Demo Abstract: Route Selection of Mobile Sensors for Air Quality Monitoring

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***Abstract*—Monitoring air pollution in cities requires installation of a huge number of static sensors which is both cost and labor intensive. For this reason, we consider the installation of mobile sensors on top of public transport vehicles. This leads to the problem of selecting a subnetwork of a city's public transport network to achieve a good coverage in the area. Since failures and signal drift over time are typical for low-cost sensors, the selected vehicles have to occasionally be in each others vicinity to allow sensor recalibration. If the vehicles can pass by reference stations, the recalibration quality can be further improved. In this demonstration, we illustrate different solutions to the problem of subnetwork selection based on the tram network of Zurich and visualize the results in Google Maps and Google Earth.**

I. Air Quality Monitoring in a City

Air pollution has risen to be the most pressing matter of environmental policy in modern urban areas. High concentration of traffic and industrial facilities heavily impact ecological sustainability and quality of living in the area. Monitoring air pollution has been addressed at many levels, but mostly through legislative decisions and standards. Due to high cost, weight, and size of traditional air pollution measurement instruments, there are still no *detailed* maps of air pollutant distributions in cities. To address this deficiency, we work on combining low-cost gas sensors, that become available on the market in the last several years, with wireless sensor networks for air pollution monitoring applications. In particular, we install sensing stations on top of several public transport vehicles to achieve better coverage than provided by statically deployed measurement stations. Public transport networks form an attractive backbone for performing periodic measurements due to a large number of spatially spread predefined routes, a fixed timetable, and a usually good operability.

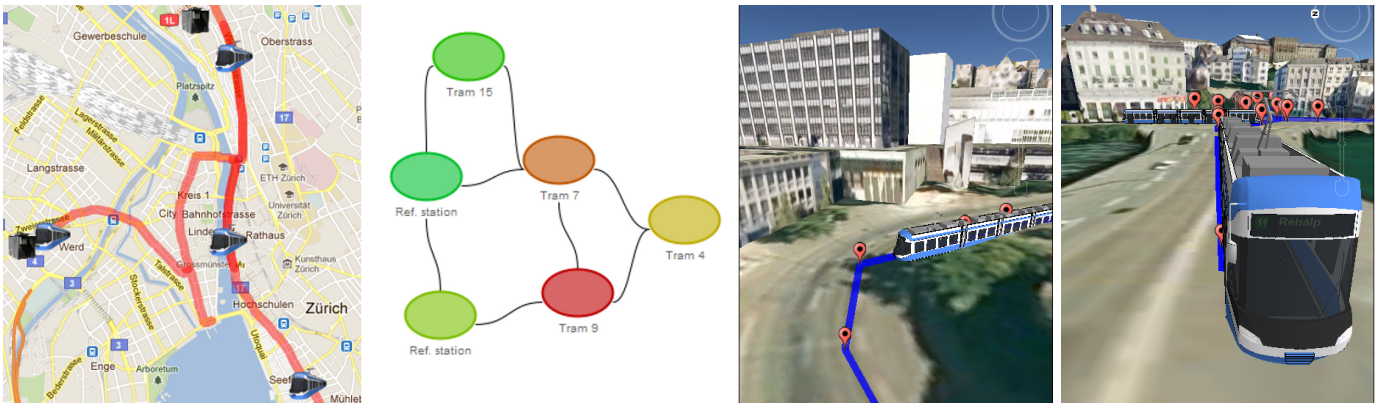
The problem we face is, given a route plan and a timetable, how to choose a subnetwork of the public transport network to provide a good coverage of the city with a limited number of sensors. Additionally, since our measurement stations are equipped with low-cost gas sensors, the final subset of selected vehicles has to allow comparing sensor readings of different sensors, *i.e.*, we require that different sensors occasionally take measurements at the same time and location. We refer to this problem as *sensor checkpointing*. This allows detecting sensor failures and provides the necessary support for sensor recalibration, possibly over multiple hops [3]. Sensor checkpointing naturally implies the simultaneous presence of the corresponding mobile vehicles at the same place.

We analyze the coverage problem with and without sensor checkpointing based on the pollution monitoring scenario in the city of Zurich, Switzerland as part of the OpenSense project [1]. The long-term goal of OpenSense is to raise community interest in air pollution data and to encourage involvement of the public using enhanced cell phones or pocket sensors. We hope to foster community interest and involvement in data gathering by establishing an initial coverage of the city with a network of ten measurement stations installed on top of trams in Zurich. The goal of this demonstration is to visualize the solution to the problem under various parameter settings including the number of deployed mobile stations, the spatial and temporal checkpointing constraints, and the locations of the reference stations. The solution is demonstrated in Google Maps and a simulation drive with a selected tram in Google Earth.

II. Sensor Checkpointing

We consider an area of interest to be the spatial spread of a city and a time interval. A mobile vehicle with a sensing station installed on top of it is moving along a spatiotemporal curve. It can take measurements everywhere during its movement with no restrictions. A measurement consists of a location and a timestamp, and has no duration. A measurement is valid in a certain area and for a certain time. The validity of measurements taken by a mobile vehicle gradually decreases towards zero with the distance from its spatiotemporal movement curve. A checkpoint occurs when the validities of two measurements performed by different vehicles are above a certain threshold, *i.e.*, if the spatial and temporal distance between them is below a certain threshold, which is a parameter of the route selection algorithm. In this demonstration we assume that a uniform coverage of the city is the goal of the route selection algorithm. One of the uniformity metrics presented in [2] can used as coverage measure. Given checkpoints between all pairs of mobile vehicles, it is possible to construct a *checkpoint graph*, where the set of nodes corresponds to the set of mobile vehicles equipped with sensing stations. There is an edge between any two vehicles if they make at least one checkpoint, see Fig. 1(b).

To enable sensor checkpointing we need to ensure that the checkpoint graph is connected. We refer to this type of checkpointing as X-checkpointing (*cross checkpointing*). X-checkpointing facilitates pairwise tests among low-cost sen-



(a) Selected trams and their positions (b) Checkpoint graph (c) Making a turn at Voltastr., Zurich (d) Checkpoint at Central, Zurich

Fig. 1. Given two reference stations, four trams of the Zurich tram network are selected for the installation of measurement stations. Visualization with Google Maps and Google Earth. Cobra tram model from the Sketchup 3D warehouse, http://sketchup.google.com/.

sors which are essential for being able to identify sensor faults and sensor recalibration needs.

The quality of checkpointing can be further improved if the sensors are regularly synchronize with a set of reference stations. Reference stations can be static or mobile and are usually capable of performing high-quality sensing. We assume that all reference stations reflect the ground truth and can be used to calibrate low-cost sensors from time to time over one or several hops, *e.g.*, using the calibration approaches described in [3]. This problem is referred to as R-checkpointing (*reference checkpointing*). Many big cities have a very sparse network of highly precise fixed stations, which can be used as references. For example in Zurich, Switzerland, there is one station of the national air quality monitoring network NABEL[1] and four smaller stations are part of the cantonal measurement network OstLuft[2]. The availability of this infrastructure allows to considerably improve the system reliability by selecting a timetable subnetwork which fulfills R-checkpointing constraints.

III. Algorithm and Demonstration Setup

The problem of route selection involves high computational complexity even for moderate-sized cities. For this reason, we use an evolutionary algorithm to solve the problem. A chromosome is a subnetwork of size k. The fitness function is the coverage of the city provided by the subnetwork. The calculation of the coverage involves discretization of the region with Monte Carlo sampling and computation of the level of coverage at sampled points. A chromosome satisfies the X-checkpointing constraint if the checkpoint graph is connected. To test a chromosome for R-checkpointing, we extend the checkpoint graph with the set of reference stations as additional nodes connected among themselves and check the extended graph for connectivity. Recall that R-checkpointing requires that each mobile vehicle is connected to a reference station, possibly over multiple hops. We use random crossover and mutation operators to generate new offsprings.

[1]Swiss National Air Pollution Monitoring Network, www.bafu.admin.ch
[2]Cantonal Network OstLuft, www.ostluft.ch

Zurich is one of the target cities in the OpenSense project to deploy a network of mobile sensors on top of public transport vehicles. The first out of ten nodes is already installed on top of a tram[3]. We run the algorithm on up-to-date data of the Zurich tram network. The track plan is obtained from OpenStreetMap[4] and the timetables from the ZVV information service[5]. The Zurich tram network comprises 13 tram lines with the involvement of maximal 260 individual trams. All demonstration runs of the algorithm are based on the tram timetable of a work day. The speed of the tram between two stations is linearly interpolated. Among others, the following input parameters can be adjusted as part of the demonstration:

- The number of *measurement stations* k.
- Evolutionary algorithm parameters: *population size, recombination and mutation rates*.
- *Locations of the reference stations* within the city.
- *Checkpointing constraints*. Relaxation of temporal and spatial checkpointing constraints generally results in a greater coverage achieved by the algorithm.

With this demonstration we aim to tackle the difficulty of visual representation of a problem solution that involves several movement paths in a three dimensional space. This problem is found when solving planning and scheduling problems on top of a timetable network. As part of this demonstration, we simulate a drive through the city on Google Earth with a selected tram and visualize checkpoints during the drive.

References

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[3] David Hasenfratz, Olga Saukh, and Lothar Thiele. On-the-fly calibration of low-cost gas sensors. In *EWSN*, 2012.

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[3]OpenSense data online access, data.opensense.ethz.ch
[4]OpenStreetMap, www.openstreetmap.org
[5]Zürcher Verkehrsverbund, www.zvv.ch