Toward a high resolution temperature distribution map using crowdsourcing smartphone battery temperature

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Introduction

- Temperature is a physical quantity that is very important to environment and human health
- Air temperature data, including urban one, is important for meteorology, energy demand planning, urban heat islands (UHI)[1], effects of temperature on human health
- Air temperature data of cities is often not available, especially high temporal and spatial resolution data

[1] UHIs are areas in urbans those have temperature higher than their surroundings

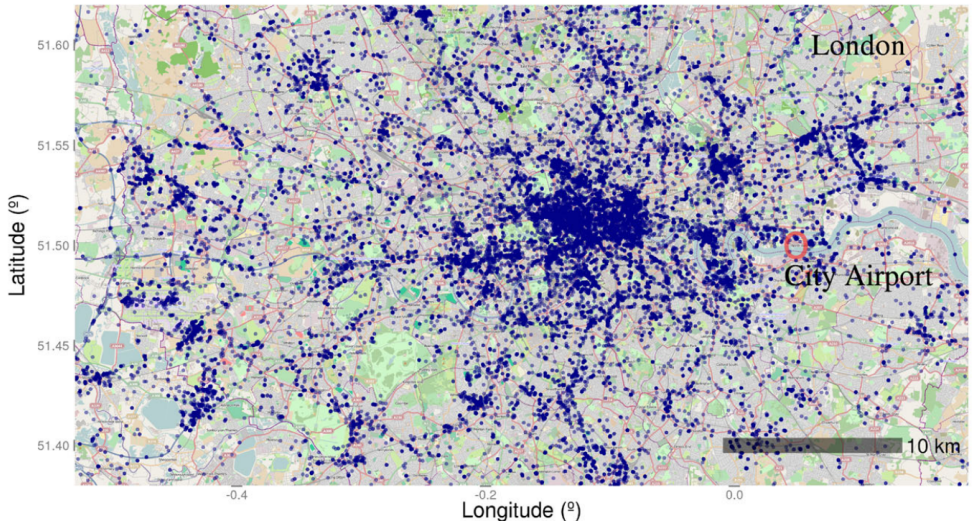
Temperature data observation approaches

- Observation approaches:

Method	**Temporal resolution**	**Spatial resolution**	**Accuracy**
Weather station	High	Low	High
Satellite	Low	High	Good
Internet of Things	High	Average	High
Smartphone	High	High (in cities)	Good

- Each smartphone has a battery temperature sensor to avoid overheating
- The sensor can be used to measure air temperature indirectly

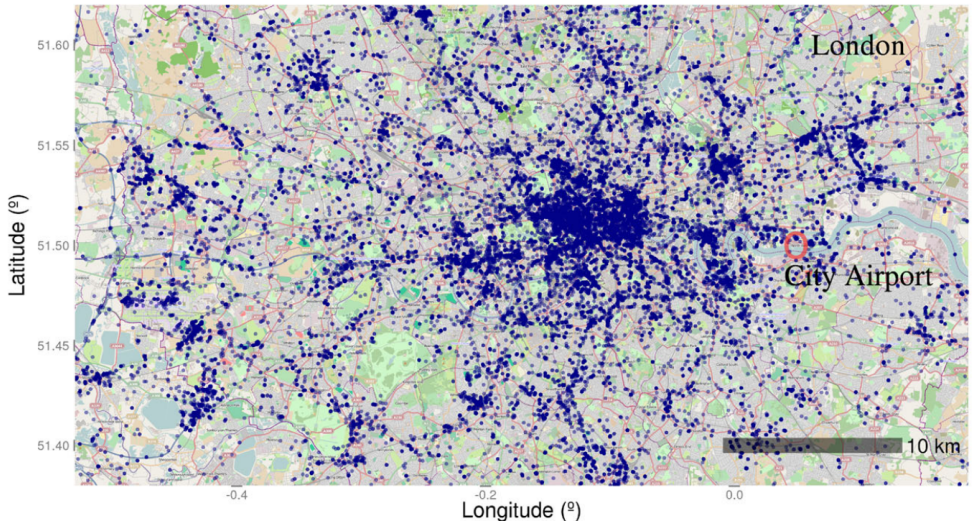
Overeem's crowdsourcing approach



- Overeem et al.: Collect data from a large number of smartphones, then use a **heat transfer model** $(HM)^2$ to estimate air temperature:
  1. Filter: [Just plugged in + start charging] and [being turned on/off + discharging] and [battery temperature from 10-47°C]
  2. Average temperature readings by space and time
  3. Build a simple linear regression model to estimate air temperature from the averaged values

[2] A. Overeem et al., *Crowdsourcing Urban Air Temperatures from Smartphone Battery Temperatures*, Geophysical Research Letters **40**, 2013, 4081–4085

Overeem's crowdsourcing approach



- Estimated temperature is representative for areas, such as cities
- Accuracy depends on number of readings
- Assessment: Compare to a weather station (distance 5-27 km)
- Android app: WeatherSignal (https://goo.gl/Fefgoi)
- Promising results in some cities: Rome, Sao Paolo[3], Buenos Aires

[3] A. Droste, A. Overeem et al., *Crowdsourcing Urban Air Temperatures through Smartphone Battery Temperatures in Sao Paulo, Brazil*, Journal of Atmospheric and Oceanic Technology **34**, 2017

Our approach: crowdsourcing + statistical model

- We use a **statistical model** (SM):
  - When a smartphone is in idle state, its battery temperature is correlated with its surrounding air temperature
  - We build a simple linear regression model to estimate air temperature from *idle* smartphone battery temperature readings
- Difference from HM approach: Estimated temperature is representative for each smartphone environment:
  - Each smartphone estimates air temperature independently
  - *Ability to have maps of temperature distribution*
- Assessment: Compare to a nearby thermometer

Experiments design and model building

- Equipments:

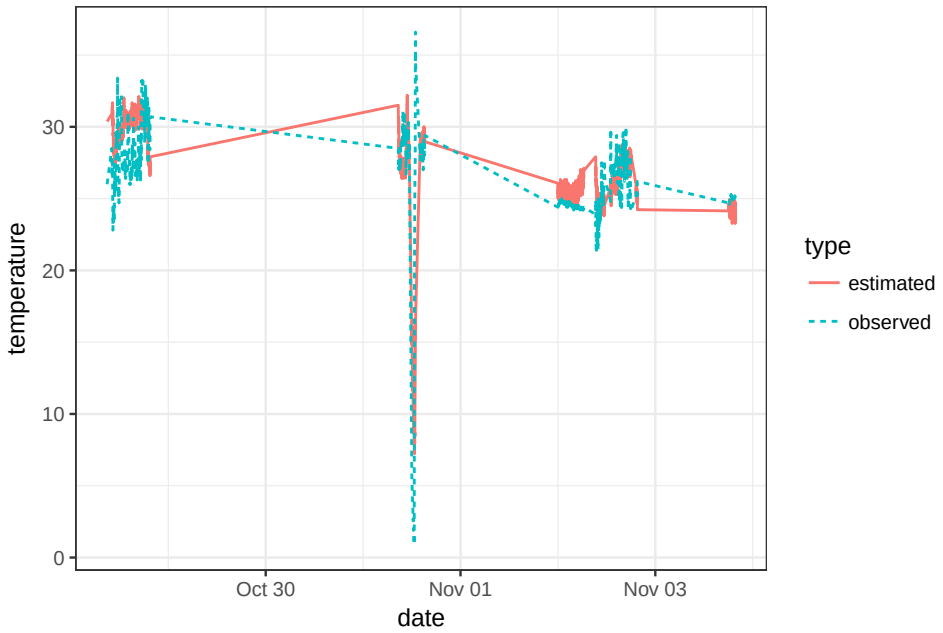
Smartphone model	Manufacturer	OS version	Air temperature sensor
Nexus 4	LG Electronics	Android 5.1	not available
Galaxy Note 2	Samsung	Android 4.4.2	not available
Galaxy Note 3	Samsung	Android 4.4.2	available

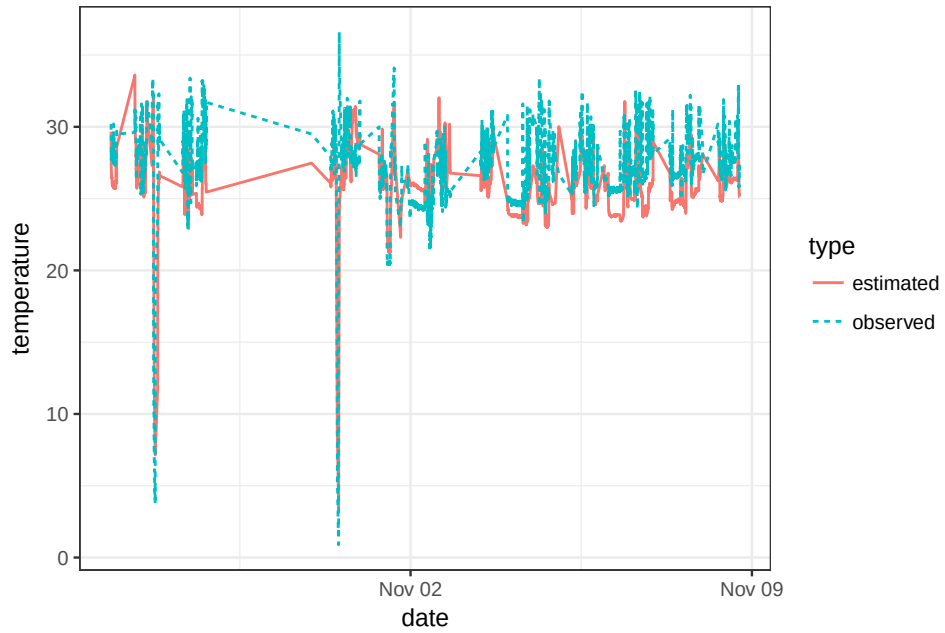
- Environments to collect data: $0 - 4°C$, $20 - 25°C$ and $30 - 35°C$
- A part of temperature data collected from the Note 3 is for training data, the rest and data from Nexus 4, Note 2 are testing data
- Our model for air temperature estimation:

$$T_{air} = 0.8765 \times T_{battery} + 0.4776, \quad (1)$$

coefficient of determination of the model is $R^2 = 0.79$.

Experiment results



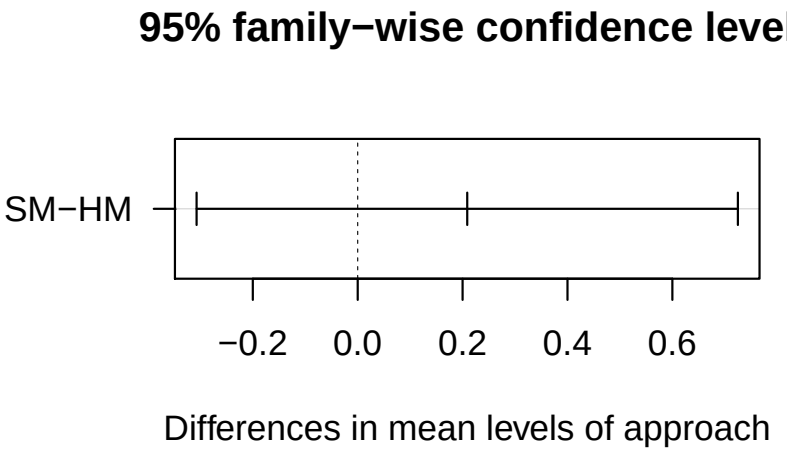


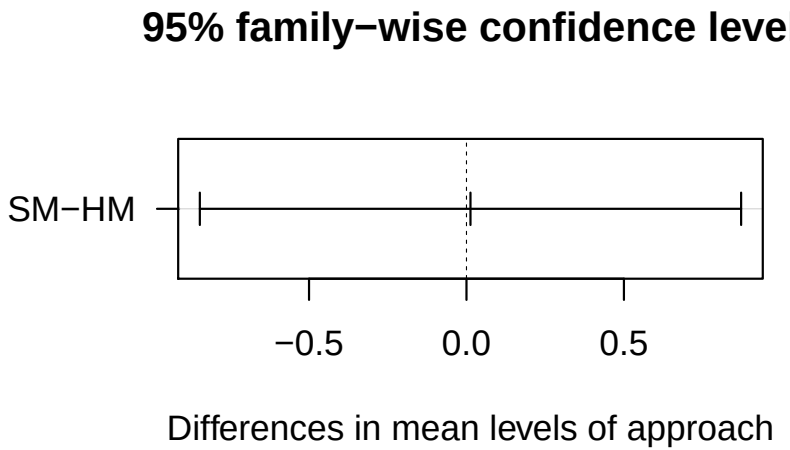
Left: Test result for Samsung Galaxy Note 2, right: test result for LG Nexus 4.

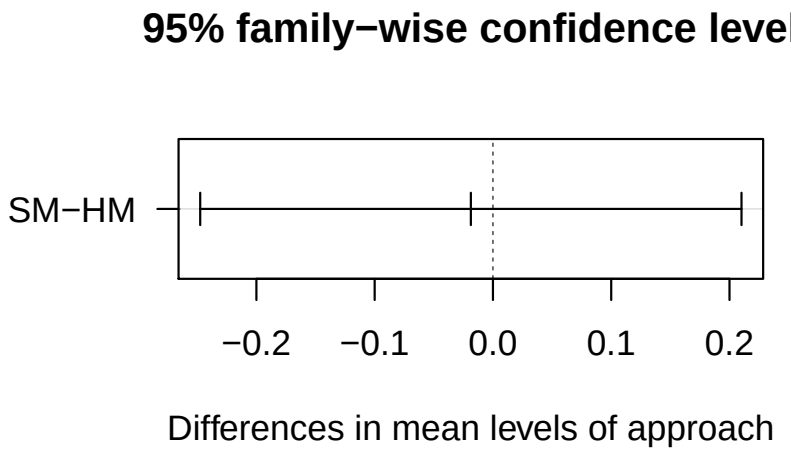
Smartphone model	**ME**	**MAE**	**Correlation**	**R^2**
Nexus 4	1.11	1.86	0.79	0.62
Galaxy Note 2	-0.82	2.03	0.74	0.55
Galaxy Note 3	0.00	0.95	0.89	0.79

ME: Mean error, MAE: Mean absolute error, R^2: Coefficient of determination

Comparison of SM and HM approaches





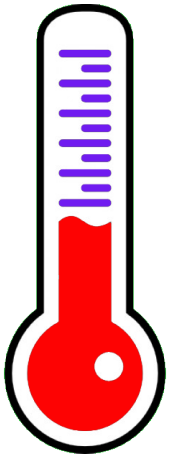


Left, right, bottom: Comparison using ME, MAE and R^2 metrics

SM = Statistical model, HM = Heat transfer model

Smart Thermometer: A Proof of Concept app

- Smart Thermometer (https://goo.gl/G2BEPQ) is an Android app for estimation of air temperature using Equation (1)



- Beta launch: end of 2015, public launch: Mar 2016. Current status:
  - More than 60K downloads, average 1,200 use per day, user rating = 3.2/5.0
  - Data from the app is not yet collected

Summary

- SM is comparable to HM in ME, MAE and R^2 metrics
- Advantages of SM:
  - Each smartphone estimates air temperature independently
  - Maps of temperature distribution
- Future works:
  - Additional predictor: *battery current* (Android 5.x or newer)
  - Use an independent temperature sensor for model building
  - Recognization of smartphone context: Indoor/outdoor, in pocket (clothing), in transportation means
  - Anonymous data collection, data fusion with other source of data (Landsat, IoT)

Thank you for your attention!