GOES-16 Urban Land Surface Temperature Calibration Using a Handheld Infrared Sensor Framework

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Abstract

Satellite based remote sensing data are increasingly used for urban meteorological applications, particularly to study urban heat island impacts. However, the land surface temperature, a critical variable used to characterize the urban thermal state has never been calibrated for urbanized landcover. This will in turn escalate the uncertainties in various applications (like weather forecasting in urban areas) which use remote sensing data. This research focuses on the development and testing of an Arduino-based, GPS-enabled, non-contact passive infrared temperature sensor that provides ground-truth temperature validation of the Geostationary Operational Environmental Satellite, GOES-16, and its LST operational product. It is posited that high-resolution, multi-point, near-surface temperature information will improve LST algorithms and ultimately advance the application of satellite data to study urban climate. New York City (NYC) is used as a test site for the temperature sensor along with its geographically-respective satellite calibration points. The analysis anticipates expansion into several U.S. cities, pending preliminary evaluation and testing in NYC. GIS tools will be used to visualize data points atop geographic maps, with the intention of correlating more built-up landcover regions with temperature differences quantified by the ground-based sensor and the GOES-16 LST data. The Arduino sensor is equipped with a thermocouple to provide real-time calibration measurements on the encountered surfaces to ensure that parameters such as emissivity are captured, as well as accurate and repeatable infrared temperature readings. The enhancement of satellite information improves the well-being of the general public, which can save lives during extreme weather events such as heat waves. The research presented here intends to broaden the LST calibration network available to satellites by providing a ground-based, portable sensor framework that is implementable across cities and urban areas.

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Motivation

Satellite-based remote sensing data are increasingly used for urban meteorological applications, particularly to study urban heat island impacts. One important variable, the land surface temperature (LST), is often used to characterize the urban thermal state. Unfortunately, LST calibration is sparse in cities, which can escalate the uncertainties in various applications (such as weather forecasting). This research introduces the development and testing of a portable, GPS-enabled, ground-truth, non-contact infrared temperature validation tool for comparison against LST products developed by environmental satellites.

Design and Theory

The following were the primary design constraints for the sensor:

- Portability and handheld structure
- Non-contact temperature measurement
- Data saving capabilities
- Geographic positioning (GPS)
- Secondary temperature measurement for calibration

Non-contact temperature measurement has periodically been used to calibrate land surface temperature and emissivity of materials (Wan, 1996; Rigo, 2006; Chen, 2016), and the methods applied to those studies are used as guidelines for the sensor developed here.

Using a common radiation balance used in pyrometry, the emissivity of an object can be found using the following relationship (Coppa, 2005):

$$\epsilon = \frac{T_{obj}^4 - T_{amb}^4}{T_{tc}^4 - T_{amb}^4} \quad (1)$$

where T_{obj} is the temperature of an object measured by a thermal infrared (IR) radiation sensor with assumed emissivity of 1. The ambient temperature is T_{amb}, and the true temperature of the object is T_{tc} - which is measured using a thermocouple. Finally, ϵ is the emissivity of the radiative body.

The inverse of Eqn. 1 is also used as the approximate LST value for the IR sensor:

$$T_{LST} \approx \left(\frac{T_{obj}^4 - T_{amb}^4}{\epsilon} + T_{amb}^4 \right)^{1/4} \quad (2)$$

where T_{LST} is the land surface temperature approximated by the non-contact IR sensor after the thermocouple is removed from the ground. This LST temperature allows for faster and easier collection of temperature points on the ground.

Implementation

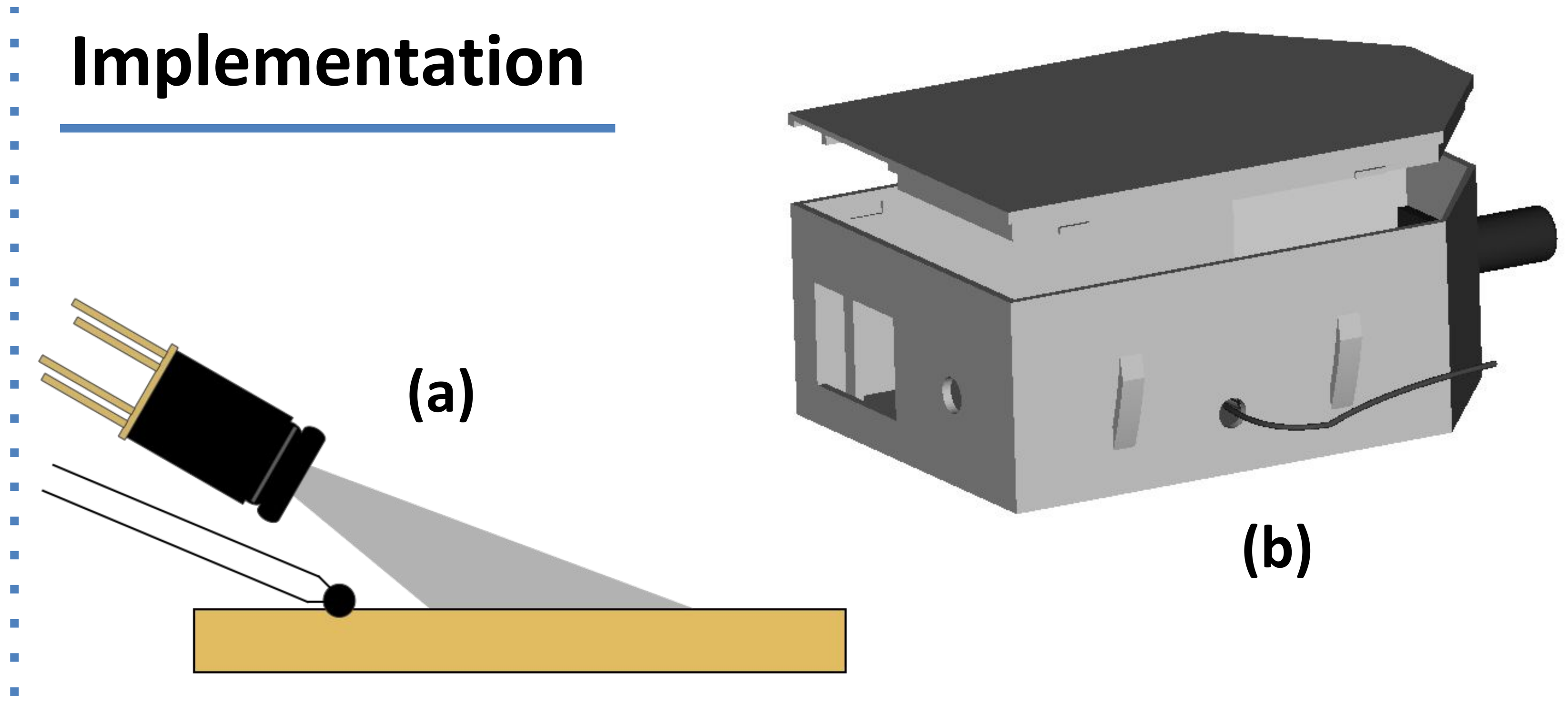

Figure 1: *(a) demonstration of in-field usage of IR sensor and thermocouple (not to scale). (b) computer drawing of the handheld infrared sensor.*

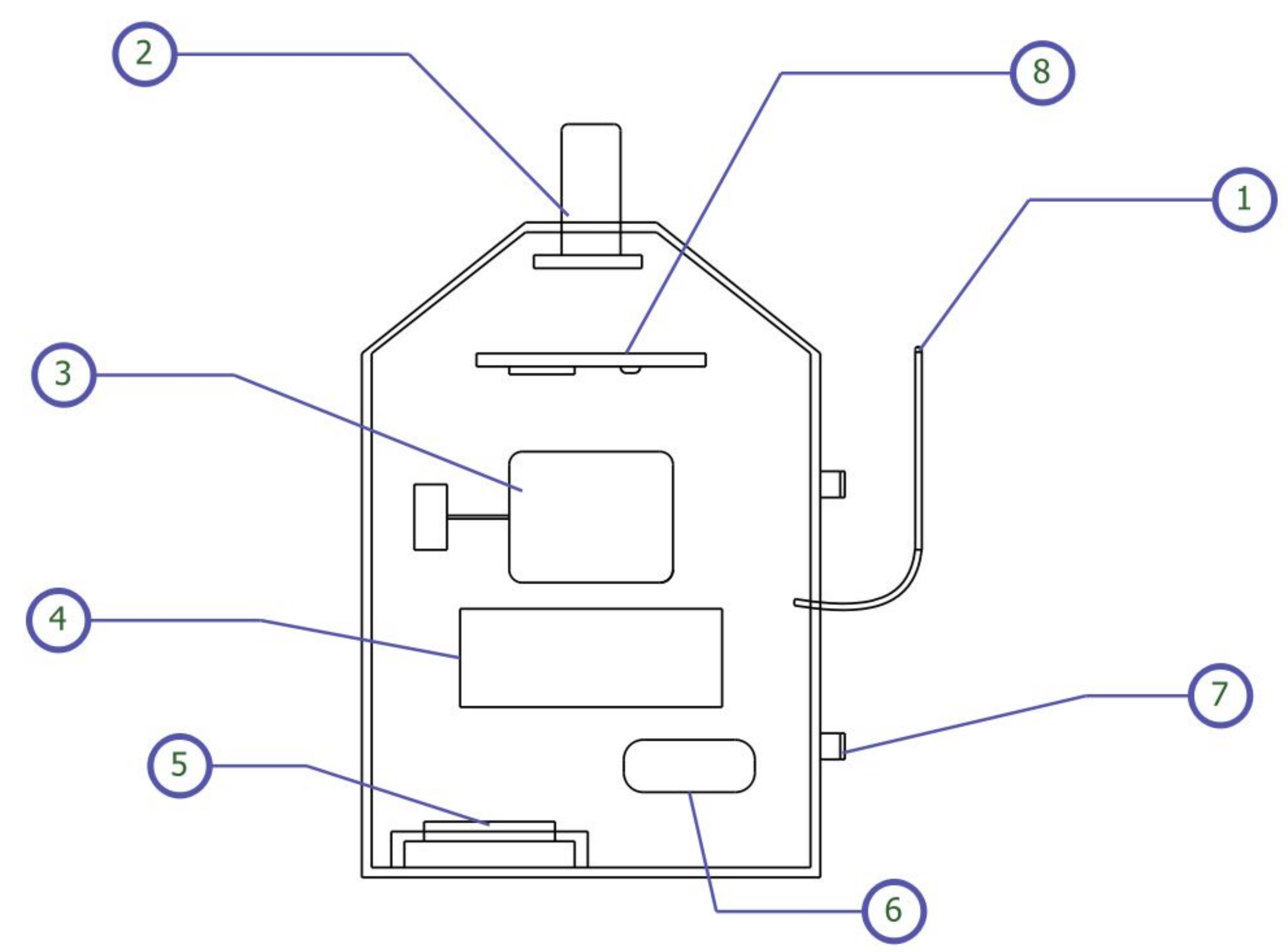

Figure 2: *Component breakdown of the handheld infrared sensor.*

1. Thermocouple
2. Non-Contact IR Sensor
3. GPS Module
4. Microcontroller
5. LCD Display
6. Battery
7. Thermocouple Supports
8. Data Saver Module

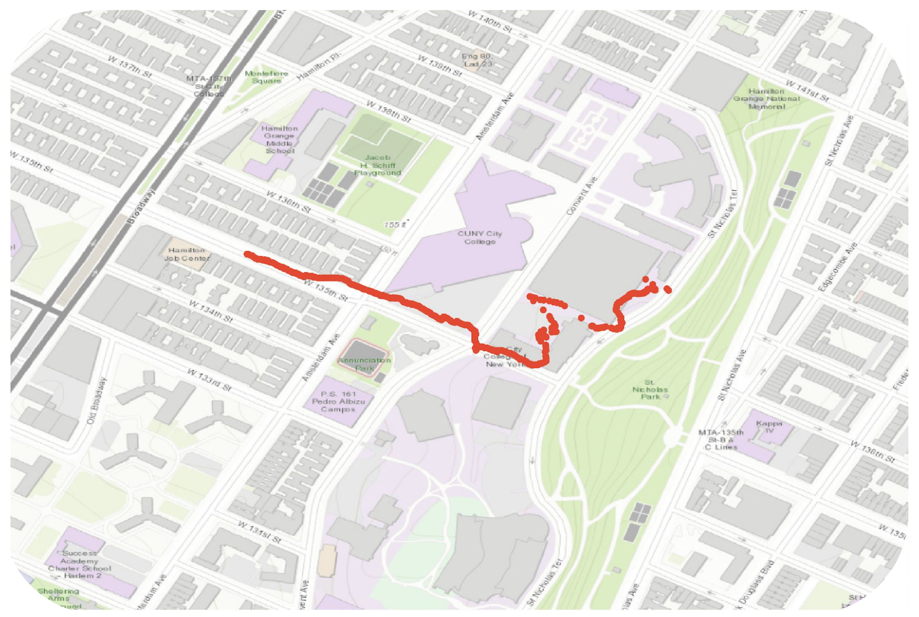

Figure 3: *Map of data points used as test coordinates in NYC for the IR sensor.*

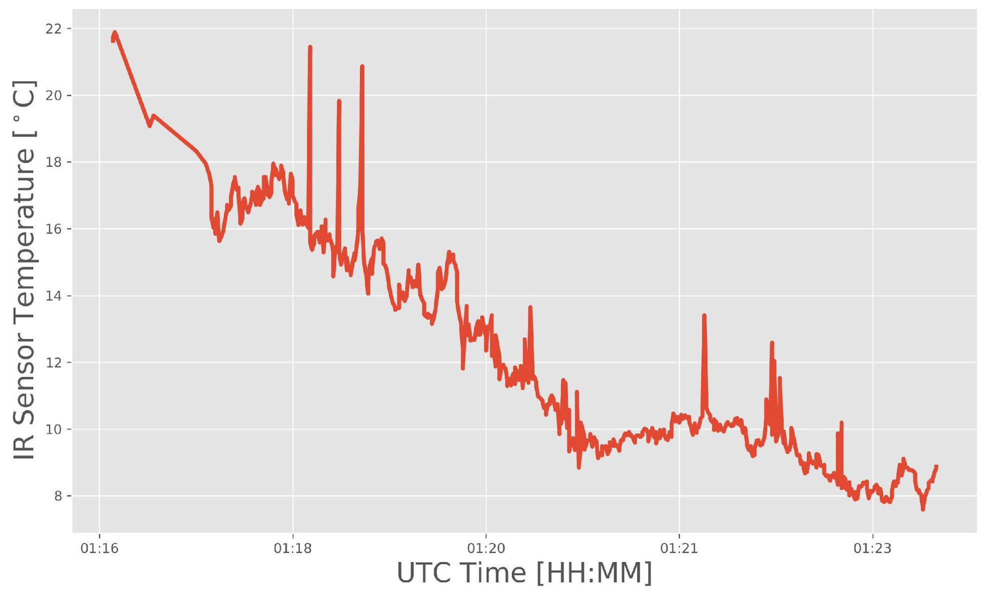

Figure 4: *Temporal variability of surface temperature points in NYC for test period. Note: satellite points were unavailable due to cloud cover.*

Conclusion and Future Work

A handheld infrared sensor framework was introduced as a method of calibrating land surface temperature data produced by environmental satellites, specifically for improved representation in urban environments. The design and implementation of the sensor was presented, and the necessary steps for a large-scale analysis to follow. In the future, the research will be expanded in both New York City and to other cities with varying landscapes – all with the desire to decrease the uncertainty between land surface temperature derived from satellites and ground-truth surface temperature. The sensor framework has also been submitted as a provisional patent.

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