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The progress of the research project Centauro

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Abstract

The research project Centauro (Connected Environments for Negotiated Traffic Control and Urban Optimization) has been introduced with a technical paper in the 12th ITS European Congress in Strasbourg. The project deals with the evolution of traffic signal control in the era of Big Data and the Internet of Things. The current technical paper describes the most important developments and achievements of Centauro, as well as the next steps for the simulations and field tests. The goal and the research approach of the project are presented. Centauro covers four main tasks: Building the laboratory environment, analysing the potential of new data sources, developing prototypical algorithms and finally testing in the real world. The latest developments on these core tasks are being described in this paper.

Keywords:

Urban Traffic Control, Connected Environments, Traffic State Estimation

Introduction

Motivation

Urban Traffic Control (UTC) is one of the key components of dynamic traffic management and contributes greatly to safe and environmentally friendly cities. Adaptive, model-based UTC systems are considered state of the art in traffic signal control and cities invest in these systems to optimize traffic flows in their networks. However, even the most modern systems rely mainly on stationary detection, failing to capitalize on the emerging new technologies, such as Big Data and Internet of Things (IoT). A new generation of UTC systems that takes advantage of the new sensor and communication possibilities is needed. Swarco AG and the Chair of Traffic Engineering and Control of the Technical University of Munich initiated the research project Centauro, in order to examine the evolution from conventional UTC systems to connected UTC systems.

Goal

Traffic state estimation plays a central role in model-based traffic management and control applications (1). The estimation module (typically called observer) uses the measurements coming from the different sensors and feeds the controller that is responsible for the optimization (2). In order to include new measurements from new sensors in the control loop the observer needs to be extended (Figure 1).

Goal of the project is to achieve optimal traffic state estimation for traffic signal control, by integrating new data sources in the control loop of UTC systems (primarily Connected Vehicles, but not exclusively).

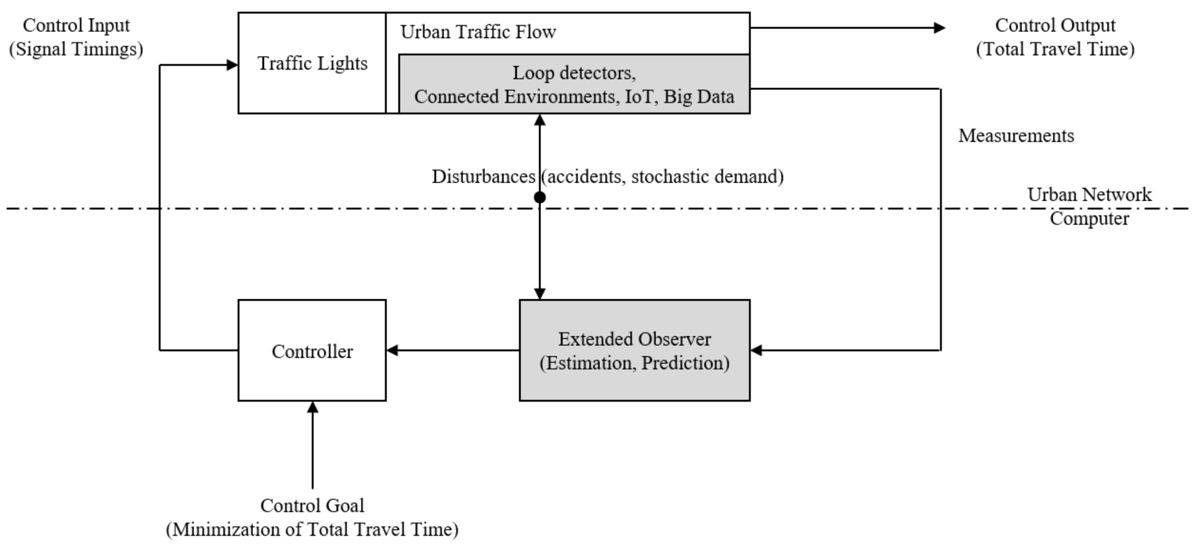

Figure 1 – Control loop of Centauro based on (2)

Approach

The project builds on the existing, state of the art, model-based, adaptive UTC system Utopia/Spot from Swarco AG. Utopia/Spot is considered perfect for research of future traffic signal control, since it provides on the one hand a solid scientific basis for further development and on the other hand a robust approach with numerous real-world implementations.
The research work of Centauro can be divided in four main tasks:

- Build the laboratory environment (technical architecture)
- Identify the potential of new data sources
- Develop algorithms in a prototype
- Perform field tests

The rest of the paper presents the latest developments of these main tasks.

Technical architecture - LAB

The laboratory environment of Centauro is built around the Utopia/Spot system. Spot contains the main intelligence and is performing the local control at intersection level, whereas Utopia is the central system that performs the network control. The traffic state estimation in Spot includes the estimation of the predicted arrivals (2 minutes' rolling horizon), the estimation of queue lengths, the estimation of turning rates and the estimation of the clearance capacity. With this information, the controller optimizes the signal timings every 3 seconds and the actuator implements the control action every second.

As mentioned previously, in Centauro an extended observer is developed, which utilizes data that go beyond inductive loop detector data (e.g. vehicle counts and detector occupancy). The new algorithms for extended traffic state estimation are developed outside of the Spot unit. This enhanced traffic state estimation is communicated to the Spot units through the communication protocol from Utopia/Spot (Figure 2). This architecture has two major advantages in terms of testing the developed algorithms:

- Flexibility in testing in a simulation environment; no need to change the source code of the Spot units.
- Simplicity in testing in the real world; tests are possible on current Spot units.

For the real world tests, the Vissim microsimulation and the Utopia Vissim Adapter are replaced by the real urban network.

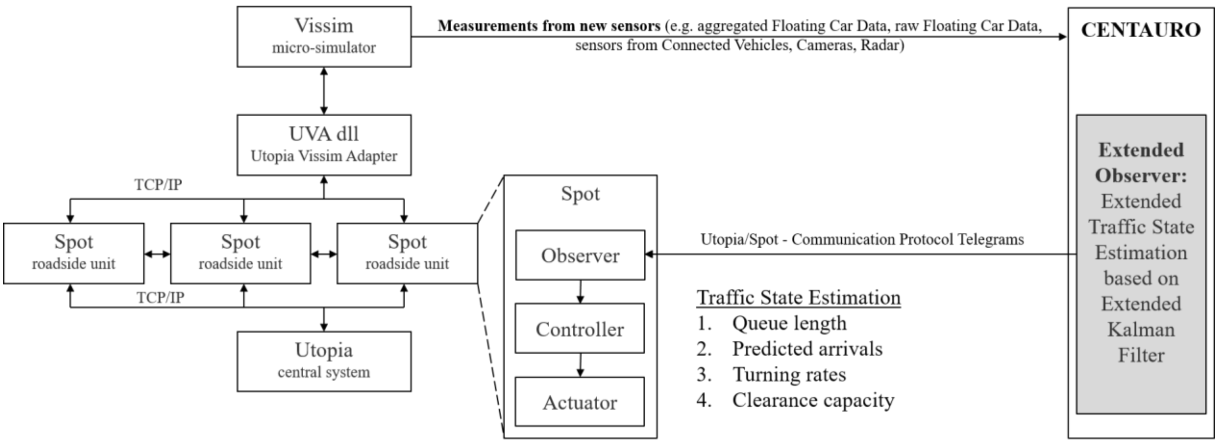

Figure 2 – Technical architecture (LAB)

Potential of currently available new sources

Even though the applications of Connected Vehicles on signal control are typically limited in demonstrations and pilot projects, there have been several simulation studies that examine the potential benefits from the introduction of Connected Vehicles in traffic state estimation (3, 4, 5, 6).

However, the focus of Centauro is not only to check the potential of theoretically available future data (e.g. sensor data from Connected Vehicles) in simulations, but in parallel to explore possibilities (in simulations and field tests) with currently available alternative traffic data. For that purpose, the most well-known traffic data providers (TomTom, Here, Inrix) are analyzed in order to evaluate their applicability in traffic signal control. For that purpose, a web application has been developed, where the three aforementioned traffic data providers can be overlaid and compared. Figure 3 shows an example analysis of a street segment in Verona, Italy where the TomTom API (Intermediate Traffic Service) is used to collect data. Figure 4 shows an example analysis of a street segment in Munich, Germany where the APIs from Inrix and Here have been used. The user interfaces shown in the figures below are not provided by the traffic data providers, but have been developed in the scope of Centauro by Noack (7). Figure 4 shows the latest version of the prototype web application.

Figure 3 – Example analysis for street segment in Verona (using the TomTom API)

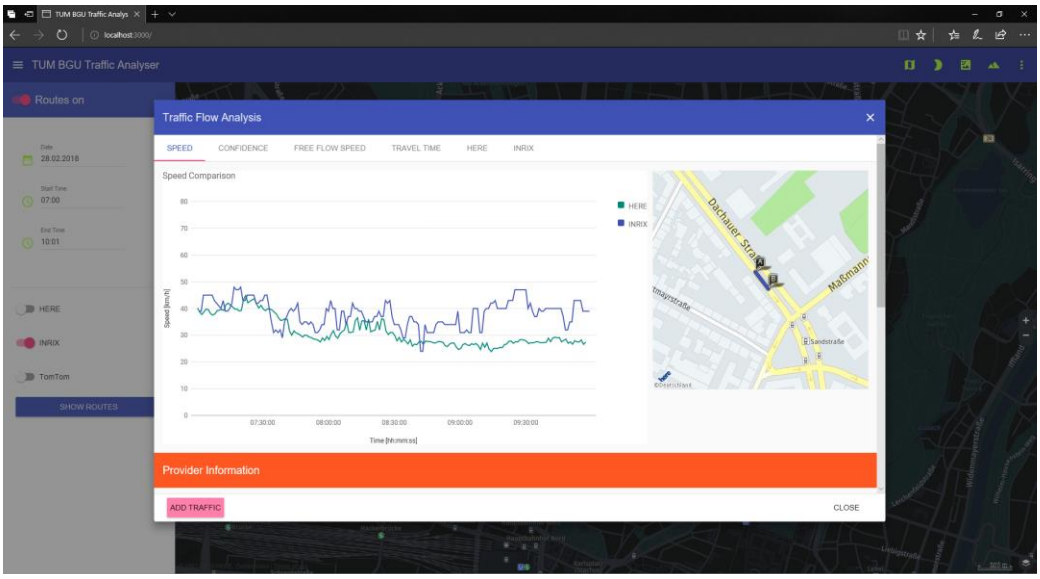

Figure 4 – Example analysis for street segment in Munich (using the Inrix and Here APIs)

Table 1 shows an overview of the data availability from the investigated traffic data providers through their APIs. At the moment all providers make only aggregated traffic data available (aggregated speeds and travel times in 1 minute intervals) and thus are not very suitable for real time traffic state estimation (e.g. queue length, turning rates), where the positioning and speed of the individual vehicles is crucial. In addition, no provider gives any information about the penetration rate. Instead, in some cases, a confidence indication is given. The map matching has proven to be the biggest challenge in the comparison of the different traffic data providers in one interface not only because of the differences in location referencing techniques, but mainly because of the differences in length segments for the same signalized approach.

	TomTom	Here	Inrix
Raw data (individual vehicles)	✗	✗	✗
Aggregated data	✓	✓	✓
Update interval	60 seconds	60 seconds	60 seconds
Data format	XML, Protocol Buffers	XML, JSON	XML, JSON
Location referencing	TMC, OpenLR	TMC, SHP	TMC, OpenLR
Penetration rate indication	✗	✗	✗
Current speed	✓	✓	✓
Free flow speed	✓	✓	✓
Travel time	✓	✓	✓
Access	License restricted	License restricted	License restricted

Table 1 – Overview of real-time traffic data providers

In the next chapter some preliminary results of the developed algorithms are shown, based on simulations of real-time raw Floating Car Data (raw FCD) and not on real-time aggregated Floating Car Data (aggregated FCD) that are in the real world currently available.

Algorithmic development

The core scientific work of the project is to develop a robust methodology that allows for optimal traffic state estimation for traffic signal control. The algorithms are based on the Extended Kalman Filter (EKF). Kalman filter is a sensor and data fusion algorithm that utilizes measurements from sensors (that might be subject to noise) and a mathematical model of the system (8). It is one of the most widely used estimation algorithms and works in two steps: the time update (based on the process equation) and the measurement update (based on the measurement equation). Many researchers (8, 10, 11, 12) have showcased that Kalman filter is a very powerful technique that, despite its limitations due to its underlying assumptions, shows good results in traffic management and control applications (1).

Figure 5 shows an example of the EKF implementation for turning rate estimation at a simulated signalized approach (one lane) based on raw FCD in the scope of Centauro. The term FCD is used in this work as synonym to Connected Vehicles, since the developed algorithms just need the typical information of timestamp and location from the equipped (connected) vehicles. If this information comes via V2I communication or via a FCD backend makes for the algorithms in the simulation no difference (i.e. communication errors are in this example ignored).

The state to be estimated is the total turning ratio based on the turning ratio coming only from the simulated FCD measurements (measurement equation). The process equation assumes a certain non-linear historical model. The blue circles in Figure 5 represent the turning rates coming from Connected Vehicles, assuming a penetration rate of 5%. The red marks show the ground truth (i.e. the actual total turning rate) and the black dots the results of the filter. For example, at simulation second 7200, the actual turning rate is 82%, the observed turning rate from the FCD is 40% and the result of the filter is 68%. It is worth mentioning that even in cases of large errors in the observations, the filter gives a quite accurate estimation of the turning rate. For example, at second 32400 the observed value is 100% (since apparently all Connected Vehicles followed this turning movement) but the actual turning rate is 58%. The filtered value of 66% is in any case more appropriate for traffic control than the extreme value coming straight from the Connected Vehicles (in this case 100%).

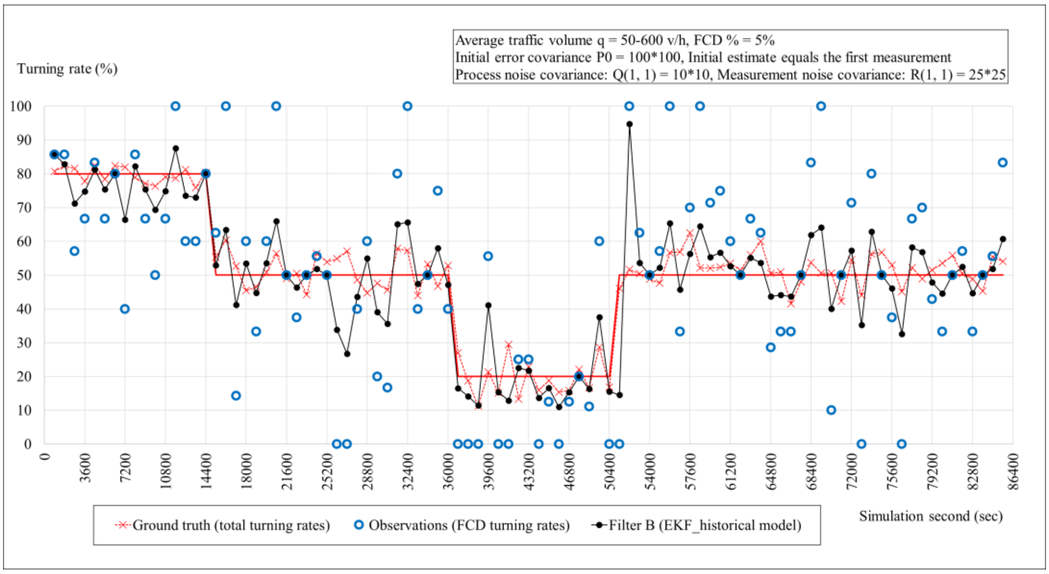

Figure 5 – Example of EKF implementation for turning rate estimation in simulation

For the turning rate estimation in the above example, the filter runs in 15 minutes' intervals. The data needed for the turning rate estimation is the timestamp and the position of the Connected Vehicles. For the estimation of the queue length, predicted arrivals and clearance capacity, an interval of around 60 seconds is used (one estimation for each approach at the beginning of the relevant green time). The data needed in this case are the timestamp, the position and the speed of the Connected Vehicles.

Field tests

The final task of Centauro will be to test the developed algorithms on the field. A test area in Verona that includes 8 fully adaptive signalized intersections has been identified as suitable test field because of the availability of Utopia/Spot system. Tests are planned for the last year of the project, depending on the ongoing results from the previously described tasks (as described in chapters *Potential of currently available new sources* and *Algorithmic development*). Figure 6 depicts the approach for the preparation for the tests in three steps.

In step 1, the calibration and validation of the microscopic simulation takes place. All components of the microsimulation (i.e. street network, traffic flows, detectors and signal control) emulate the current real situation. In step 2, the algorithms are evaluated in the simulation environment in terms of improvement in the signal control (e.g. reduction of total delays in the network). In this step, the new data sources are added in the simulation. In step 3, the field tests take place in order to assess in what extent can new data sources replace conventional inductive loop detectors. In this final step, the integration of the new data sources in the extended observer will be tested and the validation of the algorithms in reality is going to be assessed.

Conclusions and future work

This paper presented the latest developments of the four core tasks (lab, current alternative sources, algorithms and field tests) of the research project Centauro. The laboratory environment has been built around the Utopia/Spot system from Swarco AG but the developed Extended Observer is not limited to Utopia/Spot. The extended traffic state estimation can be also used as input in other systems that need state estimation of signalized intersections. Moreover, the three main traffic data providers (TomTom, Here, Inrix) and their APIs have been examined as potential new data sources for Urban Traffic Control (UTC) systems. The main obstacle for integrating these sources in UTC systems is the fact that they provide only aggregated data and not information about individual vehicles. At the same time, future scenarios that assume the availability of raw Floating Car Data and extended information from Connected Vehicles are being tested in simulations. The developed Extended Observer is based on the Extended Kalman Filter and the preliminary results are promising, as shown in the turning ratio simulation example. Last but not least, an approach for potential field tests for the evaluation of the algorithms has been presented. The immediate next steps of the research project include the integration in the extended observer of sensors from Connected Vehicles (e.g. radar, cameras) and other infrastructure sensors (e.g. stop-line detection and cameras) in simulations (development and evaluation). Finally, the algorithms will be tested in the real world, initially as a proof of concept and later as prototype implementation.

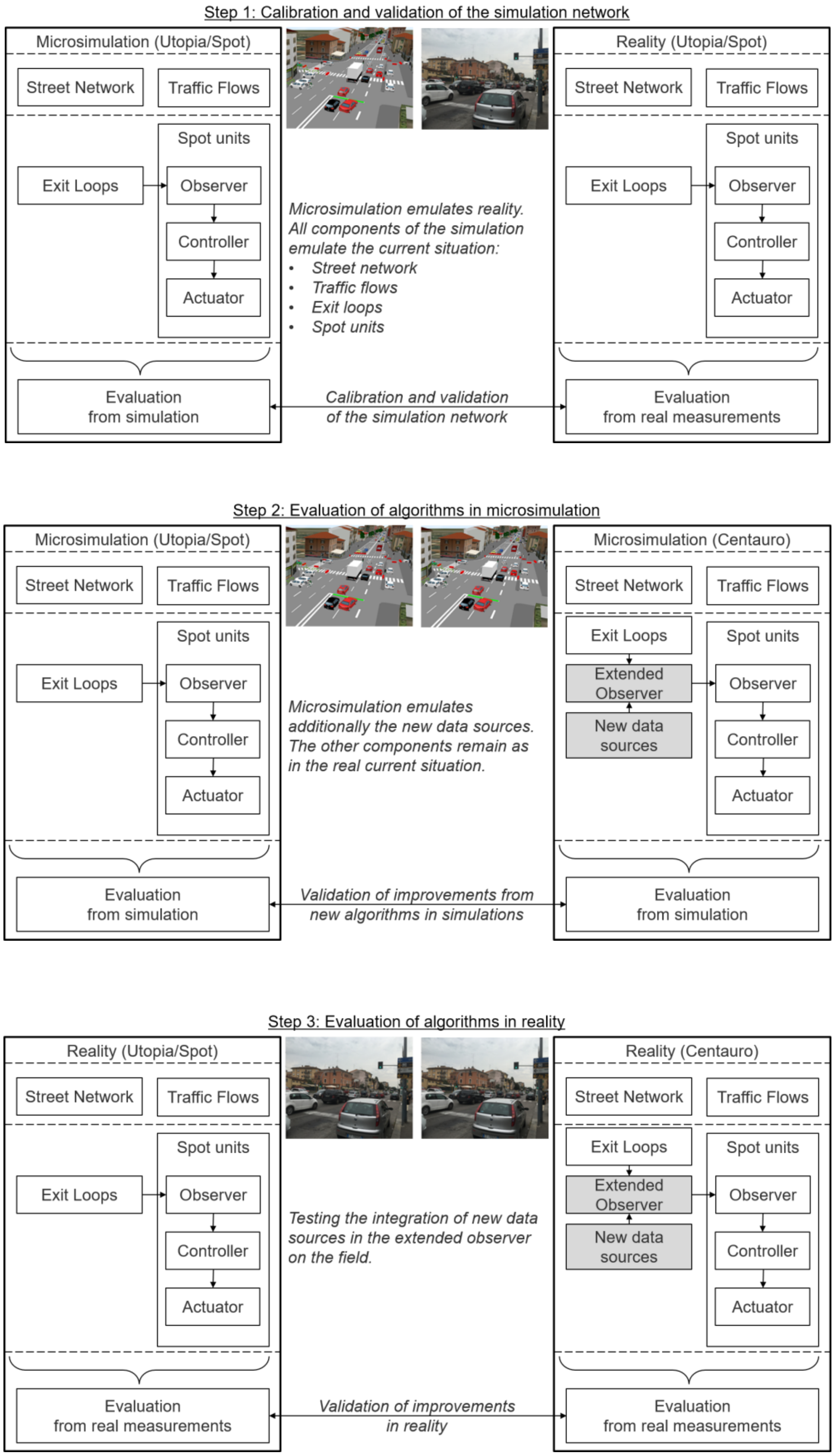

Figure 6 – Preparation for field tests

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