APPROACHES TO FUSE FIXED AND MOBILE AIR QUALITY SENSORS

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MOTIVATION

- Current fixed stations are sparsely distributed (mainly due to costs)
- Fixed stations usually avoid measuring the air at head height
- Fixed stations are expensive

- Fixed stations also are the most accurate source of measurements available

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- Mobile sensors are inaccurate
- Mobile sensors are hard to calibrate

- Mobile sensors are cheap, so can be used in numbers
- Mobile sensors measure where the people are

A TYPICAL FIXED STATION FOR AIR QUALITY

TYPICAL MOBILE SENSORS

NANO SENSOR AGING

- Reduced sensivity
- Shifting zero readings

- Longer time constants
- Noise?

- → Sensors get unreliable over time

- Recalibrating those sensors take away most of their benefits.

THE CHALLENGE 1

- Get an approximation of the Air quality at any location of an area (city) for a certain point in time.
  - Current goal: Get input for a pollution driven routing service for pedestrians and bikers.

- Mathematical view point: Get a function value at any location from just a few known locations
- Use all available information
- Model reliability when using information

THE CHALLENGE 2

- Replace missing calibration of mobile sensors by other means
- Find unreliable sensors

SOLUTION APPROACH FOR INTERPOLATION

- You need an interpolation method that takes sensor errors into respect.
- You need an interpolation method that models the representative area of a sensor

- Candidate: Kriging
- The kriging approach:
  - A sensor is representative for an area.
  - The closer a location is to a sensor, the more the sensor reading reflects the real value at that location.
  - If several sensors represent the same location, the resulting value is chosen from the conflicting values such that the error (sum of squares) is minimized.
  - $Z(\vec{l}) = \sum \gamma_i Z(\vec{l}_i)$. (Constraint: $\sum \gamma_i = 1$)

THE COVARIANCE FUNCTION

- With Kriging the covariance function is usually chosen such, that it is 1 at the exact location and zero at infinity. In between the function decreases monotonically.
- → Many different functions are possible

- There is no mathematical reason why the covariance function must be 1 at the location (remember, the sum is normalized to 1 anyway).
- We use this to express the reliability of a sensor, i.e. we integrate „trust“ into the covariance function such, that a less trusted sensor has a covariance value of e.g. 0.5 instead of one. → Trust factor
- → A fixed station dominates the readings of mobile sensors in its vicinity.
- → But if several mobile sensors have the same reading they can still „overrule“ the fixed station.

GAINING TRUST FACTORS

- We assume that the mobile sensors are well calibrated.
- We also assume we can measure the same value often without other influences
- Then the measurements show only random errors around the „real“ value (Gaussian distribution)
- The width of the distribution is a measure for the „trust“.

- In real life you cannot measure the value often
- Other effects will „pollute“ the sensor readings. How to distinguish those from sensor related noise.
  - Solution:
    - Compare each mobile sensor to an interpolated value.
    - „Low pass“ filter trust values so that single events don‘t have too much effect.

GAIN CORRECTION VALUES (1) (ON-THE-FLY CALIBRATION)

- As mobile sensors age and can‘t easily be re-calibrated we need a way to get correction factors

- Solution: Compare the sensor readings to other readings.

- Approach 1:
  - Each time a sensor comes to the vicinity of a fixed station the values can be compared.
  - Use this as a reference value to calculate individual correction factors for the mobile sensors
  - Problem: Will only work if sensors get near enough to a fixed station to have reliable values

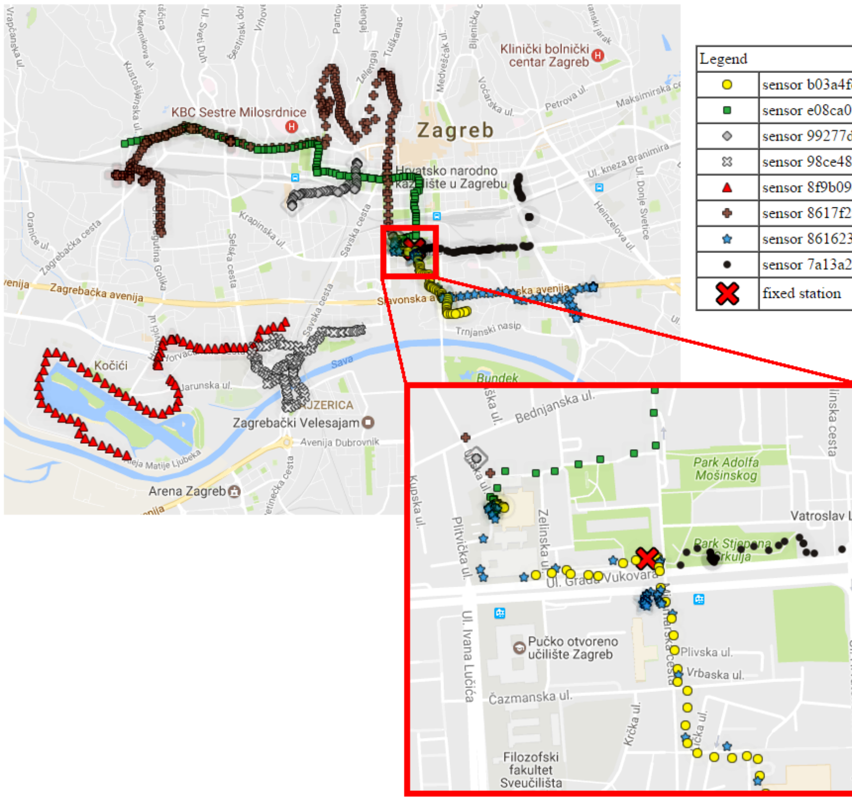
GAIN CORRECTION VALUES (2) (ON-THE-FLY CALIBRATION)

- Approach 2:
  - Each time two sensors measure at the vicinity of each other they can be compared.
  - Use kriging of all values to get an interpolated value field.
  - Use this as a reference value to calculate individual correction factors for the mobile sensors so they all measure the same. This is not necessarily what the fixed stations will measure!
  - Calculate a correction factor that minimizes the error of the interpolated mobile sensors compared to the fixed stations. Apply these global correction values to each individual correction set of corrections.
  - Problem: Much more complex and effort

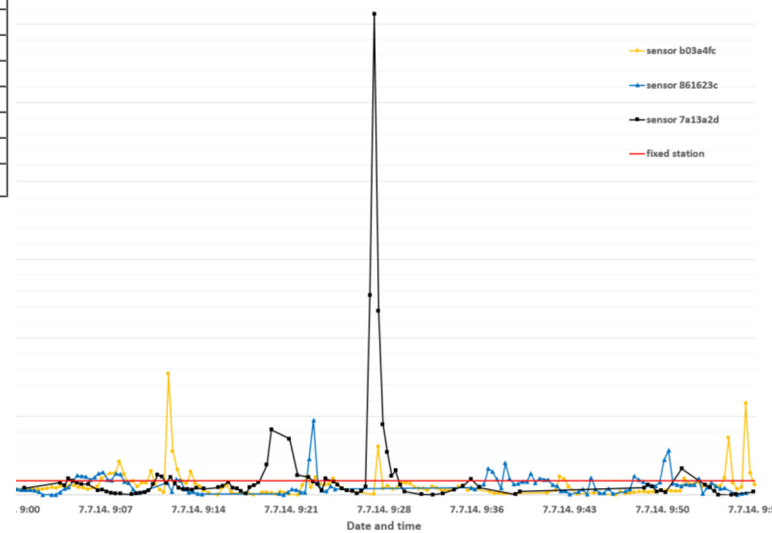
TRYING THE CONCEPTS IN PRAXIS

- We tried these concepts with sensor data from a field trial in july 2014.
- Data evaluation was done in 2017, so there was no chance to repeat those measurements easily.

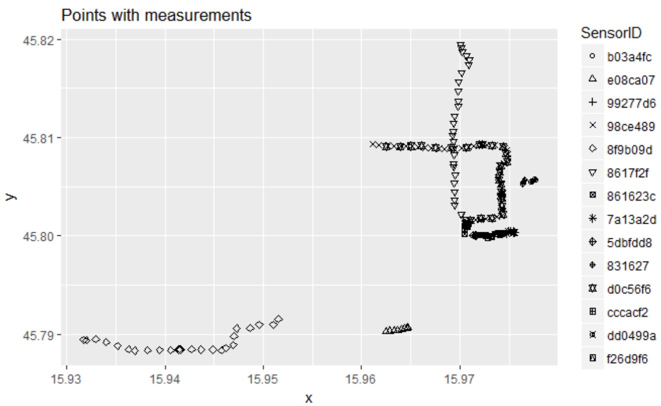
TEST SETUP

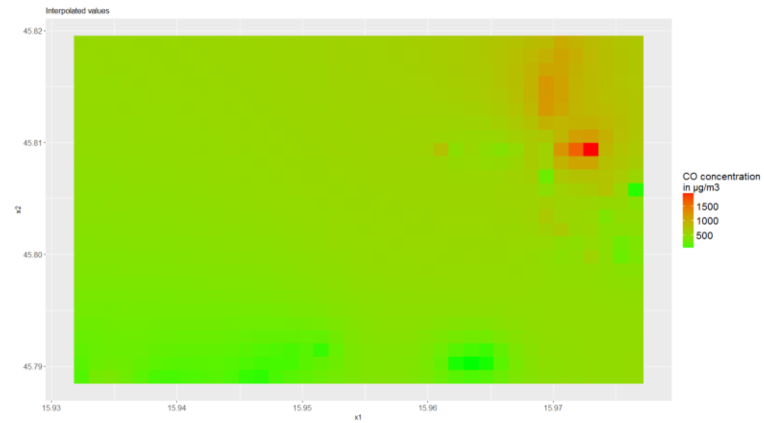


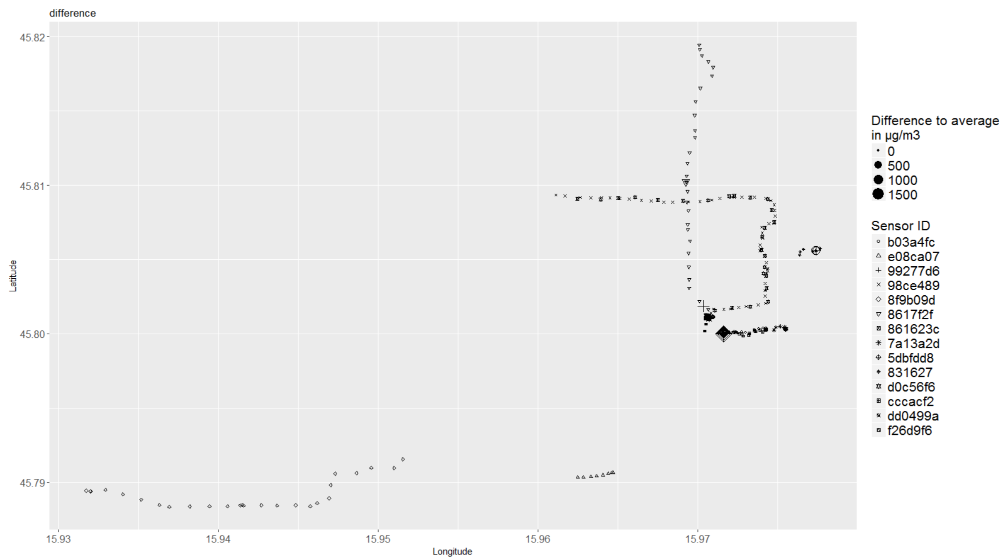
Legend	
○	sensor b03a4fc
■	sensor e08ca07
◆	sensor 99277d6
✻	sensor 98ce489
▲	sensor 8f9b09d
✚	sensor 8617f2f
★	sensor 861623c
●	sensor 7a13a2d
✖	fixed station



DATA EVALUATION







TEST RESULTS

- Participant paths where not planned well so there aren‘t many meetings
- Sensors worked well with very low deviations when they met so there was not enough data to try correction algorithms.

- The different sampling periods between mobile sensors (20 sec.) and the fixed stations (1 hour) were much too different. → Doing a Least Mean Square fit simply isn‘t possible if there is only one value to fit against.

RESULT DISCUSSION

- Using Smart Sensors needs a certain density to allow significant statistics.

- Using Smart Sensors needs collaboration of Fixed Station Operators. The officially published values have a much too low time resolution.

- Pure kriging is not sufficiant in an urban environment. We need methods to take asymmetrical spreading of pollutants (mainly due to street canyons) into account → complex modelling needed?

OUTLOOK

- We are planning another field test in June 2017.
  - We want to restrict the area of the test and we want to control sensor locations to have more „meetings“.
  - We want to manipulate some sensors to have malfunctions.
- We try to collaborate with the Vienna Monitoring Network to get data with better time resolution.
- We want to evaluate other mathematical methods for the interpolation.

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TOMORROW TODAY

THANK YOU!

Gerhard Dünnebeil, 10.May 2017