Construction and Geovisualization of 3D Thermal Models of Urban Areas

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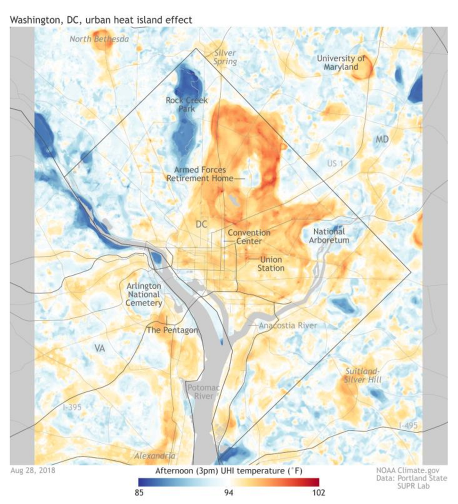
Abstract

While satellite-based remote sensing techniques are often used for studying and visualizing the urban heat island effect, they are limited in terms of resolution, view bias, and revisit times. In comparison, modern UAVs equipped with infrared sensors allow very fine-scale (cm) data to be collected over smaller areas and can provide the means for a full 3D thermal reconstruction over limited spatial extents. Studies suggest that higher resolution data helps in the decision-making process and increases the stakeholder interaction in policy-making processes. However, methods for constructing high-resolution 3D thermal models using the Structure from Motion (SfM) technique and solutions for camera calibration issues while constructing the models are not widely available. The poster will draw a comparison between satellite-derived and UAV-derived urban thermal models, illustrate the importance of high-resolution urban thermal models and describe the method for constructing 3D urban thermal models using SfM techniques.

Background

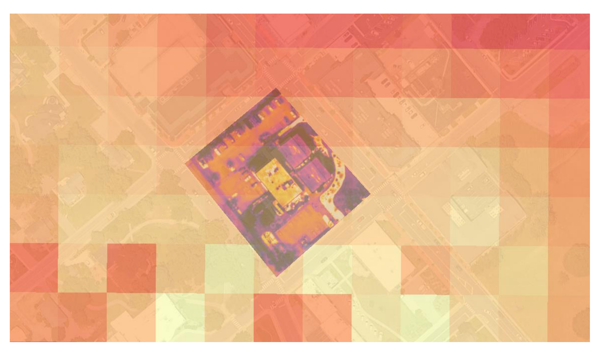


Urban heat island effect map of Washington, DC

- The urban heat island effect (UHIE) is measured mostly using satellite images which allow inspecting land surface temperature at 30m – 1km resolution.
- UAVs equipped with IR sensors fly at a lower altitude which generates higher resolution (cm level) imagery

- Using the Structure from Motion (SfM) technique, thermal images can be processed to build high-resolution thermal models (Kniaz & Mizginov, 2018)
- Factors such as heat trapped in vertical walls, radiation entrapment, sky view factor, and heat emission from individual structures are not considered in satellite image-derived UHIE measurement.
- High-resolution and 3D thermal models allow users to understand how urban micro-climate functions in response to LST variability
- It also improves the map-reading ability of the users which allows them to better understand the scenario (Carrera et al., 2017)

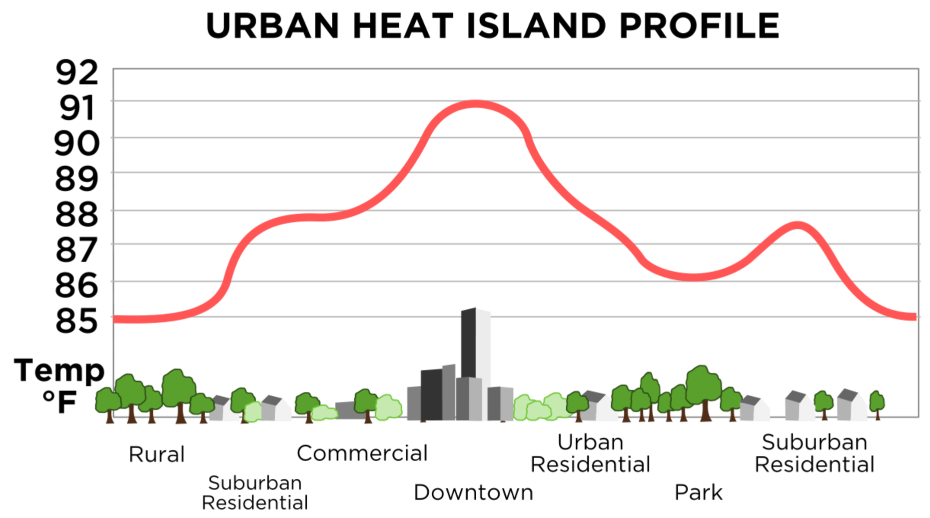
Comparing UAV & Satellite images



Thermal image overlay on a satellite image of Blacksburg, VA (Source: Dr. Theodore Lim)

- Satellite images have low revisit times while UAVs can collect high-resolution data at high temporal resolution
- Collected UAV images can have cm-level precision whereas the satellite images mostly have 30m – 1km resolution
- Satellite images may have view bias at the horizontal surface level and does not capture the complexity of the environment
- 3D models can be quickly and robustly reconstructed using the SfM technique

Urban Heat Island Effect



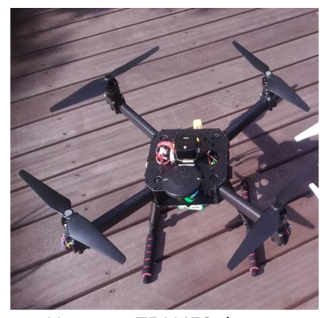
The Urban Heat Island Effect (UHIE) is the phenomenon of increased temperature in urban areas compared to the surrounding rural areas.

The average temperature of cities in 2100 is projected to increase 2ºC above that of a global temperature increase, compared to a 2006-2015 baseline, and expose 2.3 billion people to severe heatwaves (UNEP, 2021).

Building the Thermal Model

Data Collection

FLIR Duo Pro R camera

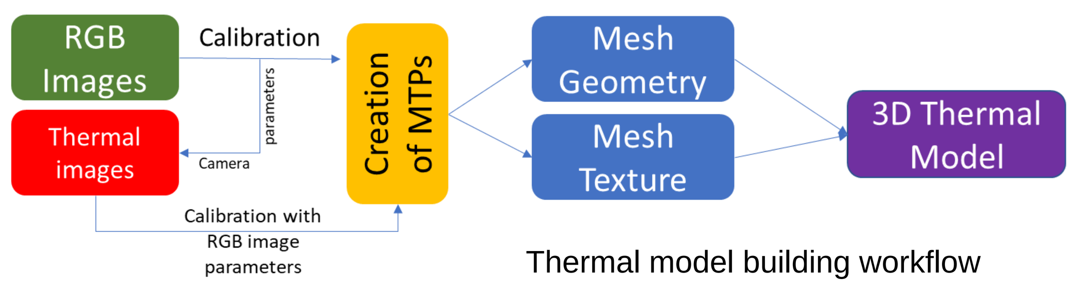


Hexsoon EDU450 drone

The images were collected using FLIR Duo Pro R camera which has an IR lens and an RGB lens. The IR lens has a resolution of 640 x 512 (0.3 MP), 1.33 aspect ratio, 13 mm focal length, and temperature range -40ºC to +550ºC. The RGB lens has a resolution of 4000 x 3000 (12 MP), and an 8 mm focal length. The images will be collected using a Hexsoon EDU450 drone which was built by the members of NEIL.

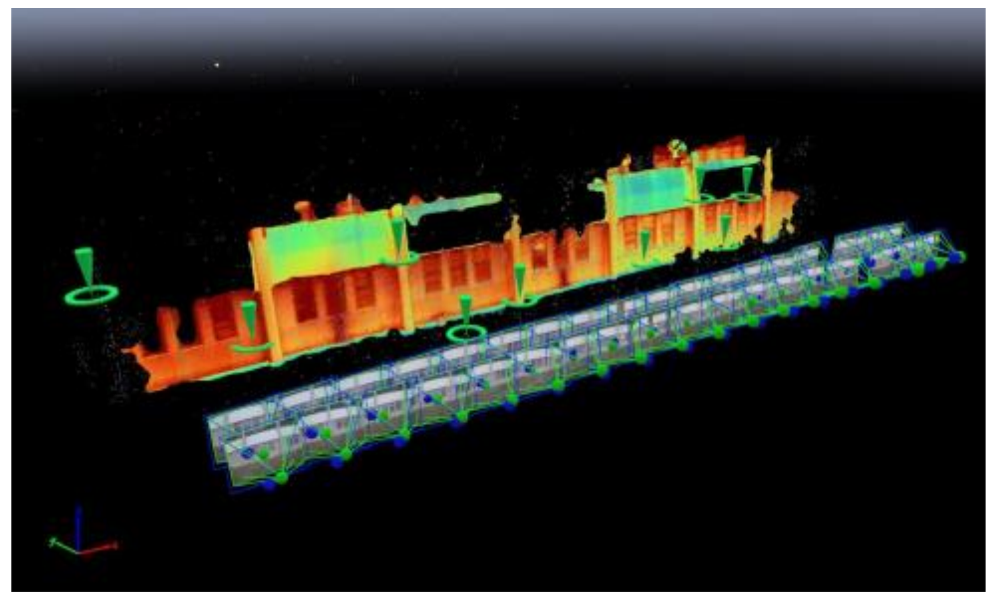
Image Processing

Using the SfM technique, the collected images were in Radiometric JPEG format which was separated into RGB and tiff using Pix4D software. The RGB images were calibrated first. Using Python script, RGB colormap was applied to the IR images. Separately, using the RGB image external camera parameters, the IR images were calibrated. Then, 5-6 MTPs were created for better image stitching. Afterward, the mesh geometry was created using RGB images and mesh texture was created using the IR images to build the 3D thermal model

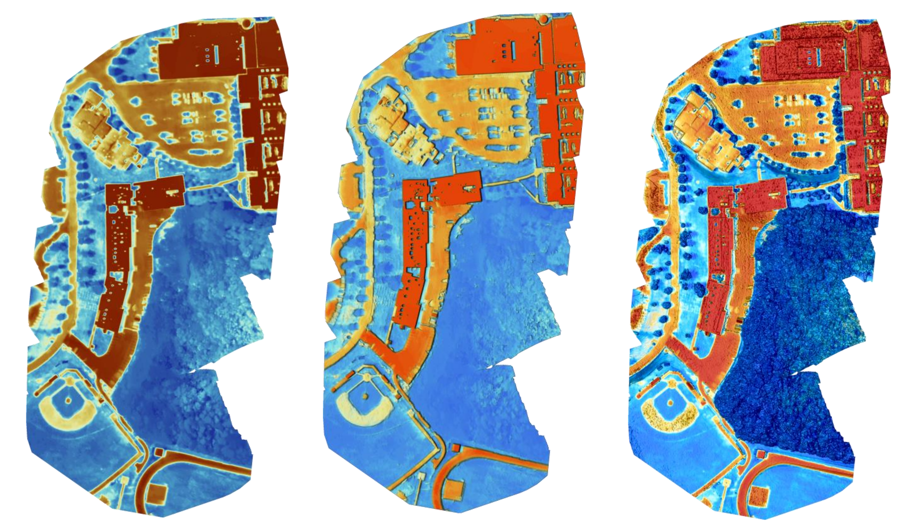


Thermal model building workflow

A shading effect was applied using the shaded relief operation in ArcGIS Pro. The shading effect allows delineating and understanding the temperature variances among the features. Using the multidirectional hillshade and pan-sharpening tool, the thermal layer was overlaid on DSM which gives a 2.5D effect on the orthophoto.



3D thermal model of Wallace Hall Façade generated using our new method.



Unshaded, thermal shaded and DSM shaded images of Patrick Henry High School, Roanoke, VA

Challenges

Infrared cameras have been mostly used by the industry for inspection purposes and there are very few examples of using them for building 3D thermal models. We used Pix4D software to build the models using a new approach:

- A new camera calibration method was developed, thereby simplifying the intrinsic calibration in Pix4D.
- Yang & Lee (2019) suggested a layer-stacking method, but this technique throws away valuable RGB-channel data that can be used to develop the spatial model of the terrain and features. Our method uses the external camera calibration from the RGB channel to seed a secondary thermal camera calibration. However, since both internal and external calibrations have at this point already been completed, the software is able to easily merge even not-well differentiated scenes.
- A small set of MTPs are used for quality control and to precisely overlay both models. which we tried, but it's difficult to execute as the image size for the RGB and the thermal camera doesn't match, and the field of view is also different

Importance of High-Resolution Thermal Imagery

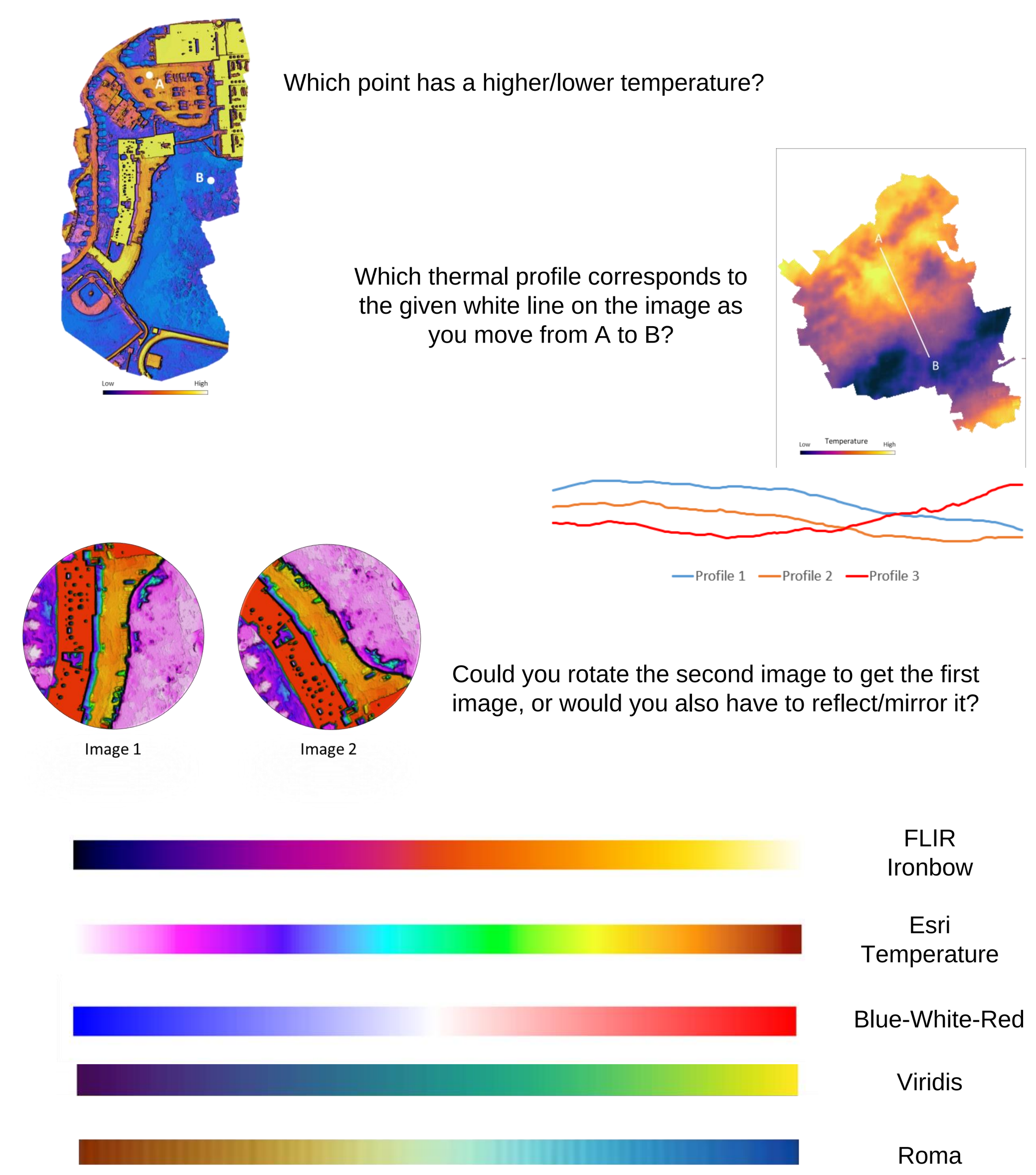
- Improvements in spatial resolution of thermal imagery make buildings, trees, and sidewalks directly visible in the scene, removing a layer of generalization that may make novice users directly apprehend their thermal properties.
- Helps users understand how the urban landscape elements exert influence at a small scale to relate to their heating experience
- High-resolution UHI data will provide additional data on land surface temperature variability which will help urban planners, architects, and landscape planners to design neighborhoods in a heat-effective manner

Next Steps: User Study

A user study will test accuracy and response time on three different map-reading tasks, five different popular thermal colormaps, and a shaded-vs-unshaded condition. We expect to test 100 participants.

Additionally, we will make a comparison of drone-based thermal maps to satellite-derived, city-scale thermal maps to investigate whether and how drone imagery adds value.

Map-Reading Tasks



Colormaps to be tested in the perception study

Hypotheses

We expect that the Ironbow colormap will perform the best. We also expect that the high-resolution thermal map will perform better. Furthermore, we expect that shading as a cartographic augmentation will perform better than the maps without augmentation.

Acknowledgments

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