A SYSTEM FOR VEHICLE DATA PROCESSING TO DETECT SPATIOTEMPORAL CONGESTED PATTERNS: THE SIMTD-APPROACH

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Abstract
In the German project simTD (“Sichere und Intelligente Mobilität- Testfeld Deutschland”) the so-called Car2X-technologies support the generation of traffic related vehicle data for further use at the infrastructure by traffic control centres. The research lab DRIVE-Centre in the federal state of Hessen has been prepared to process the simTD vehicle data based on Kerner’s three-phase traffic theory (e.g, [1]-[4]). Within this project, a system for data processing of vehicle data and their fusion with the traffic information reconstructed by the models ASDA/FOTO (devoted to the reconstruction of congested traffic patterns based on Kerner’s three-phase traffic theory) based on detector data has been developed. In this paper, the system approach and practical methodology for the data fusion of FCD (“Floating Car Data” sent by the Car2X-vehicles) and ASDA/FOTO will be presented. Furthermore, the implemented GUI in the federal state of Hessen and some real measurements will be discussed.

Keywords:
Vehicle data (FCD/FPD), Traffic data processing, Car2X, Probe Vehicles, Kerner’s Three-Phase traffic theory, Data fusion, simTD field trial

INTRODUCTION

This paper is about the German public founded project simTD which stands for safe and intelligent mobility - test area Germany, (in German: “Sichere und Intelligente Mobilität -
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Testfeld Deutschland’’). The project has started in September 2008 and runs till April 2013. During the project the DRIVE-Centre (a traffic control centre as a research laboratory near Frankfurt owned by the federal state of Hessen) has been prepared to process the simTD vehicle data to detect spatiotemporal congested patterns. Within Hessen all traffic data measured by stationary detectors since 2002 are processed by the models ASDA/FOTO based on Kerner’s three-phase traffic theory [1, 2]. These models have been enhanced for processing simTD vehicle data.

The simTD project covers several information and vehicular safety scenarios [6] while this paper is about “identification of traffic situation” which is important because only if the traffic situation is exactly known in the traffic centre, the traffic management and information via dynamic controllable street signs could be done.

This paper is structured as follows: In the following chapter the system architecture of the simTD approach is discussed to understand how the traffic control centre is extended by the DRIVE-Centre of the federal state of Hessen to process vehicle data of the field trial. Then chapter 3 shows the algorithms that allow combining floating car data and stationary detector data to create a combined traffic situation. The last chapter 4 presents the user interface and some first real measured results of the field trial.

**SIMTD SYSTEM ARCHITECTURE**

The overall system architecture approach is illustrated in Fig. 1. The blue marked areas are the system components which are used before and “outside” the project simTD for traffic management. The traffic control centre in Hessen (TCC) collects and distributes stationary detector measurements. Similar to that the City of Frankfurt (IGLZ) computes a traffic situation that is based on measurements from stationary detectors for the urban area of Frankfurt. Both systems are legacy systems from simTD’s point of view and forward the described data to the newly developed simTD test centre which are part of the research laboratory DRIVE-Centre Hessen or Intelligent Control Station (ICS).

The grey highlighted blocks are new hardware components that were introduced in the simTD projects. Vehicles that take part of the field trial were equipped with ITS Vehicle Stations (IVS) which are able to transmit data over the ITS Roadside Stations (IRS) directly to the ICS. If the vehicle is outside in the communication range of a road side station also a 3G communication directly to the simTD ICS is possible (e.g. GPRS, or/and UMTS). Among others the vehicle ID and its current GPS position are transmitted periodically.
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The orange area in the diagram highlights the components of the ICS which take care about reconstructing and visualising the traffic situation on highways and secondary roads. For highway models ASDA/FOTO and for secondary roads UTA were applied [1]. Both models process measurements of stationary detectors (collective data). In the context of simTD the federal state of Hessen will examine how vehicle trajectories can contribute to improve the online reconstruction of the current traffic situation and which numbers of equipped probe vehicles of the total flow rates are necessary for high quality. The ICS is, therefore, able to reconstruct a traffic situation based on floating car data (individual data). Additionally the ICS is able to combine these both traffic situations (based on detectors and FCD) and uses the advantages of both.

As a result precise positions of reconstructed synchronised flow and fronts of wide moving jams were written to the central ICS storage. The graphical user interface should offer a map view of the field trial road net as well as road segments and space-time-diagrams as they are used in ASDA/FOTO models. The software architecture should allow the user to visualise different types of input data and their contribution to the overall network traffic state.
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**TRAFFIC STATE DETECTION AND FUSION**

According to Kerner’s Three Phase Traffic theory beside free flow there are two types of congested traffic: synchronized flow and wide moving jams. Synchronized flow has occurs on bottlenecks and is almost fixed at the origin. Wide moving jams can emerge in areas of synchronised flow. The phase of wide moving jam shows the characteristic feature that it propagates against the direction of travel through bottlenecks and other traffic phases with nearly constant speed around 15km/h. Reliable information about the current, passed and prognosticated traffic situation requires a precise reconstruction of the both phases of congested traffic in time and space.

In the simTD project beside floating car data shall be used to improve the traffic situation which is reconstructed based on stationary detector measurements. This is done by the following steps:

1. Detect traffic state transitions based on vehicle trajectories. Therefore, a new approach for autonomous traffic state detection in vehicles has been developed [3, 4, 5]. In simTD vehicle trajectories will be transferred to the ICS and at the ICS the traffic state detection is done.
2. Reconstruct the traffic situation based on traffic state transitions in space and time.
3. Data fusion of detector based traffic situation and vehicle based traffic situation.

Figure 2 shows a number of vehicle trajectories in space and time. All vehicles drive through a traffic pattern which is composed out of an area of synchronised flow (marked as yellow area) and an area of wide moving jam (marked as red area). Considering its speed and position the vehicle is able to detect traffic state transitions that are marked by a black circle.

![Figure 2 - Vehicle trajectories and traffic state transitions](image-url)
In case of simTD the central side knows the trajectories of all vehicles and is able to detect traffic state transitions. Considering a time step appropriate traffic state transition will be connected to one continuous area of congested patterns. Hereby between traffic phases, entry and exit must be differentiated.

Figure 3 shows an example for reconstruction areas of wide moving jam based on vehicles traffic state transitions. Black circles symbolise detected traffic state transitions from free flow to wide moving jam or from synchronized flow to wide moving jam. Grey circles mark detected traffic state transitions from wide moving jam to free flow or from wide moving jam to synchronised flow.

The dashed line which is described by \( s(v_g) \) visualizes the propagation of the wide moving jam. The propagation speed can vary a little caused by weather, percentage of lorries and driver characteristics [1], so \( \Delta v_{\text{max}} \) is the maximal tolerance which is acceptable.

The red marked is the already reconstructed spatio-temporal area of the wide moving jam. This area is expanded if the spatio-temporal position of a newly detected traffic state transition matches the following criteria:

The spatio-temporal position has to be inside the area with is bordered by the slopes \( s(v_g - \Delta v_{\text{max}}) \) and \( s(v_g + \Delta v_{\text{max}}) \). Regarding to the latest traffic state transition of the same type the spatial and temporal distance have to be small enough: \( \Delta t < \Delta t_{\text{max}} \) and \( \Delta d < \Delta d_{\text{max}} \). Reconstructing areas of synchronised flow works similar and is described in [7].

If vehicle based traffic state is known it can be merged with the detector based traffic situation. This is done by converting detector based patterns processed with ASDA/FOTO to traffic state transitions. Then the set of these traffic state transitions are joined with the set of the traffic state transitions that are detected based on vehicle trajectories. Last the algorithm (Fig. 3) is applied to reconstruct the congested traffic phases for the merged traffic situation.
EXAMPLES FOR REAL MEASUREMENTS

For presenting the traffic situation to the staff of the simTD test centre at the DRIVE-Centre of the federal state of Hessen two different views were implemented during SimTD and embedded to the framework of the simTD traffic centre software. First a road overview is shown in Figure 4. Here the current traffic situation for one specific road is visualised. Among others the number of lanes, positions and names of detectors, positions and names of junctions, on- and off-rams as well as the current traffic state are drawn. The figure presents real measurements at Thursday the 19th of July in 2012 on the Freeway A5 in south direction between the junction Bad Homburger Kreuz and Frankfurt am Main. The staff in the test centre can see exactly where currently the traffic is congested.

![Figure 4 - Visualising the current traffic situation at simTD ICS](image)

The second view that was implemented is a time space view that shows the spatio-temporal expansion of the current traffic phases (see Figure 5). The axis of abscissas shows a time range between about 7 a.m. and 10 a.m. and the axis of ordinates shows about 10 km of the A5 between the junctions Friedberg and Bad Homburger Kreuz. Within the diagram a Mega-Jam [2] traffic pattern could be seen which is typical after an accident happens on the road. Each of the green lines which cross the pattern is a real simTD vehicle trajectory. One can see that deceleration and later the acceleration of vehicle velocities matches very well according to the area of the red pattern. Some of the vehicles notify the simTD ICS about a dangerous deceleration within a short time which is indicated by the small red circles at the beginning of the Mega-Jam.
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Figure 5 - Traffic situation as time-space diagram with real simTD vehicle trajectories

A traffic situation that is reconstructed based on simTD vehicle trajectories by applying the algorithm described in the previous chapter is presented in Figure 6. It could be seen that there is the need for several vehicles within a relatively short range of time to be able to reconstruct an area of synchronized traffic and wide moving jam. Here, about 15min of simTD test vehicle data have supported a reconstruction of an almost 3km synchronized flow region.

Figure 6 - Traffic situation reconstructed by real simTD vehicle trajectories

CONCLUSIONS

✓ In this paper the simTD system architecture for the ICS with regard to reconstructing the traffic situation was discussed. The user interface that was developed for simTD for visualising the current traffic situation as well as the related time-space diagram was presented. Some examples of real simTD vehicle trajectories were shown and discussed.
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- Spatiotemporal congested traffic patterns were reconstructed with Kerner’s three-phase traffic theory and the models ASDA/FOTO that could now process floating car data which are submitted by simTD probe vehicles.
- The algorithm how floating car data could be used to improve the traffic situation based on stationary detectors and is especially helpful on roads with only less detector equipment rate or if detectors are temporarily not working. DRIVE-Center Hessen could profit from probe vehicles mostly in the secondary road network, permanent roadworks and/or higher distances of detectors on freeways.
- As shown in [8],[9] with the use of ASDA/FOTO models an equipment rate of 1-1.5% of all vehicles could give the same data quality as road detectors of 1-2km distances.
- Such precise traffic information will open the research fields of, e.g., traffic prediction, arrival time estimation, dynamic route guidance and jam front warning on a new level.

References