Seeing Heat in 3D: The Role of Resolution and Reconstruction Method on Thermal Models

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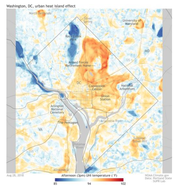
Abstract

Thermal imagery has previously been focused on improving 2D visualizations of heat in urban areas to better communicate how land cover impacts heat emissions. To better understand the impacts of building façades on heat emissions, we developed 3D fully interactive thermal models. During this project, we compared the outputs of three different camera resolutions, the FLIR One, FLIR Duo Pro R, and FLIR Vue Pro R to understand what quality of camera is required to effectively construct 3D thermal models. Several other variables were also considered, including terrestrial vs. drone-sourced imagery, and Structure from Motion (SfM) vs. newer Neural Radiance Field (NeRF) 3D reconstructions.

These 3D models will form the basis for a future user study in which they will be assessed for how well they improve users' learning about the thermal properties of a location compared to more traditional thermal orthoimagery.

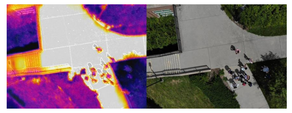
Background

What are some examples of thermal visualizations?



Urban heat island effect in Washington DC from climate.gov

In addition to temperature maps to visualize weather and climate, thermal imagery and maps are common ways to show how land cover and temperature relate.



Thermal imagery of people walking across walkways from Lim et al. (2022)

Perception of Thermal Maps

The interpretation of thermal maps varies with the color ramp used over the area. The ironbow colormap (used in several images) is not only well-liked but also the most effective for thermal map reading.

Unshaded, thermal shaded and DSM shaded images (using turbo colormap) of Patrick Henry High School, Roanoke, VA from Barua et al. (2022)

What are Neural Radiance Fields (NeRFs)?

Structure from Motion (SfM) uses a single camera to create a 3D scene based on the matching of key points in overlapping images, and is commonly used to create 3D models from UAV-sourced imagery. Because the software must model both the environment and the camera, distortions such as "doming" can appear in the reconstruction. The best way to avoid this issue is to create and use GCPs of identifiable objects or placed targets when the drone flight is being conducted in order to have exact references within the image.

Neural Radiance Fields (NeRFs) extend the SfM technique. A NeRF incorporates textures, lighting, and shadows to best create an accurate visualization. This technology is newer than SfMs and has been shown to be more successful when creating interpolated flythroughs and 3D models, even those that are reflective or spatially complex. The output of a NeRF is neither a mesh nor a point cloud, but these can be derived from them. Nvidia published a tool to create NeRFs in 2022, and Luma AI (lumalabs.ai) provides an online tool for simple reconstruction.

Visualization of NeRF creation from Mildenhall et al. (2021)

Methods

Cameras

Three different camera models were used to compare the differences in thermal resolution. Thermal imagery was collected of the ICTAS II building on campus with the FLIR One, Duo Pro R, and FLIR Vue Pro R. They were also compared based off of their pixel size, Field of View (FOV), sensor, and Ground Sample Distance (GSD). Cameras were walked around the building about 50 meters from the building, with stops when pedestrians passed by.

FLIR One

160 x 120 pixels
50 x 43 deg FOV
1.92 x 1.44 mm sensor
GSD at 100 m: 61.9 cm

Vue Pro R

336 x 256 pixels
45 x 35 deg FOV
5.712 x 4.352 mm sensor
GSD at 100 m: 24.6 cm

Duo Pro R

640 x 512 pixels
45 x 37 deg FOV
10.88 x 8.704 mm sensor
GSD at 100 m: 13.0 cm

Terrestrial Image Collection

Images were either captured by moving around a structure while setting the cameras to capture a time-lapse or were set to collect imagery of the same scene. The study area for terrestrial data collection was the ICTAS II building on campus.

Comparison of pictures taken with the (a) Duo Pro R and a (b) standard RGB of ICTAS II. (c) Path of image collection around ICTAS II

Aerial Imagery Collection

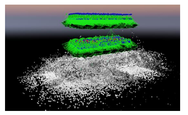
Images were collected using a Hexsoon 450 drone with a FLIR thermal camera and GoPro Hero 9. The study area was the Old Blacksburg High School Baseball Fields, which was selected because it had a number of different land cover types including buildings, trees, and grass. Ground Control Points (GCPs) were taken with an Emlid Reach RS2. Ice packs were placed with GCPs so they would show up in thermal images. Imagery was collected at 50 and 100 meters. Park officials were notified before data collection.

(a) Flying a data collection mission, (b) Hexsoon 450 drone, (c) gathering GCPs, (d) launch pad with ice pack, (e) field GCP, (f) thermal image from FLIR Vue Pro R at 100 meters, (g) study area - Old Blacksburg High School Baseball Fields, where the red area is where drone flights were conducted.

Model Creation

The software Luma AI and Pix4Dmapper were used to photogrammetrically stitch the resulting images together and to produce NeRFs or point clouds. Images that were processed using Pix4D were georeferenced using GCPs to NAD83 (2011) UTM 17N / NAVD88. The videos and images that were processed using Luma AI remained non-georeferenced.

Example interfaces for lumalabs.ai



rayCloud of a Pix4D reconstruction in progress

Results

Structure from Motion / Pix4D

- Models created from aerial imagery turned out well on this platform.
- Models created for building facades did not reconstruct for any camera. Even the much higher resolution RGB data did not reconstruct well compared to the NeRF models.
- Non-aerial thermal images that were taken with the FLIR One did not reconstruct
- Images that were collected using the Vue Pro R and Duo Pro R reconstructed well.

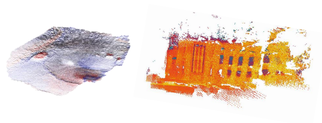
Neural Radiance Fields / Luma AI

- Had tremendous success with creating façades as seen by the video on the QR code.
- Aerial models reconstructed somewhat well with this tool, though not as well as those made with SfM / Pix4D

Resolution

- Higher resolution cameras produced better models. The FLIR One was not effective.

Building models did not reconstruct well with either SfM (left) or FLIR One NeRFs (right). Repetitive and reflective features are difficult for SfM, and the FLIR One's resolution was too low.



NeRF of park reconstruction (left) and ICTAS II using the middle-resolution FLIR Vue Pro R. These reconstructions were of overall medium quality.

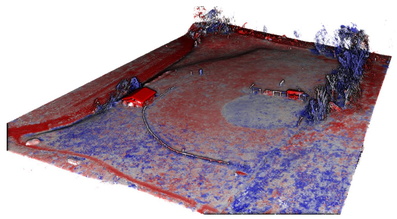
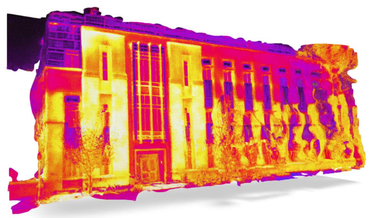


Image is thermal model of a park that was reconstructed using Pix4D with a Vue Pro R. The thermal data was overlaid on a spatial model derived from a GoPro Hero 9 captured at the same time.



tinyurl.com/ictas2nerf

A render of a NeRF for ICTAS II reconstructed using only thermal images (no RGB) from the FLIR Duo Pro R. Video animation at QR code.

Conclusions

- Higher resolution thermal cameras improved models. Thermal reconstructions can be done with the Duo Pro R and Vue Pro R, but they come out best with the higher resolution Duo.
- NeRFs produced impressive results without the need for RGB-based reconstructions, but they worked best for terrestrial image collection of buildings.
- SfM models using Pix4D worked better than NeRFs to create thermal models of large areas captured by drones, but were less effective for 3D thermal reconstruction of buildings.
- The low-resolution of the thermal cameras made drone 3D reconstruction challenging as it requires high image overlap.

Advantages of 3D thermal models

- 3D visualizations make the data more equivalent to the human experience.
- 3D thermal models take advantage of interactive displays or video to communicate more information about a scene.
- Thermal NeRFs of the façades of buildings were easy to make with lumalabs.ai web tool.

Disadvantages of 3D thermal models

- The high cost of a camera and processing software to create accurate and clear reconstructed 3D models are available to a limited audience. Aerial thermal photos rather than complete 3D reconstructions may communicate as well.
- 3D models can be hard to visualize in a static, 2D platform.

Challenges

- Thermal images have both a lower resolution and contrast than typical RGB images. This makes thermal SfM reconstructions more complex than with RGB images.
- Both data collection and model processing required significant preparation and time.
- The FLIR Vue Pro R camera used in the study was backordered and did not arrive until March.
- Individuals walking and/or living near the study area were both curious and concerned about drones flying; some were especially worried about the drone capturing imagery of their property without their consent.

Future Work

In future applications, it would be ideal for there to be a model of an entire building (rather than just one side). This could be done with one scan or by merging multiple façades together to create one building. This would be the most successful currently by being done as a NeRF, but currently they do not construct a whole building - most likely due to its larger scale. NeRF thermal models could be interpolated to a spatial model, provided they are not excessively warped.

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References

Barua, G. Pingel, T., Lim, T., Rijal, S., and S. Zick. 2022. Construction and Geovisualization of 3D Thermal Models of Urban Areas. Poster presented at the Virginia Tech OGIS Symposium, Blacksburg, VA. 9 April.

Kniaz, V. v., & Mizginov, V. A. (2018). Thermal texture generation and 3D model reconstruction using SFM and GAN. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 42(2), 519–524

Lim, T. C., Wilson, B., Grohs, J. R., & Pingel, T. J. (2022). Community-engaged heat resilience planning: Lessons from a youth smart city STEM program. Landscape and Urban Planning, 226, 104497.

Mildenhall, B., Srinivasan, P. P., Tancik, M., Barron, J. T., Ramamoorthi, R., & Ng, R. (2021). Nerf: Representing scenes as neural radiance fields for view synthesis. Communications of the ACM, 65(1), 99-106.

Yang, Y., & Lee, X. (2019). Four-band thermal mosaicking: A new method to process infrared thermal imagery of urban landscapes from UAV flights. Remote Sensing, 11(11).