



# Unmanned Aerial Vehicle (UAV) Technology

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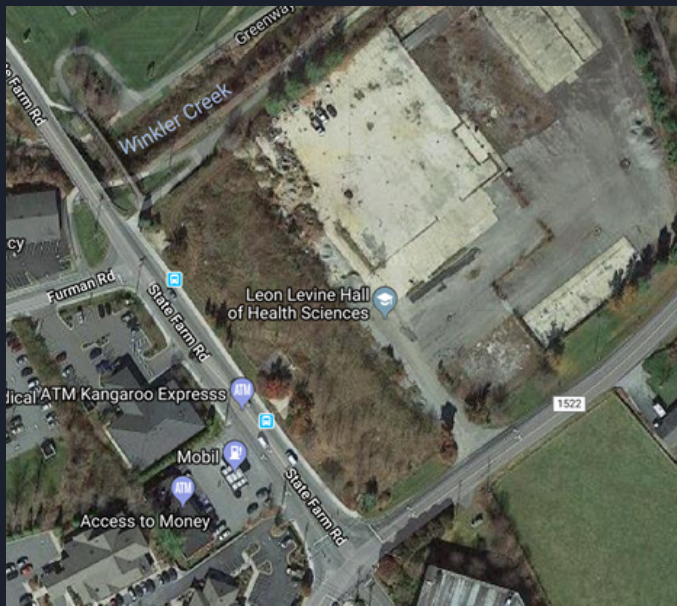
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Martin

# Resources



- Drones
  - DJI Matrice 100
  - DJI Phantom 4 V2
- Software
  - DatuSurvey / DatuFly
  - Drone2Map
- Thermal imaging camera (DJI Zenmuse XT)

# 1. Soil Erosion Monitoring Using Unmanned Aerial Vehicle (UAV) Technology



Leon Levine Hall of Health Sciences



# Problems & Motivation

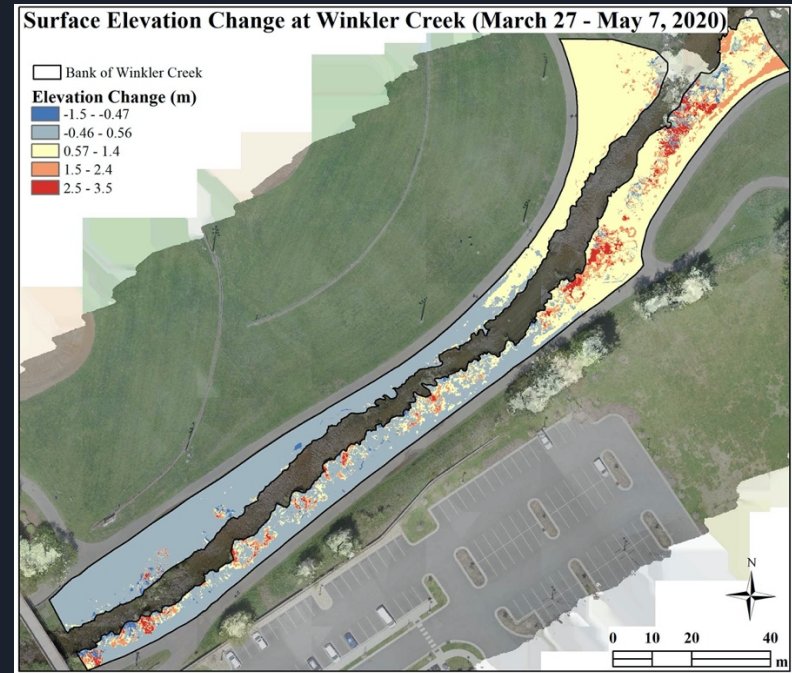
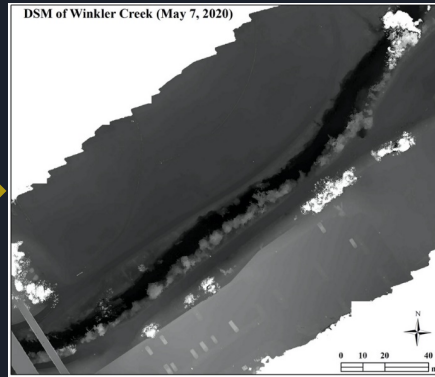


Pictures taken on 10/11/2018 (During Hurrigan Michael)

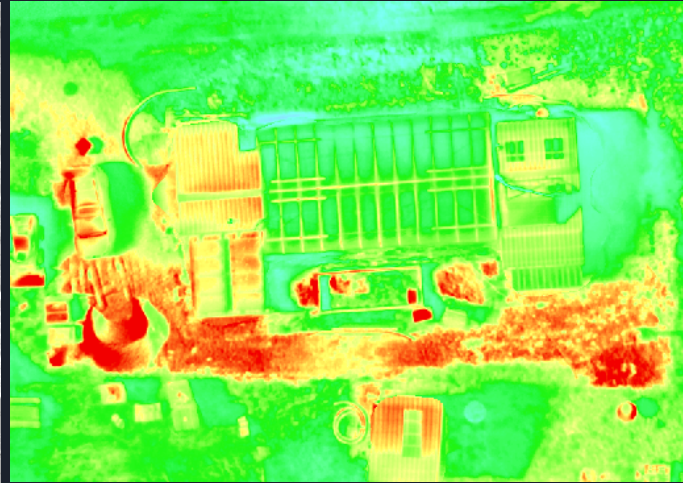


# Research Goal

- To develop an automated approach to assess the rate of soil erosion caused by storm water runoff.



## 2. Use of UAV-Based Thermal Infrared (TIR) Remote Sensing in Building Energy Performance Analysis





## Background and Objectives

- The biggest energy consumption in NC can be seen in the building industry. However, with advances in construction technology (e.g., TIR), significant improvements in terms of energy consumption can also be observed.
- Develop a set of standard procedures for collecting and producing surface dimensional and thermal data.
- Evaluate the accuracy of UAV-based dimensional and thermal data by comparing with design drawings and energy simulation results.
- Assess the potential of integrating these different types of data for building energy performance analysis.



# Progress Toward Goals and Objectives

- Developed a set of standard procedures for collecting and producing surface dimensional and thermal data using UAV-based TIR remote sensing technology.
  - **Trial and Error Process for Thermal Mapping of Building Envelope:** Our goal has been to create a thermal map of the building envelopes on our campus. We selected Katherine Harper Hall as the test building with which to refine our process. In order to create these maps we have been using the Matrice 100 attached with the Zenmuse XT thermal camera and Drone2Map to stitch the photos together. Prior to using the Zenmuse XT camera, we successfully produced visual maps using our optical camera as can be seen in Figure 1.



Figure 1. Ortho-visual photo of Katherine Harper

## Failed Processing Report



Generated with ArcGIS Drone2Map

### Processing Failed

**Error:**  
No calibrated cameras.

**Substep:**  
Processing

**Cause:**  
No cameras could be calibrated because either:

- The image quality is not sufficient (blurry images, no texture, etc.).
- There is no overlap between the images.
- The camera model associated to the cameras is not correct.
- The image geolocation or coordinate system is not correct.
- The GCP geolocation or coordinate system is not correct.

**Solutions:**  
Verify all the following conditions:

- The image quality is sufficient.
- There is enough overlap between the images.
- The camera model associated to the camera is correct.
- The image geolocation and coordinate system is correct.
- The GCP geolocation and coordinate system is correct.

### Summary

Project	KH_4_7_2021_Evening
Processed	2021-04-07 22:57:36
Camera Model Name(s)	
Time for Initial Processing (without report)	18m:08s

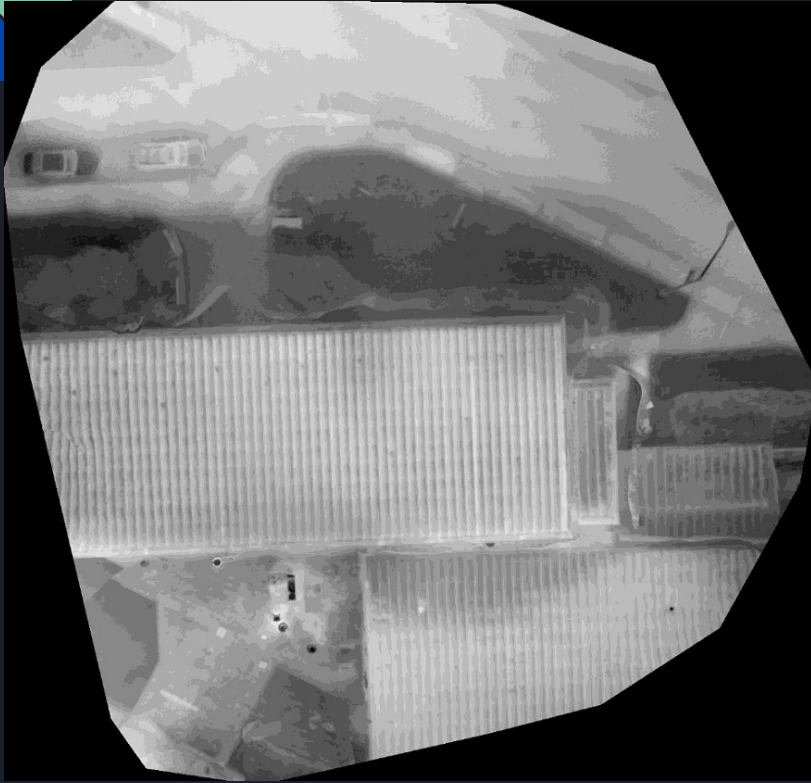
### Quality Check

Images	median of 6241 keypoints per image	⚠
Dataset	484 out of 484 images enabled	⚠
Camera Optimization	not available	⚠
Matching	median of 4284.09 matches per calibrated image	✅
Georeferencing	no GCP	⚠

Trying to produce a thermal map using the Zenmuse XT, however, has proven to be more difficult. Our original attempt to produce a map of the whole Katherine Harper Building failed and produced the following error message (Figure 2):

Figure 2. Recurring error message produced by Drone2Map





The message claims the failure was due to there no being a calibrated camera. Looking through the causes the only one that seemed valid was the image quality not being sufficient. To get a better understanding of what was going on, we then tried to create a map of only part of the building (Figure 3).

We then played around with creating a map of the other sections of the building and stitched them together (Figure 4).

Figure 3. Thermal map of section of Katherine Harper



Figure 4. Stitching sections together

However, as can be observed in the Figure 4, the sections did not line up well. We attempted to add ground control points (GCPs) to teach Drone2Map where the images were spatially, but we then received the camera calibration message from before.

We also attempted altering our flight pattern. Normally, our drone flies in a grid like pattern, so we tried flying it in circles of different sizes and even flying it manually, but this did not produce the result we were looking for.

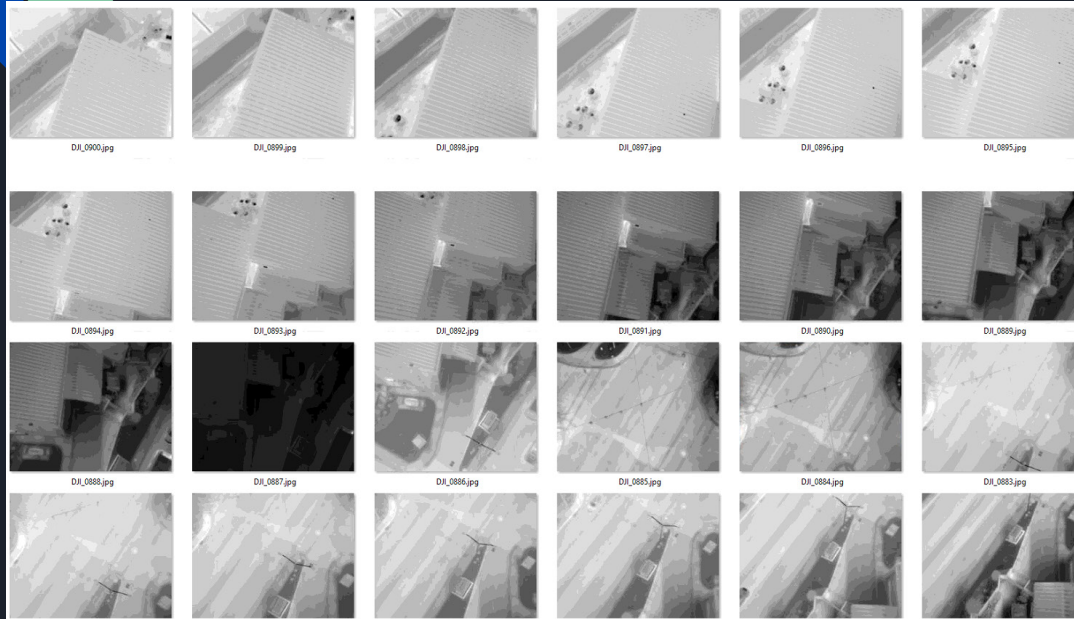


Figure 5. Images from drone flight displaying contrast discrepancies

Most of the time we got the same error message involving the camera. After further investigation we determined that the issue was due to the discrepancy in the brightness of the photos that were being captured. Some photos appeared much brighter and others were darker with better contrast (Figure 5) which prevented Drone2Map from successfully producing a map.



After reading through the Zenmuse XT manual and speaking with DJI support team we discovered the Region of Interest (ROI) setting for this camera. This setting can be used to exclude either 33% or 50% of the sky. In images with large portions of the sky this is helpful because due to the sky being much colder than the building, it takes up a lot of the pixel values in the lower range forcing other features to appear brighter. By excluding a certain percentage of the sky more pixel values in this range can be allocated to the building (Figure 6).

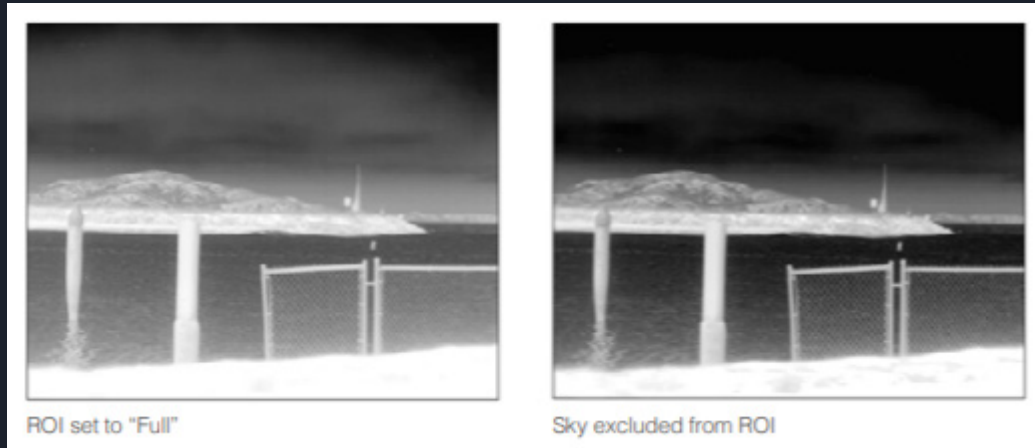


Figure 6. Image from Zenmuse XT manual showing effect of ROI (sky excluded)

Despite our optimism, this still did not allow us to produce the thermal maps of Katherine Harper's envelope. It did lead us to adjusting other camera settings such as Automatic Gain Control which allocates pixel values relative to the features in each photo. Our thought was that the relative pixel values that this produced forced the same feature of the building to appear different in separate photos. To remedy this we tried switch to both Low Gain mode which makes the camera less sensitive and High Gain mode which makes the camera more sensitive. Both of these settings are consistent. Still, we received the same camera error message.

Other things that we tried were changing the height that the drone flew at, changing the software versions our camera was using, and trying to make a map of a smaller building, the boiler building across the street from Katherine Harper (Figure 7). We were more successful in creating the map for the boiler building, it still was not consistent. Additionally, we tried to fly at night after the sunset to see if the glare from the sun was responsible for our issues. Again it didn't solve the problem.



Figure 7. Thermal map of boiler building

After speaking with DJI support further they suggested using the FLIR Tool (Figure 8) to improve the picture quality. This software allowed us to set the temperature range for the pixels and produce better contrast for the photos (Figure 9), but there was no way to give every photo the same temperature range at the same time other than manually setting it for each one. Given that there were often around 200 photos we did not believe this was a good method. Also, if we were to do this, either some photos would still have contrast issues due to not being in the optimum temperature range, or the photos would have different temperature ranges (Figure 10).

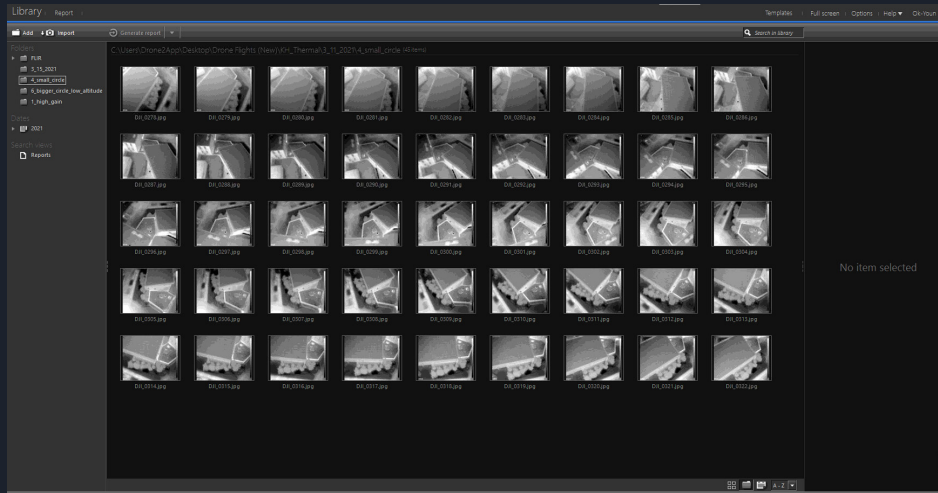


Figure 8. FLIR Tools dashboard with thermal images of Katherine Harper



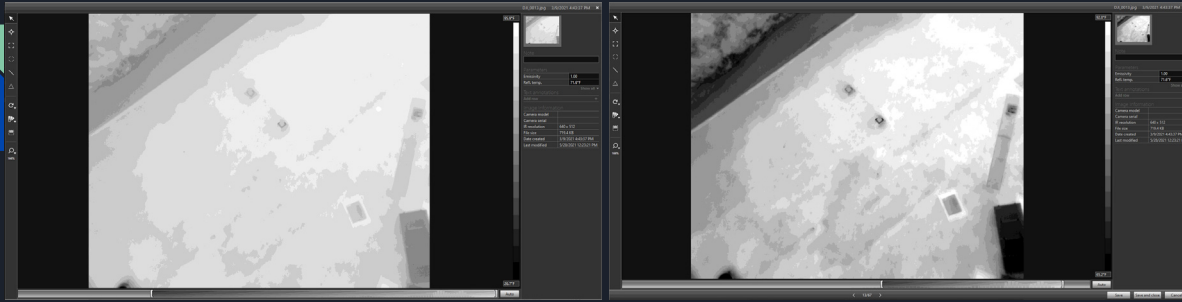


Figure 9. (Left) pre-contrast adjustment (Right) post-contrast adjustment

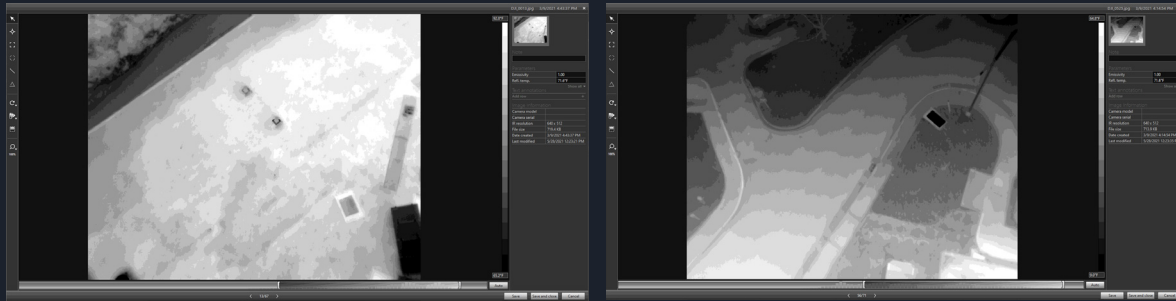



Figure 10. Bottom bar shows difference in temperature range between photos



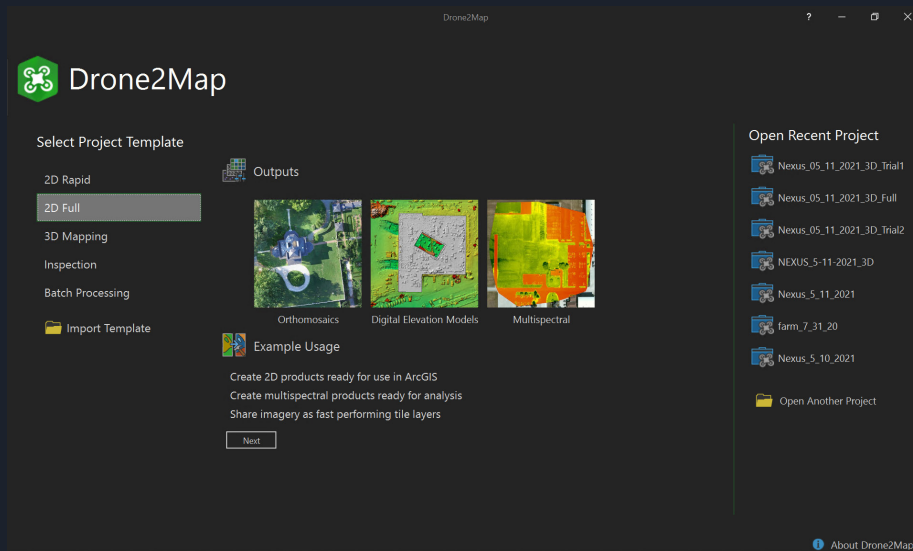
We finally made some progress when we read through the study, A Thermal Performance Detection Method for Building Envelope Based on 3D Model Generated by UAV Thermal Imagery. In this study researchers were pursuing a similar goal as us, but they were capturing their photos in TIFF format. Prior to reading this study we were capturing photos using the Radiometric JPEG (R-JPEG) format. By switching to the TIFF format the camera could now allocate values ranging from 0-65,535 rather than the 0-256 range the R-JPEG format provided.

We also temporarily switched our testing site from Katherine Harper to the Nexus Greenhouse because of accessibility (e.g., less traffic, smaller building). We have been successful in creating our thermal maps for this building.

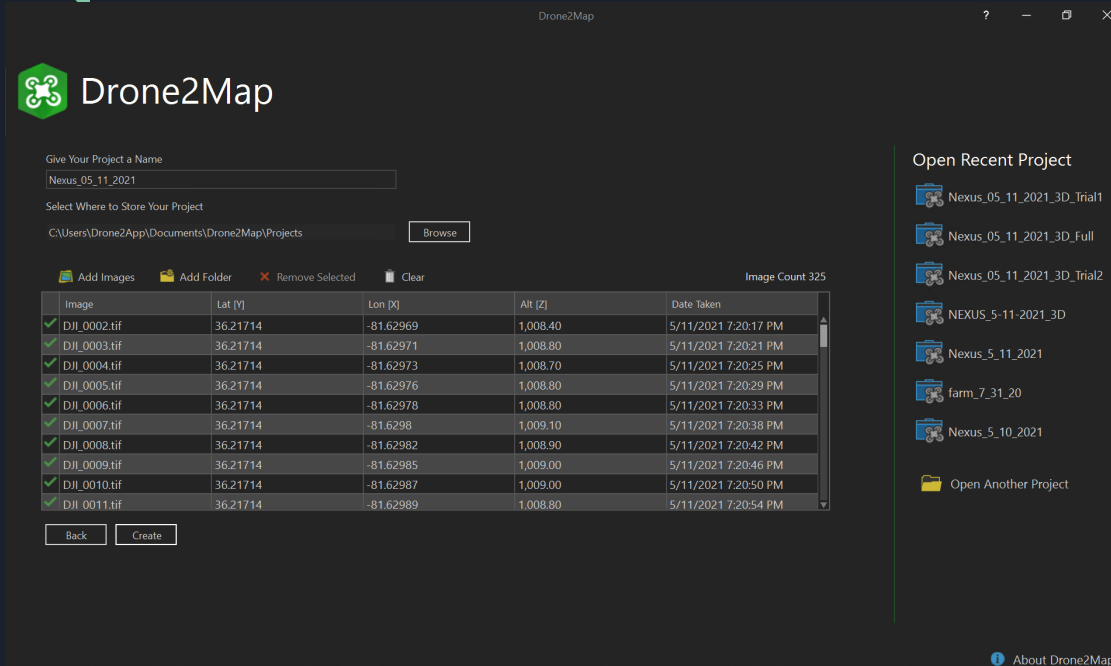
# Create Orthometric Thermal Map with Drone2Map

After thermal photos were collected by Matrices 100 with the thermal camera Zenmuse XT, they can be processed with Drone2Map to generate the thermal orthometric map, which covers the area of our interest. The data processing can be briefly summarized as the steps below:

1. Start Drone2Map and select the 2D Full mapping template and click Next.



2. Provide a name for the project (Nexus\_05\_11\_2021), choose a location to save it, and choose the location of the folder that contains the thermal photos. As shown below, we collected 325 thermal photos for the area of interest. Then click Create to create the project.



The screenshot shows the Drone2Map application window. The title bar reads "Drone2Map". The main interface includes a logo, a text input field for the project name containing "Nexus\_05\_11\_2021", and a file path input field for the project location containing "C:\Users\Drone2App\Documents\Drone2Map\Projects" with a "Browse" button. Below these fields is a table of image metadata with columns for Image, Lat [Y], Lon [X], Alt [Z], and Date Taken. The table lists 11 image files with their respective coordinates and altitudes. At the bottom left are "Back" and "Create" buttons. On the right side, there is a sidebar titled "Open Recent Project" listing several recent projects, including "Nexus\_05\_11\_2021\_Trial1", "Nexus\_05\_11\_2021\_3D\_Full", "Nexus\_05\_11\_2021\_3D\_Trial2", "NEXUS\_5-11-2021\_3D", "Nexus\_5\_11\_2021", "farm\_7\_31\_20", and "Nexus\_5\_10\_2021". At the bottom right of the sidebar is an "Open Another Project" button. An "About Drone2Map" link is visible at the very bottom right of the window.

Drone2Map

Give Your Project a Name  
Nexus\_05\_11\_2021

Select Where to Store Your Project  
C:\Users\Drone2App\Documents\Drone2Map\Projects

Image Count: 325

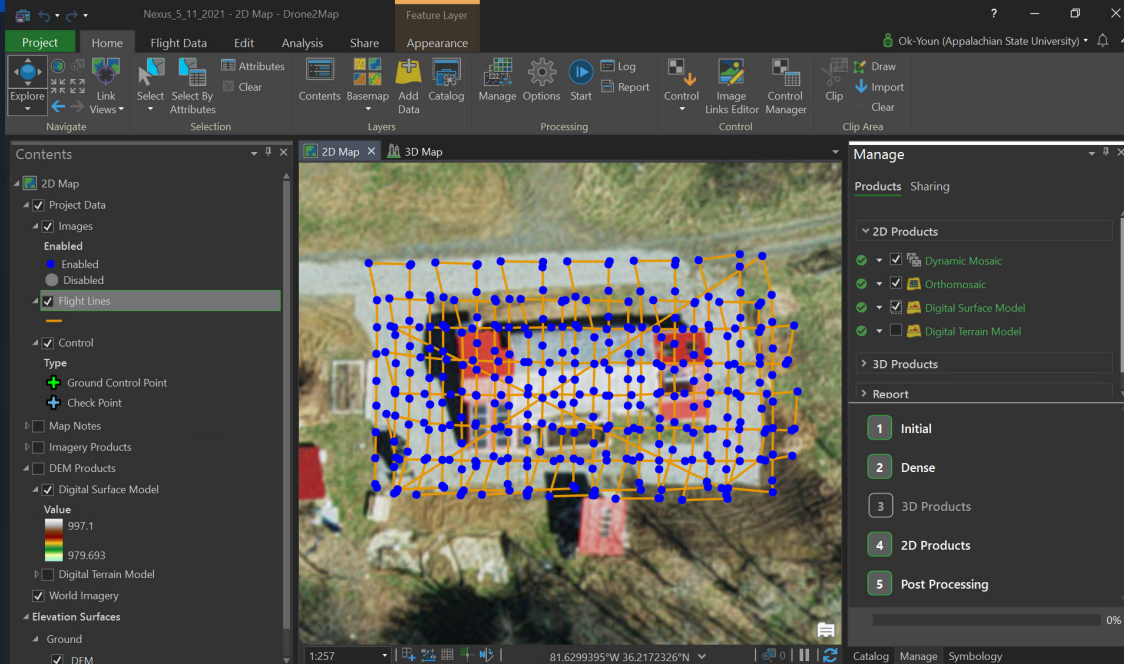
Image	Lat [Y]	Lon [X]	Alt [Z]	Date Taken
✓ DJI_0002.tif	36.21714	-81.62969	1,008.40	5/11/2021 7:20:17 PM
✓ DJI_0003.tif	36.21714	-81.62971	1,008.80	5/11/2021 7:20:21 PM
✓ DJI_0004.tif	36.21714	-81.62973	1,008.70	5/11/2021 7:20:25 PM
✓ DJI_0005.tif	36.21714	-81.62976	1,008.80	5/11/2021 7:20:29 PM
✓ DJI_0006.tif	36.21714	-81.62978	1,008.80	5/11/2021 7:20:33 PM
✓ DJI_0007.tif	36.21714	-81.6298	1,009.10	5/11/2021 7:20:38 PM
✓ DJI_0008.tif	36.21714	-81.62982	1,008.90	5/11/2021 7:20:42 PM
✓ DJI_0009.tif	36.21714	-81.62985	1,009.00	5/11/2021 7:20:46 PM
✓ DJI_0010.tif	36.21714	-81.62987	1,009.00	5/11/2021 7:20:50 PM
✓ DJI_0011.tif	36.21714	-81.62989	1,008.80	5/11/2021 7:20:54 PM

Open Recent Project

- Nexus\_05\_11\_2021\_Trial1
- Nexus\_05\_11\_2021\_3D\_Full
- Nexus\_05\_11\_2021\_3D\_Trial2
- NEXUS\_5-11-2021\_3D
- Nexus\_5\_11\_2021
- farm\_7\_31\_20
- Nexus\_5\_10\_2021

[About Drone2Map](#)

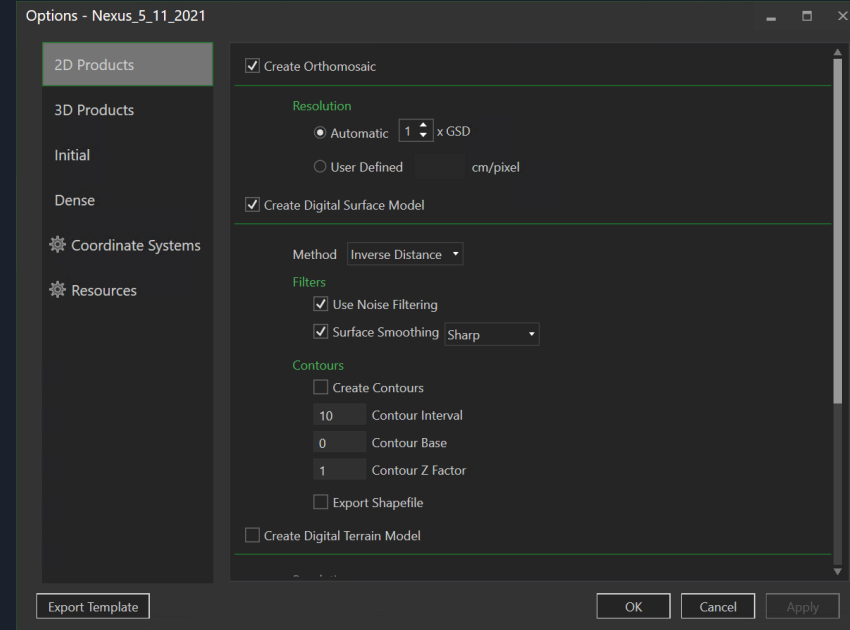
3. After the project is created, we can have an overview of the location of each thermal photo (blue points) and the drone flight path (the orange lines).





4. On the Home Tab, click Options. The pop-up window allows us to manually refine (if needed) the settings of the data processing and the final data products. The “2D Products” entry includes the settings for 2D products, such as the orthometric map and the digital elevation models. The “3D Products” entry is for the setting of 3D products, including cloud points and textured meshes.

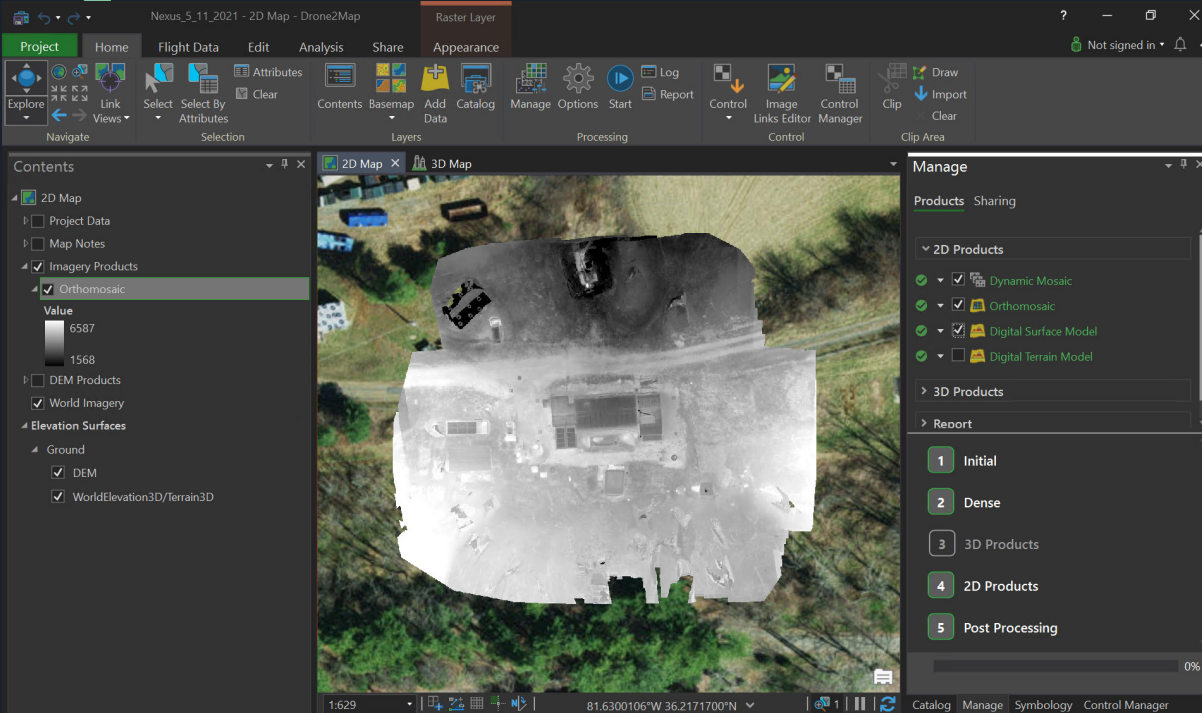
The “Initial” entry provides the detail settings for the initialization of the data process, for example Keypoints Photo Scale, Matching Photo Paris, Matching Strategy, and Camera Optimization, etc. The “Coordinate Systems” entry allows us to specify the geographic and project coordinate systems for our final data products. Click Ok to accept the default settings.



5. We can also import ground control points (GCP) to the project by clicking Control Manager in Home tab. In the pane of Control Manager, by using the Photo Links Editor (the first icon), we are able to link each GCP to its corresponding point on each thermal photo that covers the GCP.



6. After finishing the settings above, click Start in Home tab to begin processing. The software will then begin to stitch the thermal photos together and then produce an orthometric thermal map for the area of interest, as shown in the figure below.



# Derive Real Temperature

The thermal camera used in this project (DJI Zenmuse XT) is a non-radiometric camera instead of a radiometric thermal camera that can yield real temperature readings of ground surface objects. Therefore, as shown in Figure 11, the pixel values of the initial output orthometric thermal map range from 1568 to 6587, which indicates the relative temperature difference between surface objects. The hot objects are shown in bright color and the cool objects are in dark color. We need to convert the relative temperature difference between different objects to real temperature readings.

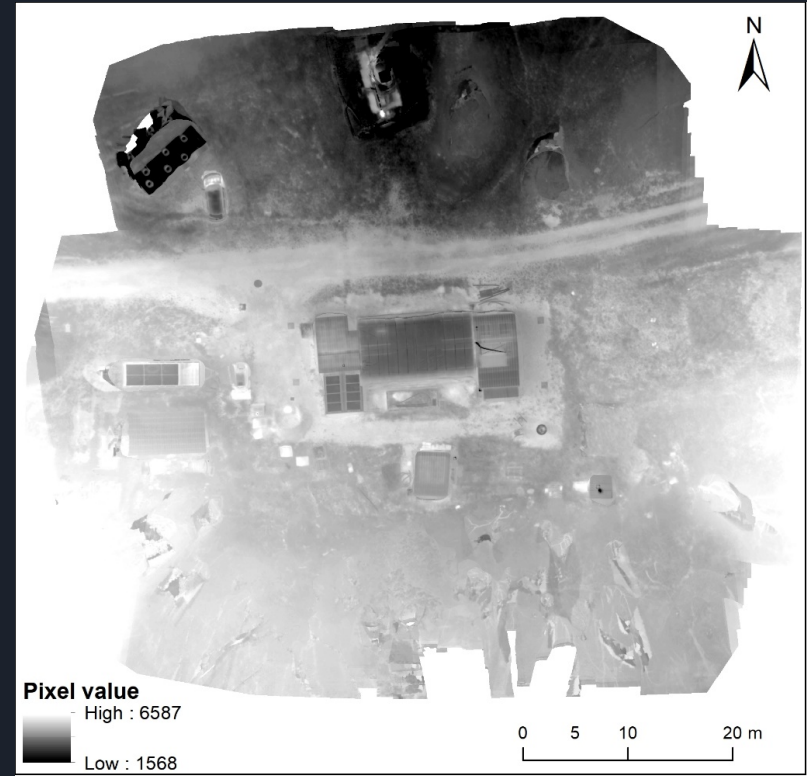


Figure 11. The initial output orthometric thermal map

# Derive Real Temperature

First, we extract the thermal map for the area of our interest. As shown in Figure 12, the pixel values of our study area range from 2395 to 6587. To convert the pixel values to real temperature readings, we need first establish the linear relationship between the pixel value and the real temperature. For that purpose, six temperature sensors were deployed to measure the real temperature of six objects (marked in Figure 12) while we were flying the drone to collect the thermal photos.

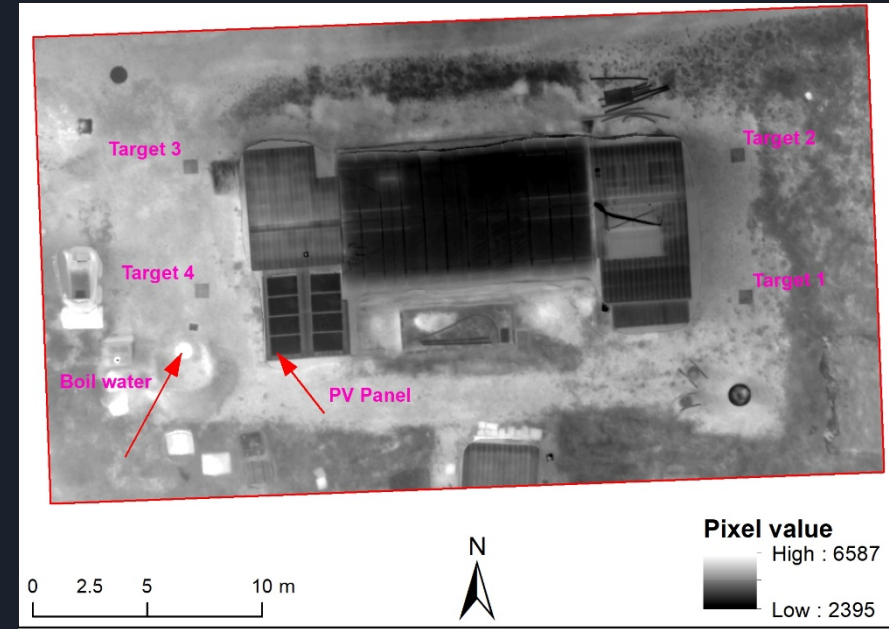


Figure 12. The thermal map of our study area (Nexus greenhouse)



# Derive Real Temperature

We used two objects to establish the linear relationship between the pixel value and the real temperature reading, including the boil water with a temperature of 95.61 °C and a pixel value of 6587, and the PV panel with a temperature reading of 11.72 °C and a pixel value of 2825. Based on the two pairs of pixel value and temperature readings, the linear relationship between them was obtained, as Equation (1) below.

$$y = 0.0223 \times x - 51.277 \quad (1)$$

Where  $y$  represents the real temperature reading in °C,  $x$  represents pixel value from the initial output thermal map.

# Derive Real Temperature

With the equation above, we are now able to convert the pixel values to real temperature values as shown in Figure 13.

The other four temperature sensor readings were used to verify the accuracy of our drone-based temperature map. By comparing with the actual temperature readings, the result shows that the deviation is within **1.30 °C**, which is a very accurate assessment (our drone-based method overestimated the surface temperature by 1.12 °C with a standard deviation of 1.28 °C).

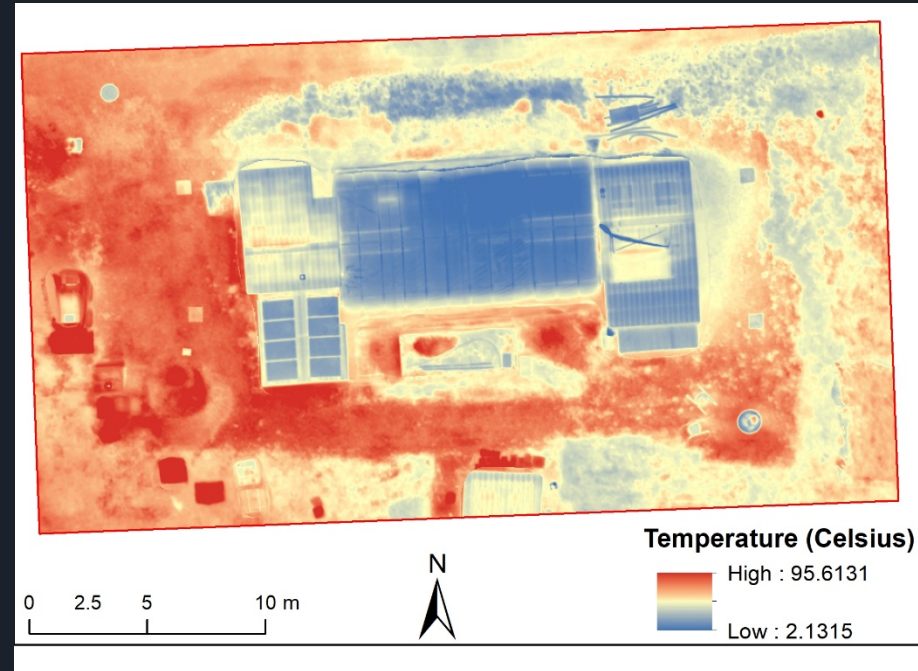


Figure 13. The map of surface temperature (°C)



## Realization of Benefits to North Carolina

- Aerial thermal imaging performed by UAVs can be very beneficial (i.e., **easy to access, faster, and safer**) in the building industry to detect defects and to identify thermal losses due to lack of insulation or air leakage.
- The proposed research will help the construction industry more adopt UAV technology for building energy performance analysis.
- Regular monitoring by thermal imaging technology using UAVs can lead to significant cost savings and defect removal in the early stages.



## Next Steps

- Refine a set of standard procedures for collecting and producing thermal data using UAV-based TIR remote sensing technology.
- Develop a thermal performance detection method for building envelope based on 3D model generated by UAV thermal imagery.
- By using this method, it will be possible to achieve a comprehensive, accurate, and efficient on-site assessment of the building envelope.

### 3. Monitoring Snow Accumulation in Appalachian Mountain Regions with UAV, Airplane, and Satellite Surface Elevation Observations







## Background and Objectives

- Mountain ranges are widely regarded as water towers that balance water budget for adjacent lowland areas through the storing of snow in cold months and the releasing of it in warm months.
- How can UAVs be implemented as an easy and quick tool to help measure the snow accumulation in mountain regions?
- What is the accuracy of the UAV elevation data and the snow accumulation measurements derived from the UAV data?
- To quantify the snow storage for the watershed surrounding Boone based on the snow accumulation measurements and estimate the snowmelt contribution to the downstream runoffs.

## 4. Comparative Analysis of Unmanned Aerial Vehicle (UAV) Surveying and Traditional Surveying Techniques





# Research Questions

- How does the accuracy of the the UAV imagery surveying compare to traditional surveying methods?
- What is the difference in workflow and associated labor cost between UAV surveying and total station surveying?
- How do two identical UAV survey flights' accuracy compare to each other?

# Preliminary Work



High Country Fairgrounds

