  - Pick two GCPs
    - Click once on the first GCP to select it. In the Selection window on the right side of the screen change the dropdown Type from 3D GCP to Checkpoint. Click on Apply.
    - Repeat this step for the second GCP.

**5. Reoptimize Project**

1. Navigate to **Process > Reoptimize**.
   - You may receive a warning. If so, click on OK.
2. This will reprocess the bundle adjustment with GCP corrections.
3. Verify results in the **Quality Report** once complete.
   - Pix4D does not automatically create a new quality report. Click on Process -> Generate Quality Report.
     1. Note that quality reports are saved in your Pix4D project folder.
   - Scroll down to the quality check and confirm that our georeferencing values are now green.
   - So what does that actually mean? Root Mean Square Error (RMSE) is a key accuracy metric in the Pix4D quality report that measures the average difference between the true, surveyed positions of ground control points (or checkpoints) and their corresponding positions in the processed model. Essentially, it quantifies how closely the reconstructed data matches real-world coordinates. A lower RMSE value indicates higher spatial accuracy and better alignment between the imagery and ground measurements. For example, an RMSE of 0.007 m suggests that the positional error across all GCPs averages just 7 millimeters—excellent accuracy for most mapping applications. Monitoring RMSE helps verify that georeferencing and camera

calibration were successful and that the resulting orthomosaic or DSM can be trusted for precise spatial analysis.

**Save your project**

**6. Run Final Processing**

It is now time to run the last two steps of the model so we can build the digital surface model (DSM) and orthomosaic. This will take several minutes to process on your lab computer.

1. In the Processing section at the bottom of the screen, Uncheck step 1 since you just re-ran it.
2. Check the “2. Point Cloud and Mesh” and “3. DSM, Orthomosaic, and Index”
3. Click on Start.

Because this is going to take some time to complete, we are going to switch activities at this point to learn how to use QGroundcontrol for mission planning and let Pix4D continue to process in the background.

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Now that Pix4D has finished processing, let’s explore the outputs in the software and then we’ll show you where to find the deliverables you would give to a client.

- Orthomosiac
    - Many clients will want to have updated, high resolution imagery of their area of interest. Let’s explore the data you just created.
        - On the left side of the screen, click on Mosaic Editor to view the orthomosaic. Remember that for the sake of time, we ran the Rapid version of the tool today, which means the resolution of the final product is not as good as it would normally be.
            - Give the computer a minute to generate the image
        - Zoom in on the image and compare what you see to what is available in an online web map like Google Maps. Even using the low resolution/rapid settings the resolution is much better than what is available online.
        - What is wrong with the section of sidewalk just north of the steeple?
- Digital Surface Model
    - In addition to the imagery, many people will want a 3D model of the area of interest so they can generate value added products like contour lines for engineering projects. Let’s view your 3D data next.

    - On the left side of the screen, click on the Volumes button to view the DSM.
    - Navigate around the structure to see the building in 3D. As you zoom in, you will see the individual points that make up the 3D image.
- Where to find the outputs from Pix4D
  - In Windows File Explorer, navigate to the folder you created at the beginning of lab (probably something like GEOG314_Lab01_Pix4D_Project).
  - Open the 1_initial folder and the folder called report
    - The pdf is the final quality report
  - Open the 3_dsm_ortho folder
    - Within 1_dsm you will find a folder called tiles along with 3 files
      - The file that ends in .tif is an image file (the actual dsm)
      - The files that end in .tfw and .prj are specific files that help your tif work in a GIS software
- Open 2_mosiac and you will see a similar file structure with the same types of files. TAKE A SCREENSHOT OF THE QUALITY CHECK AND PREVIEW SECTIONS FROM THE FINAL QUALITY REPORT FOR YOUR DELIVERABLES.

**Save your project**

**Copy your Pix4D project folder to your OneDrive**

**Take screenshots of various parts of your project to include in your digital portfolio**

### Deliverables

Submit the following for grading:

- Screenshot of your **Pix4D project window** after Step 1 processing.
- Screenshot of **GCP marks** in at least 3 images.
- Screenshot of **Quality Check and Preview** from final Quality Report.