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An Automotive Distributed Mobile Sensor Data Collection with Machine Learning Based Data Fusion and Analysis on a Central Backend System

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Abstract

One of the most extensive examples for ubiquitous computing today is automotion. The equipment of sensors and independent computing devices in current vehicles is vast if not endless. Furthermore, traffic infrastructure is realized using global and local computing devices. Communication initiated by the car itself (e.g., to an emergency hotline) will be obligatory in some countries soon. And finally, by using a smart phone the driver brings an additional powerful computing device and sensor set to the vehicle.

However, all these automotive sensors and computing devices are used just for fixed (and in most cases single) purposes. Data exchange between vehicles or vehicles and infrastructure is rarely done. And dynamic changes like compensating for a broken sensor with available other data, using old sensor equipment for new functions, or improving old driver assistance systems with new sensors is not possible, either.

The objective of the collaborative research project Smart Adaptive Data Aggregation (SADA) is to develop technologies that enable linking data from distributed mobile on-board sensors (on vehicles) with data from previously unknown stationary (e.g., infrastructure) or mobile sensors (e.g., other vehicles, smart devices). One focus of the project is the dynamic and fully-automated switching between different sensors or sensor configurations, including the adaptation of data fusion processes. Technically, one important component for some of the SADA use cases is a central backend system that (1) collects sensor data of the vehicles and/or the infrastructure, (2) fuses these data, and (3) carries out machine learning (ML) based analysis of the data to generate new information for the drivers (sometimes refered to by the term “virtual sensors”).

The article gives a short overview of the SADA project and describes in more detail the concept of the backend system architecture, the user interface, and the methods and processes needed for a demonstration use-case.

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1. Motivation

The basis for dynamic data fusion in automotive applications has already been on the streets for years now. Sensor equipment and computing power are present in virtually every vehicle, as well as in the traffic infrastructure. And applications are obvious in the form of the advanced driver assistance systems (ADAS) offered by car manufacturers or community-driven social mobile apps guiding the driver through traffic or to parking spaces. What is missing is the possibility to dynamically adapt the system, e.g., adding or removing components, using data of local or remote sensors, for new and old applications.

The collaborative research project SADA consists of the partners SIEMENS AG (lead), NXP Semiconductors GmbH, fortiss GmbH, Baselabs GmbH, DFKI GmbH, and ALL4IP TECHNOLOGIES GmbH & Co. KG. Its objective is to develop technologies that enable dynamical linking of data from distributed mobile on-board sensors (on vehicles) with data from previously unknown stationary (e.g., infrastructure) or mobile sensors (e.g., other vehicles, smart devices). The sensors are connected independent of their brand, manufacturer, or application area in an intelligent and flexible way. SADA plans to provide interfaces and methods that enable the unrestricted dynamic integration and analysis of data from multiple heterogeneous sensors. One focus of the project is the dynamic and fully-automated switching between different sensor configurations, including the adaptation of data fusion processes. This is necessary, e.g., when, caused by the movement of the mobile sensor platform (vehicle), new sensor infrastructures become available or drift out of reach. The automatic adaptation of the system to new situations is made possible by semantic descriptions of sensor properties, the operational environment, and necessary algorithms, which are modeled explicitly and shall be provided along with the sensor data. With such a combination of (1) dynamic sensor configuration changes, (2) explicit support of heterogenous, brand/manufacaturer-independent and even cross-applicational data exchange, and (3) a consortium of scientific research institutes and industrial partners, SADA is unique.

Technically, one important component for some of the SADA use cases is a central backend system that (1) collects sensor data of the vehicles and/or the infrastructure, (2) fuses these data, and (3) carries out machine learning (ML) based analysis of the data to generate new information for the drivers. Ideally, crowd sensing (emergence of information by combination of data from spatially distributed sensors) may lead to so-called "virtual sensors" (generated in the backend system) that can be fed back into the SADA fusion process.

SADA technology could be used for example to support driving comfort functions, to increase driving safety, and to contribute to more efficient and environmentally friendly traffic (e.g., by preventing traffic jams and searches for parking space). An online data exchange from a user and their vehicle to other vehicles, to infrastructure, and back to the vehicle, its ADAS, and to the user is an intrinsic component. Therefore, ubiquitous computing, distributed data collection, and machine learning are central topics in the project.

It is planned to develop a micro-positioning use case for automotive applications where the exact location is required. Here, a sensor or a sensor cluster can be adapted instantly. Applications could be, for example, autonomous parking, autonomous fuelling of a combustion-engined vehicle, or positioning an electric vehicle over an inductive charging spot. For the intended use case, an improved localization is presented as the result of a dynamical sensor fusion process. As user interface in this positioning task a smartphone is planned to be used. An app on the smartphone shall read the coordinates and display dedicated control instructions for the user to position the vehicle precisely over the inductive charging station.

2. Related Research Projects

2.1. General Traffic-Related Research Projects

From 2007 to 2010, in the thematically wide-ranging research project "Aktiv", funded by German BMWi and BMBF, techniques were developed to help traffic-control systems collect and broadcast information, to improve the active safety in vehicles, and to improve the results by using Car2Car communication. Information was exchanged about traffic events and traffic situations [1,2].

In about the same period, from 2006 to 2010, the European research project "coopers" was conducted [3]. Its focus was on cooperative traffic management, supported in particular by car-to-infrastructure communication. A substantial part of the project were extensive field tests, demonstrating the suitability of the wireless communication channels. Another result was that drivers accept the guidance by traffic management and are not distracted by the additional information. Information exchange on lower levels was not part of the study.

A different approach was taken by the project “Ko-FAS”, funded by the BMWi, from 2009 to 2013 [4]. The question was how the use of cooperative components (e.g., active, intelligent RFID tags, among other things, on all traffic participants, like vehicles, bicyclists, and pedestrians) could improve traffic safety. The focus was on the technical feasibility of such sensors and their achievable performance features, such as precision and robustness of location and time measurements, as well as the integration of this information into an overall scenario. For communication, the standard IEEE 802.11p was used, similar to other projects. However, the content that was transmitted to other communication participants was not data on a low level or even raw sensor data, but again aggregated information. The approaches for improved traffic routing were further developed and, above all, tested in extensive field trials in the projects “Drive C2X”, “Testfeld Telematik”, and “SimTD” [5–7].

In the European project “Drive C2X”, from 2011 to 2014, a Europe-wide test of the improved features was conducted in traffic circulation, on the basis of the emerging standards for the transmission of information about traffic events and traffic situations [6,7]. The proof of both the successful technical operation of the information infrastructure and the effectiveness for safer and more efficient traffic was also provided by the German project “SimTD”, from 2008 to 2013, funded by BMWi, BMBF, and BMVI. Its emphasis was also on Car-to-X communication, and on the exchange of traffic situations and traffic events [5]. From 2012 to 2015 the BMWi- and BMBF-funded project CONVERGE dealt with flexible (and secure) communication for traffic services [8–10]. Overall, these research activities have brought the assurance that a safe, robust communication about traffic information between vehicles, as well as between vehicles and infrastructure, is feasible both technically and organizationally, and leads to safe and efficient traffic. In the process, standards for this communication have emerged.

But progress has not only been made with regard to the communication between vehicle and environment. Also inside the vehicle a reusable foundation for networking has been laid. The recently developed standard for automotive ethernet “BroadReach” brings progress in the reliability of the data transmission, as well as a cost-efficient transmission medium (two-wire line). The standard for the physical layer was developed by the industry interest group “www.opensig.org”. Up to now, BroadReach was designated for the transmission of image data inside the vehicle. The description of a backbone system is new and subject of the architectural work of the SADA project.

The topic generic data fusion was part of the sub-project “ProFusion 2” in the EU project “PReVENT”. The focus was mainly on a generic data store for data fusion applications (“Perception Memory Object”). Adaptive or even context sensitive data fusion methods, however, were not considered. Subsequent EU projects dealing with traffic safety often invested work in concrete data fusion algorithms, but without picking up the subjects adaptivity and context sensitivity.

Finally, Diewald et al. (2011) discuss the integration of mobile devices in the automotive domain [11]. They show how mobile devices can be integrated to contribute to natural user interface (NUI) experience in vehicles.

2.2. Crowd-Sensing in Traffic Applications

Mathur et al. (2010) present a very interesting proposal showing “Crowd Sensing” in a traffic application [12]. They used ultrasonic sensors attached to the passenger side of a vehicle to collect parking occupancy data while driving. The sensors measure distances to passenger-side obstacles and the measured values are classified as “occupied” or available” space. With three vehicles in a two month time frame they collected a total of more than 500 miles of data. As drawbacks of their setup they reported (potential) problems when driving at higher speeds and detecting parking occupancy on multi-lane roads (among others issues). In their data collection there was only data from roads with single lanes. Coric and Gruteser (2013) use the same data collection method to automatically generate a map of legal and illegal parking spaces [13]. Some more related references can be found in Tiedemann et al. (2015) [14].

2.3. Previous Work of Machine Learning on Traffic Data

The number of research projects applying machine learning methods to traffic data is large. In this section, examples were chosen where methods or means (software or hardware) were used that seem to be very well applicable to SADA.

In the BMUB-funded project "City2.e 2.0" the DFKI Robotics Innovation Center develops a prediction system to estimate future parking space occupancy using machine learning methods. Traffic data (parking space occupancy data measured by SIEMENS top-view sensors) is collected in a central system, analyzed using clustering methods, and the learning results are used as a data basis to generate occupancy predictions. The data collection is done online, the learning can be carried out offline [14].

Enoki et al. (2015) analyzed parking data of a large number of parking lots in Japan [15]. They used clustering methods to find groups of similar parking behaviour (with respect to different parameters). Then they used survival analysis and clustering methods to find the influence of charge changes and changing points of utilization behaviour. This was done to finally simulate changes of pricing policies in simulation to find a more appropriate pricing for the parking lots covered in this study.

Finally, Duchrow et al. (2012) present a framework for electric mobility data mining [16]. In their project a heterogeneous fleet of electric vehicles logs mobility and consumption data and sends incremental updates via GPRS to a central backend system. Duchrow et al. propose a backend using three virtual machines for a multi-layer data filtering and preprocessing process. Furthermore, they present a first analysis of trips and charge intervals from one year of telemetry data.

3. Overview SADA

Based on the state of the art, the SADA project shall expand the content that is exchanged between vehicles and environment, in order to collect and fuse also those sensor data that are distributed among different sensors within one vehicle, or among multiple vehicles and infrastructure. The semantics of the information shall be described and communicated explicitly, so that the complete system can configure itself automatically, according to the situation. This bears the potential of even better perception of the traffic situation and the situation of individual vehicles, while reducing the total outlay for sensor technology, and simplifying engineering.

3.1. Project Goal and Results

The primary goal of SADA is to develop a solution for an intelligent and dynamic integration and processing of data from moving vehicles, stationary sensor infrastructure, and carry-on sensors, allowing a rapid implementation of new application ideas. The SADA project will develop an adaptation and fusion process that can determine in real time which data is available, choose the relevant data for a given use case, and permit a fast reaction to changes in the sensor setup. A communication architecture will be developed in order to link sensors with processing units within the vehicle, as well as outside the vehicle (using Car-2-X communication). To make this possible, a platform for modular sensor fusion will be constructed. The SADA platform is comprised of five elements:

- Design & Engineering Tool,
- SADA Fusion System,
- SADA Backend,
- SADA App,
- necessary semantic models for self-configuration and parametrization of the fusion topology.

In Fig. 1 an overview of the potential participants in SADA is shown. Besides vehicles (with their data sources, sensors, and data sinks, ADAS) traffic infrastructure is an important SADA participant. Infrastructure devices (e.g., traffic cameras, induction loops, parking space sensors) and a direct access to them are good examples for ubiquitous computing: A driver could notice on his trip an appearing and vanishing of local information sources, just appropriate for the specific traffic situation and adapted to the actual needs: A warning of cross traffic when approaching a crossing or a routing to available parking spaces when close to the trip's end. This article focusses on the SADA participants backend and smart phone.

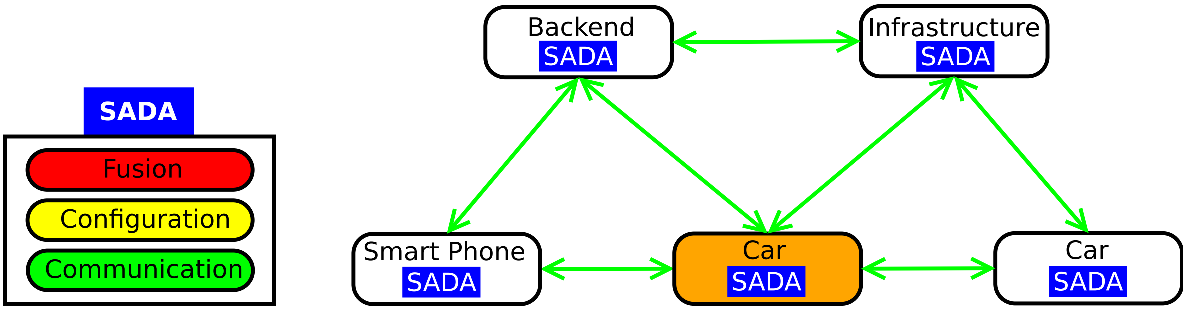

Fig. 1. Participants in SADA. A vehicle can take an active part by fusing local and/or remote sensor data ("Car" in the middle of the diagram) or can contribute passively by just serving as a remote sensor platform for other vehicles ("Car" on the right of the diagram). "Infrastructure" could be, for example, a traffic camera or an induction loop. For communication Car-to-X interfaces will be used, extended by GPRS/LTE connections where applicable.

3.2. Solution Space Description

In recent years, research has led to solutions for a safe and robust communication of traffic information between vehicles as well as between vehicles and infrastructure. Furthermore, standards for this communication have already been developed. Based on this state, SADA aims to extend the information exchanged between vehicles and the environment to enable the collection and fusion of distributed sensor data which is generated in different vehicles, infrastructure, and/or mobile devices.

The properties of sensors, of operation environments, and of appropriate algorithms shall be modeled explicitely in SADA, and these models shall be entered into the sensor data fusion system along with the data. By means of information on the semantic level, the fusion system may be configured automatically and dynamically according to the available resources. It will be investigated, whether the information description formalisms that have been developed and employed for the "Semantic Web" may be applied.

Integrating sensors from outside the vehicle and fusing their data with sensor data generated inside the vehicle requires an appropriate communication system. This includes connecting to the environment (Car-2-X), as well as networking between distributed processing units inside the vehicle. New concepts for electric mobility and autonomous driving exceedingly focus on electronic transmission instead of mechanical components (e.g., for the break pedal or steering). Besides sufficient bandwidth for the sensor data transmission into and out of the vehicle, this also requires a safe transmission of system relevant vehicle data.

As far as reasonable, model information and sensor data shall be stored and processed inside a central backend. Thereby, new opportunities open up to aggregate and analyze data over time and space. One possible approach would be "Crowd Sensing", i.e. combining synchronous sensor data from many spatially separated data providers to emergent information that no single provider possesses on their own. A "Virtual Sensor" created in this way could possibly be fed back into the SADA fusion process. Another option consists in detecting environmental properties with appropriate machine learning methods. However, one would have to take into account the special requirements of cooperative learning, e.g., heterogenous or changing data sources.

Details of the overall SADA architecture, the data fusion process, and the communication architecture will be described in more detail in separate articles. In the following sections, the focus is drawn on the SADA backend system and the role of smart phones in SADA. Both are the main SADA components related to the topics of ubiquitous computing and the interface to the user.

4. Backend System

The backend stores all information necessary for the SADA data fusion process, i.e. sensor data, fusion models, environment models, sensor models, fusion topologies, and fusion parameters. Additionally, the backend provides "Smart Traffic Services" (e.g., icy road warning) for SADA users, and creates virtual sensors, for instance based on

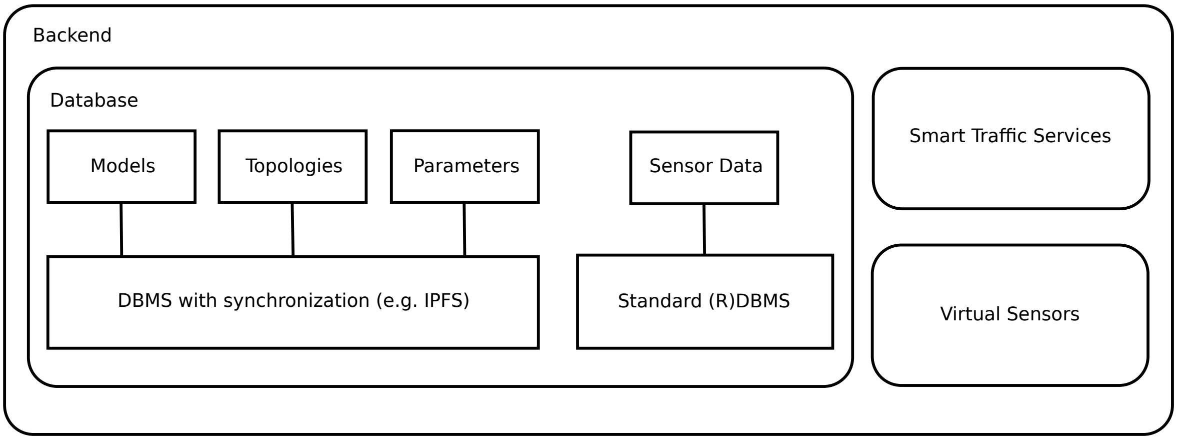

Fig. 2. Main software components of the SADA backend system. As can be seen by this diagram the backend has three tasks in SADA: (a) storing and distributing data ("Database"), (b) offering services based on gathered data ("Smart Traffic Services"), and (c) generating new information based on data measured or generated elsewhere in the SADA network (vehicles and/or infrastructure, "Virtual Sensors" in the figure).

crowd sensing and machine learning methods. To enable these tasks, further raw and aggregated data is stored, e.g., supported vehicle types, parking space occupancy information, or infrastructure data.

Depending on the application, sensor data has a varying life span. Typically, this span is rather short. For example, detecting a local road hazard or moving obstacle is useful only immediately. This is why sensor data stored inside SADA vehicles may be discarded soon after their transmission to the backend. On the other hand, in order to detect seasonal effects and trends, or to create dynamic maps and forecasts with crowd sensing and machine learning, large (training) data collections over indefinite periods are necessary. However, this long-term logging is usually needed at the backend and not at the vehicles.

The database component of the backend contains two separate database management systems (DBMS), depending on the synchronization requirements of the data types: Since sensor data do not need to be synchronized across multiple SADA systems, they may be stored and processed by a standard DBMS. Initially, to facilitate the implementation, a relational system (e.g., Postgresql) is used, which may later be replaced by a non-relational or mixed ("NoSQL") DBMS (e.g., Key-Document, Column-Family, Key-Value, Graph). A NoSQL system might turn out to be more favourable in the future because non-relational solutions seem to work and scale well for complex data models, featuring multiple levels of nesting, various data types, or dynamic schema, as it is the case in SADA. Topologies, parameters, and especially models have to be managed by a DBMS more tuned to synchronization over multiple SADA systems. The "InterPlanetary File System (IPFS)" is considered as an option, here. In Fig. 2 the main software components of the SADA backend system are shown. The two database types can be seen on the left-hand side and in the center. On the right of the figure two data processing (e.g., filtering or generating) components are depicted: The "Smart Traffic Services" component implements services for the SADA users, e.g., the icy road warning mentioned above. The "Virtual Sensors" realize a modular and potentially hierarchical data processing, for example, as one processing step for the smart traffic services.

In case of the example "icy road warning" such a virtual sensor could be a machine learning and crowd sensing based analysis of breaking (anti-lock braking system, ABS) and/or acceleration data gathered by a large number of vehicles in SADA. The virtual sensor "icy road" could be a flag set for those road sections where crowd sensed ABS and acceleration data of a past time span is classified as "icy" (using a machine learning method like support vector machine (SVM)). Eventually, the smart traffic service "icy road warning" could send warnings to those SADA users currently driving or planning to drive on roads being flagged as "icy".

By this separation of, first, the services (the application) and, second, the information generation (the sensor) again one central idea of SADA is applicable: When the sensor setup changes (data of old sensors is no longer available, new sensor data needs to be fused) the operations in the "Virtual Sensors" block needs to be adapted but the (old) application “icy road warning” continues working. And if in the future a new application is added (e.g., a routing incorporating road safety) then the (old) virtual sensor “icy road” can be reused.

5. Mobile Phone as Sensor and User Interface

In the project’s current early stage, a demonstrational use case is planned to show how the methods described in this paper provide the required function. One application example is a scenario for positioning a vehicle. Here, the sensor fusion described above is used to determine the 2D position of the vehicle as precisely as possible. Several potential applications in the automotive area can be found, for example,

- autonomous parking,
- autonomous fuelling of a combustion-engined vehicle,
- precise positioning of inductive charging for electric vehicles,
- precise positioning of the vehicle rear in front of a heavy trailer.

Traditionally, the car infrastructure uses locally permanently attached and calibrated sensors whose measured values are used to determine the position of the vehicle related to a reference point. In the case of the intended adaptive sensor fusion, we plug in sensors at runtime using a formal description of their measurement behaviour. The critical task now is to integrate these sensors ad hoc and to analyze the resulting system changes (especially in positioning precision).

Besides using infrastructure or other vehicles’ sensors, one typical scenario is using the sensor of a smartphone to increase the precision in the sensor cluster. We plan to use the camera of an Android smartphone for additional distance and motion measurement. The processed video information is computed during the sensor fusion process. Technically, this approach is to be programmed in a way that we have a smartphone app as a dynamical added client in a ROS environment. Doing so, the smartphone acts as an additional sensor borrowed for the moment from one of the human gadgets.

A second app of the (same) smartphone is used to operate as the user interface of the entire system. The task is to give the driver the necessary support to move the vehicle accurately. Here, a movement forecast will be made and the required steering angle is communicated via the GUI. The two approaches described by Diewald et al. to integrate mobile devices in an automotive application while keeping the natural user interface (NUI) experience in mind seem to be useful options for the UI in SADA, too [11].

6. Preliminary Experimental Results

First tests and experiments have been carried out to evaluate the general feasibility of the proposed concept.

6.1. Communication Tests

The general data flow chain of a potential SADA use case was successfully tested in a preliminary setup: camera data from a robot (depicted in Fig. 3(a)) was logged in a local Postgres database and continually synchronized with a backend database through a socket connection set up using WiFi. This relates to a demonstrational SADA use case in which a vehicle is continously logging radar sensor data and transmits it to the backend in case of successfull connection. The backend uses this “crowd sensed” data to extract parking space information. In a next step, the connection shall be replaced by a Car-2-X connection between two boxes by Cohda Wireless (see Fig. 3(b)). The successful data transmission between these boxes has been verified at the current state.

6.2. Local Latency

Controlling and minimizing latency between data creation and data consumption is essential to successfull data fusion. In pervasive computing, a certain amount of latency due to communication overhead cannot be avoided.

Fig. 3. (a) Seqway robot platform used in first communication feasibility tests; (b) Car2X communication hardware: on the left hand side the "road side unit (RSU)" is depicted, on the right hand side the "on-board unit (OBU)" can be seen.

Hence, it is all the more important to evaluate and, if possible, reduce the additional latency caused by data processing on each local node (i.e. inside a vehicle).

In the present SADA use case data flow concept, local lacency is produced by logging events in a database before publishing them on the SADA network. This setup is desirable, first, to avoid losing data when no connection between the vehicle and the backend is available. And second, to enable data mining applications which require a complete local backlog (e.g., local machine learning).

Preliminary latency experiments have thus been conducted with two goals: (1) Establish an empirical upper bound for logging induced latency in some realistic simulation scenarios. (2) Explore the influence of sensor model variation (message size) on the logging induced latency.

All experiments were run with a single Intel i7-2620M CPU (2.70 GHz, 4096 kB cache) on Ubuntu 14.04 (Linux version 3.13.0-85-generic) against a PostgreSQL 9.3 database server. Latency was defined as the interval between data generation and database update completion (measured in seconds). Five sensor models were simulated, with message sizes of 1 kB (1 kB = 1,000 Byte), 10 kB, 100 kB, 1,000 kB, and 10,000 kB, and a constant message rate of 10 Hz. This relates to the spectrum of typical sensors ranging from small size (e.g., GPS position data) to large size (e.g., high resolution image data).

In the first experiment, 20 sensors of each type (i.e. 100 sensors total) with a collective throughput of 2,222,220 B/s were logged, to demonstrate the general feasibility of the logging approach in a stressful scenario (see Table 1).

A second set of experiments (2 to 4) investigated how latency is affected when a given throughput (low: 10 kB/s, medium: 100 kB/s, high: 1000 kB/s) is realized either with many sensors creating small messages or with few sensors creating large messages.

As can be seen, an expected increase of latency with increasing number of database accesses (each with decreasing data size) was measured for low an high throughput. However, no such effect can be seen in the medium throughput condition. This (and the failure in the final experimental run) need to be studied in more detail. The (overall) SADA communication architecture and more detailed measurements are part of another publication. However, for the current work with the focus on ubiquitous computing (and user interaction) a first conclusion can be drawn from these measurements: For most of the test conditions and in the current implementation, the resulting latencies are too high for use cases with direct user interaction (e.g., fusing sensor data online to help a user parking a vehicle). However, in the one condition where the latency is not too high (10 sensors with 100 kB data size each packet) the data throughput is actually more than enough for the parking use case as for (radar, lidar, ultrasonic) distance sensors data sets of less than 100 kB are sufficient and using less than 10 sensors is presumably the standard case when parking in. And for another class of use cases, e.g., building a parking map based on a large number of crowd sensed data, the whole measured range of latencies is not critical.

Table 1. First latency measurements.

Test Condition	Test Results (latency in *s*)							
experiment 1 (feasibility): 20 sensors of each message size (i.e. total 100 sensors), total throughput: 2.222.220 B/s								
	num packets:	972	min latency:	0.033	max latency:	15.840	avg latency:	6.503
	num packets:	875	min latency:	0.026	max latency:	18.487	avg latency:	10.303
experiment 2 (variation, low throughput): total throughput: 10 kB/s								
1000 sensors * 1 kB	num packets:	70,014	min latency:	0.017	max latency:	37.009	avg latency:	8.024
	num packets:	69,490	min latency:	0.023	max latency:	37.221	avg latency:	8.548
100 sensors * 10 kB	num packets:	17,857	min latency:	0.046	max latency:	6.822	avg latency:	1.614
	num packets:	18,153	min latency:	0.043	max latency:	11.950	avg latency:	1.587
10 sensors * 100 kB	num packets:	1963	min latency:	0.040	max latency:	2.300	avg latency:	0.450
	num packets:	1945	min latency:	0.045	max latency:	4.496	avg latency:	0.724
experiment 3 (variation, medium throughput): total throughput: 100 kB/s								
1000 sensors * 10 kB	num packets:	40,302	min latency:	0.026	max latency:	32.711	avg latency:	7.951
	num packets:	45,301	min latency:	0.028	max latency:	38.751	avg latency:	10.420
100 sensors * 100 kB	num packets:	2313	min latency:	0.043	max latency:	19.970	avg latency:	8.475
	num packets:	2365	min latency:	0.042	max latency:	19.793	avg latency:	7.939
10 sensors * 1,000 kB	num packets:	312	min latency:	0.182	max latency:	17.990	avg latency:	7.953
	num packets:	302	min latency:	0.129	max latency:	16.981	avg latency:	8.413
experiment 4 (variation, high throughput): total throughput: 1,000 kB/s								
1000 sensors * 100 kB	num packets:	3989	min latency:	0.032	max latency:	38.238	avg latency:	14.687
	num packets:	3711	min latency:	0.041	max latency:	39.362	avg latency:	14.739
100 sensors * 1,000 kB	num packets:	314	min latency:	0.187	max latency:	19.985	avg latency:	9.534
	num packets:	318	min latency:	0.404	max latency:	19.779	avg latency:	9.677
10 sensors * 10,000 kB	experiment failed (0 packets), reason unknown							

7. Conclusion and Outlook

The automotive field is an excellent use case for ubiquitous computing. It offers a large number of different and continuously changing sensor setups, computing devices, and users. Furthermore, several applications are already in the street or seem to be realizable and interesting for a sufficiently large community.

Aiming for an explicit cross-applicational and brand/manufacturer-independent data exchange leads to mainly two kinds of challenges: scientific and economical ones. On the scientific side, all information needed for a dynamic data fusion (e.g., sensor data properties, calibration data) is to be formalized, exchanged, and the data fusion process needs to be adapted (i.e. reconfigured) accordingly. Here, especially it needs to be considered that the actual application needing the data, as well as the actual sensors to be planned for this application, and also the actual sensors available in the very moment of data fusion are all not known at design time of the SADA system. On the market side, the challenge is to get support of a sufficiently large number of sensor manufacturers and ADAS manufacturers. Therefore, the presence of the industrial partners in the consortium (and in the work packages dealing with the support and needs of potential SADA users) is important.

Presented is a first concept of a solution for such a dynamic data fusion system. The focus is drawn on the topic of ubiquitious/pervasive computing realized through automotive and smartphone IT devices and a central backend system. First experimental results are presented that indicate the feasibility of the proposed system concept. The project SADA is at a stage where the concept is about to be finished and implementation of technical components begins. The next project phase will show if the overall system concept is viable and which machine learning, crowd sensing demonstrational use cases are possible.

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