Understanding perception of different urban thermal model visualizations

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Introduction

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 high-resolution thermal reconstruction over limited spatial extents. Irrespective of the data collection method, the thermal properties of cities are typically visually represented using color, although the choice of colormap varies widely. Previous cartographic research has demonstrated that colormap and other cartographic choices affect people's understanding. This study has two parts. First, we will develop techniques to transform thermal and RGB images into high-resolution thermal models rather than the more conventional orthoimagery approach. Second, we will conduct a user map perception study to both (a) compare how these detailed 3D models improve thermal map-based understanding compared to conventional orthoimagery at site and city scales and (b) how different colormap and shading representations of the same thermal data affect users' understanding of spatially varying thermal conditions.

Method

Developing high-resolution thermal models

To develop high-resolution 2D and 3D visualizations of the urban thermal environment, an infrared camera, FLIR Duo Pro R was used which was lifted using a drone. The camera has two integrated components: a thermal camera and a second RGB camera. The resolution of the thermal camera is 640 x 512 (0.3 MP) with an aspect ratio of 1.33 and field of view (FOV) of 45^o x 37^o. It also has a focal length of 13 mm. In terms of accuracy, it has a possibility of error in up to 5% of the readings within -25^{o}C to +135^{o}C range and up to 20% of the readings within -40^{o}C to +550^{o}C range.

The collected images were processed using the Pix4D Structure from Motion software. Due to lower resolution, processing the thermal images is a bit different from processing RGB images. Using the software, only initial processing was run with the RGB images which generate an external camera parameter, which contains the relative location of all the images. Using this parameter, the initial processing of thermal images was conducted separately. These were later merged where the point clouds and the mesh geometry were produced from the RGB images, and the mesh textures were generated from the thermal images. Before processing the thermal images, a colormap was applied using Python.

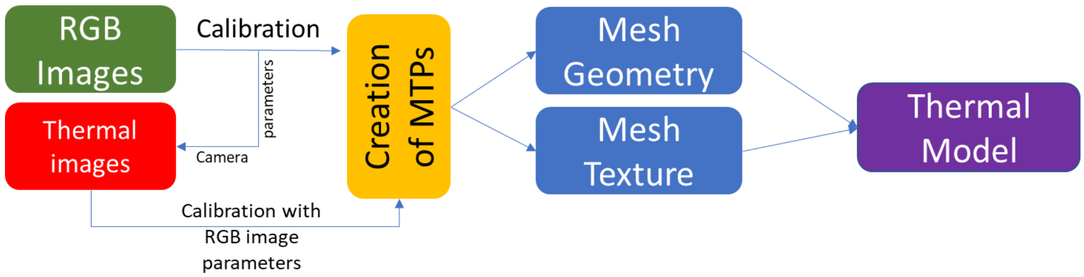

Figure 1: Thermal model building workflow using Structure from Motion technique

Figure 2: Thermal image orthomosaic constructed from images taken during a flight in Roanoke, VA using Mavic Pro Duo thermal camera, visualized with ironbow colormap

The study has used the Analysis Ready Data (ARD) Landsat Collection 2 Surface Temperature product which combines information from multiple bands (and even other satellites) to produce surface temperature estimates (Dwyer et al., 2018). The study area falls into Path 17 Row 34 in the ARD tile. Intended colormaps were applied to the images for assessing the perception of users. To develop shaded city-scale thermal maps, the thermal image was combined with a lidar-derived DSM using a custom method that involves darkening the luminosity channel in LAB colorspace according to the non-linearly weighted, slope-derived image.

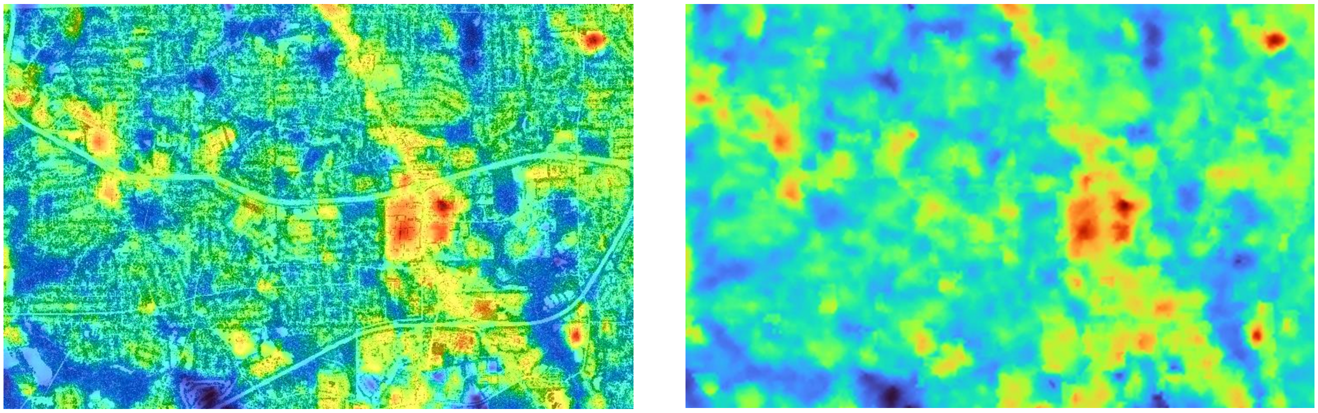

Figure 3: DSM Shaded and unshaded thermal map of Atlanta, GA

Independent Variables: Colormaps, Cartographic Augmentations, and Scale

The study is testing 5 colormaps from among those that are commonly used to visualize thermal data. For study purposes, we have chosen to test Ironbow, ESRI temperature, blue-white-red, turbo, and Viridis, a sequential colormap suitable for use by people with color blindness (Nuñez et al., 2018).

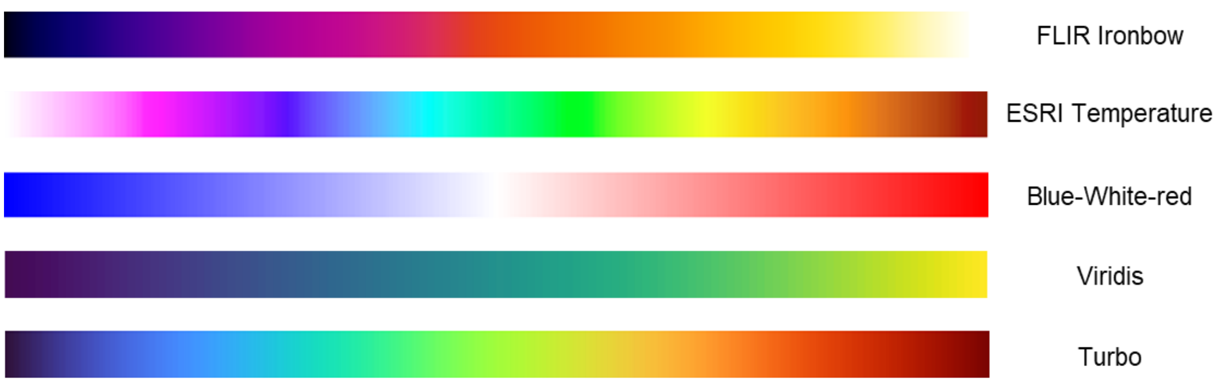

Figure 4: Colormaps for the perception study

On top of the colormaps, shading will be applied to some thermal maps to understand users' perceptions. Usually, this element is used to visualize elevation information appropriately so that the users can comprehend the difference in elevation values. For that, if this element is applied for thermal data visualization, the user may or may not understand it in a better way. The perception study will help determine whether these methods of visualization are appropriate or not.

The study will also be looking into the scales, and dimensions of the visualization. An infrared camera mounted on a drone has generated high-resolution visualization of the urban thermal environment. On the other hand, satellite images have created city-scale visualization. The perception study will help determine users' preference for scale and dimensions for interpreting urban thermal information.

Study Design

In the perception study, the users will be asked to participate in three map-reading tasks that will assess their accuracy and speed of interpretation for different types of visualizations they are shown. These tasks have been selected based on analogous similar tasks either from the widely used Topographic Map Assessment (Newcombe et al., 2015) or from a lidar visualization study (Pingel & Clarke, 2014). A minimum of 60 participants will be tested. The whole study will be administered through PsychoPy. The first task is the pairwise comparison task where the users will be asked to identify areas with higher temperatures. The participants will be given a map where two points will be identified, and they will be asked to identify the area with higher temperatures. This question is modeled after the Topographic Map Assessment Task 7 (Newcombe et al., 2015), shown in the figure below. Throughout 50 questions, users will be shown a thermal map and asked to decide which of two points (A or B) has a higher temperature. Through a series of successive comparisons in which accuracy and response time are measured, we can determine the relative effectiveness of each map type.

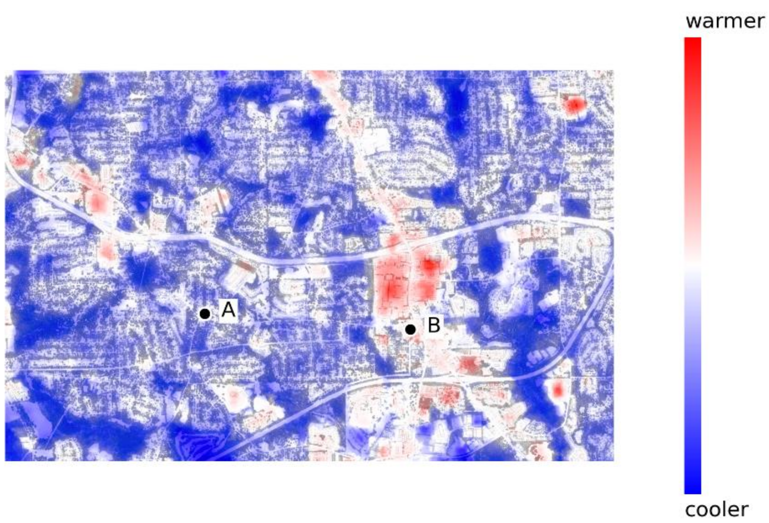

Figure 5: Pairwise map-reading task for thermal map

The next map-reading task is the profile estimation task of thermal profile for a cross-section of an area on the map. The users will be asked to select the exact thermal profile for a line that is drawn over the map image that is given in front of them. This test will help to understand whether the participants can interpret information from the map or not. As with other tasks, both accuracy and response time will be measured over 50 presentations. This test is analogous to both the TMA (Newcombe et al., 2015) and Pingel and Clarke (2014). The profile estimation task tests map-reading ability on thermal maps, in a way like how UAV-derived thermal data is presented by Song & Park (2020).

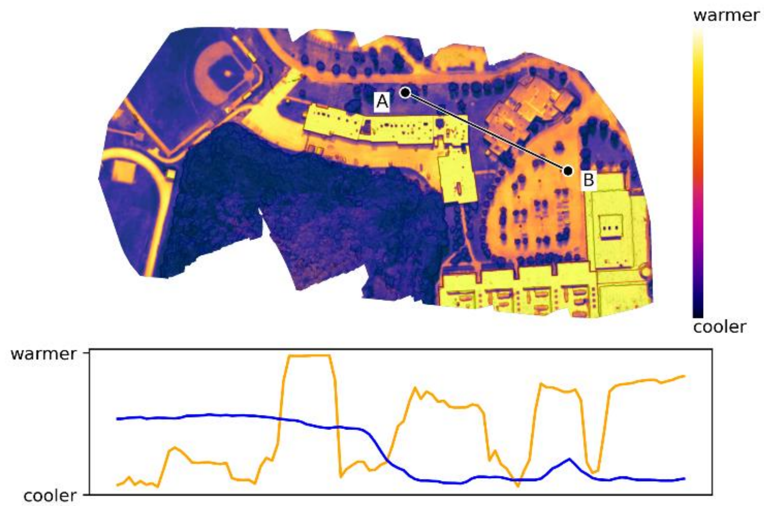

Figure 6: The profile estimation task tests map-reading ability on thermal maps

The last map-reading task is the map rotation task based on Shepard & Metzler (1971) and Pingel and Clarke (2014). This task presents two extracts of a thermal map, one of which has been rotated and a half which is also reflected/mirrored. Users are asked to identify whether the second map has also been reflected, which requires them to match key points in images and to mentally rotate them to see if they match. The task measures the saliency of visualization.

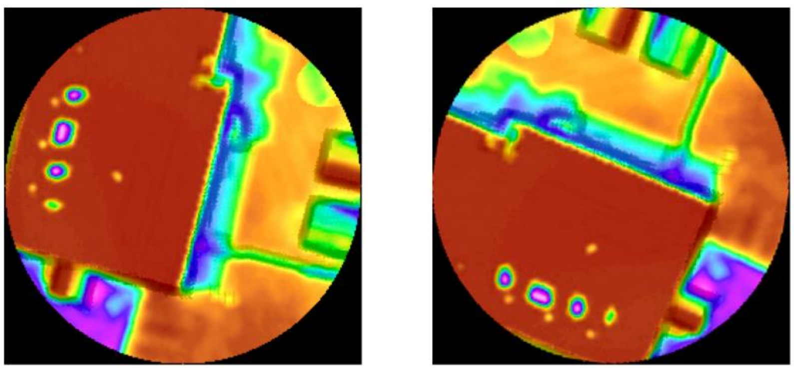

Figure 7: Map rotation task for thermal maps for the perception study

Results

The experiment is still in progress and participants are still being tested. We expect to finish the experiment and the data analysis by the end of July 2022. The hypotheses of the study are:

- We expect that some colormaps will show significant improvement over others, according to an ANOVA analysis. We expect turbo and ironbow colormaps to result in better participant performance.

- Based on users’ perception, we expect that the high-resolution urban heat map will have a better participant performance than the lower-resolution, satellite-derived heat map.
- We expect that maps with cartographic augmentations, such as shading will have a better participant performance than the maps without the augmentation.

Discussion and Conclusion

The research will focus on studying the urban heat island (UHI) effect on a finer scale by developing a novel method of building a high-resolution thermal model of urban areas using drones equipped with an infrared camera. The result will provide both 2D and 3D very fine-scale data for smaller areas in the cities. The choice of visualization method in terms of scale and colormap varies widely, and the choice of cartographic representation affects people’s understanding. To address that, a perception study comprised of 3 map-reading tasks is being conducted that will assess the perception of users for different urban thermal model visualization in terms of speed and accuracy of the interpretation.

The research will help understand how the urban landscape elements influence at a small scale to relate to their heating experience. In general, the UHI effect is studied using satellite-derived imageries which have limitations in terms of resolution, view bias, and revisit times. Studying the UHI effect with drones equipped with infrared sensors 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. On top of that, the perception study will allow for assessing the effectiveness of different UHI visualization methods which will help increase the understanding of this phenomenon.

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