Poster Contribution

Traffic Detection Using Modular Infrastructure Sensors as a Data Basis for Highly Automated and Connected Driving

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Summary

Infrastructure sensors enable the collection of reference data for automated and connected driving operations. The collected traffic data can not only be sent online to existing receivers, such as connected and automated vehicles (CAVs), but can also be stored in a central database for research and development purposes. This paper presents approaches to the functionalities of modular infrastructure sensor systems, which are used in the research projects HDV-Mess and ACCorD. Both research projects are funded by the European Regional Development Fund (ERDF) and the Federal Ministry of Transport and Digital Infrastructure (BMVI) respectively. Special attention is paid to the data processing pipeline from raw sensor data to fused object lists and their deployment.

1 Introduction

In road traffic, the complex behavior of a wide variety of participants plays a central role in the research and development of highly automated driving. With the increasing complexity of automation processes, the effort required to capture all possible scenarios is increasing as well.

Driver behavior in particular is dependent on many parameters in its environment, including the interaction of road users, but also, among other things, the type of the road, the time of the day or weather conditions. In order to have a sufficiently large database of these behavioral processes, long-term recordings, which capture the whole environment, are essential.

Vehicles already have comprehensive sensor technology to detect surrounding participants in a first-person perspective, but have the disadvantage that occluded objects cannot be captured. Drones can compensate for this disadvantage by capturing the environment from a bird's eye view. However, they have a restricted field of vision too and can only be used under supervision as well as for a limited duration.

In addition to the collection of large driving data sets, the real-time detection of non-connected road users is an important aspect. Test fields for automated and connected driving, which are equipped with infrastructure sensor technology, are able to provide this service for CAVs. During the test operation of a CAV on such a route it is essential that road users who are not able to communicate themselves in a digital way are not hidden for the CAV. The perception range of the CAV is limited to the field of vision of its sensors, which is especially critical for road users who are hidden by buildings or vehicles. With the help of the collective perception of the infrastructure sensors, the number of road users detected in a test field can be drastically increased. Moreover, the accuracy of the estimated parameters (like object position, speed, etc.) increases with the number of infrastructure measuring stations sharing information about the same object. In this case, receiving stations need to match and fuse information from multiple road users.

For this reason, we present the traffic detection methods of the research projects HDV-Mess [1] and ACCorD [2]. These methods allow long-term recordings on the infrastructural side with a large visual range and a highly accurate determination of road user trajectories.

2 Related Work

In the following, we discuss related works that show parallels or similarities to our projects. In addition, we describe a method that we use as a valuable complementary tool for our work.

2.1 Traffic Detection Using Infrastructure Sensor Technology

The use of infrastructure sensor technology for traffic monitoring has already been investigated in several projects. For example, the Ko-PER [3] project is one of the first attempts to equip a traffic intersection with Light Detection and Ranging (LiDAR) sensors and to collect information about passing road users. A further development is the Application platform Intelligent Mobility (AIM) [4], which also monitors an intersection, but using camera and radar sensors.

Large-scale test fields using infrastructure sensor technology, such as those being developed in the projects Providentia [5], Diginet-PS [6] and Testfeld Niedersachsen [7], are additionally investigating the live transmission of recorded traffic data and the development of a digital twin. The two projects HDV-Mess and ACCorD tie in with this topic.

2.2 Collection of Reference Data

The validation of collected infrastructure data requires corresponding ground truth data. Since real-world conditions, unlike simulation environments, are not able to provide ground truth data, highly accurate reference data must be collected elsewhere. In addition to the use of RTK-GPS equipped vehicles, drones are also very well suited for collecting reference data [8]. Drones observe traffic from a bird's eye view. This gives them the advantage over the RTK GPS approach of collecting reference data not only for a single vehicle but for the entire measurement cross-section. In addition, they operate in an error range of only a few centimeters. A subsequent comparison of the collected drone data with the infrastructure data allows a statement about their accuracy. In both projects HDV-Mess and ACCorD, the drone approach is used to collect highly accurate reference data and to validate the infrastructure data.

3 Method

Both projects, HDV-Mess and ACCorD, use infrastructure sensors in different ways. Although both aim at the construction and use of measuring stations, so called intelligent transport systems stations (ITS-Ss), two different approaches are pursued. In the following subsections, the project objectives of both projects will be explained first, followed by the corresponding traffic detection concepts and their respective data processing pipelines.

3.1 Project Objectives

The combined goal of both projects is to create an integrated development environment to systematically test and validate CAVs in interaction with connected infrastructure.

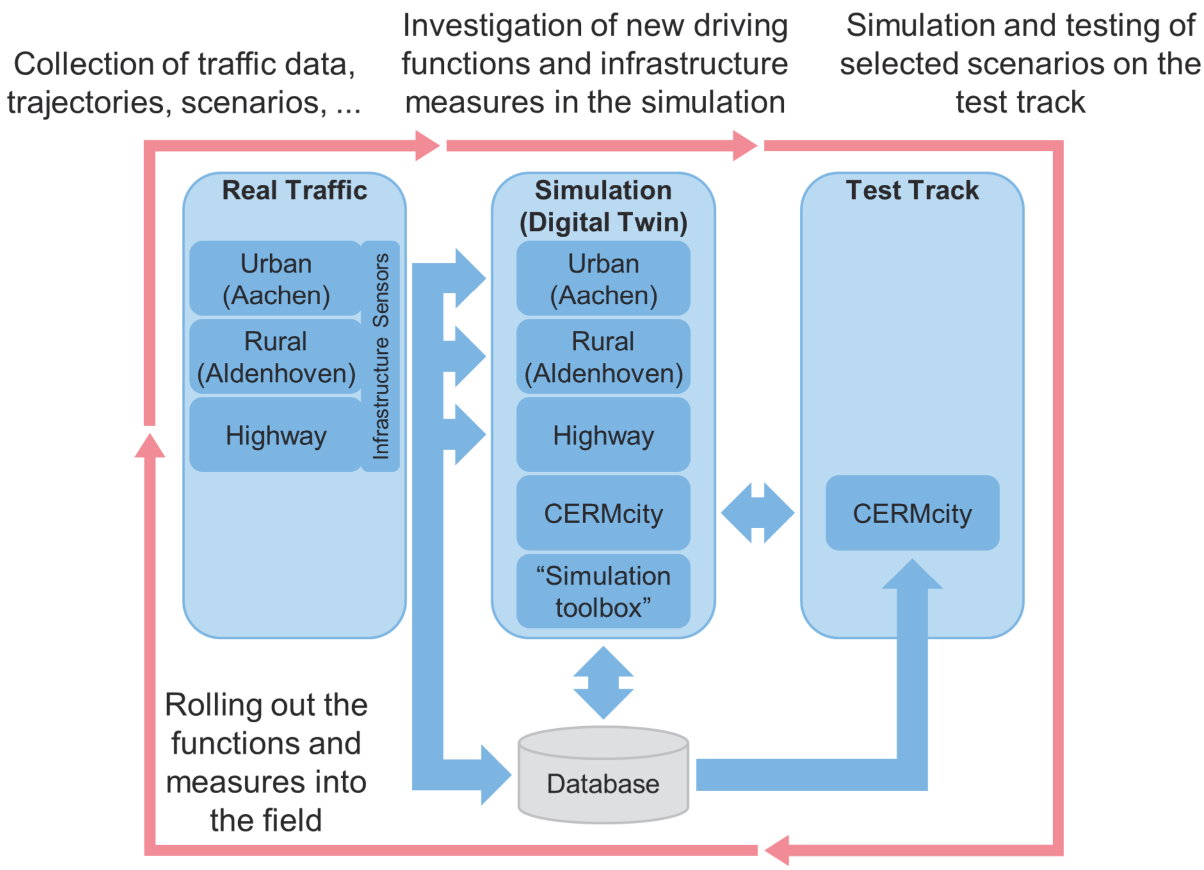

Fig. 1 Combined project goals of HDV-Mess and ACCorD.

This is achieved by a time and cost-efficient tool chain and methodology, in which simulation, closed test sites and test fields in public transport are linked in the best possible way. In order to be able to depict a wide range of traffic scenarios, an urban and a rural traffic section, a motorway section, as well as the CERMcity test site of the Aldenhoven Testing Center (ATC) are considered. A test environment will be set up which, with the help of a reference sensor system, will record traffic participants and environment on the test field sections with high accuracy. All data collected will be processed and stored in a central database and can be used for further research and development activities and for simulations. The conception and implementation of a digital twin as a virtual image of the test field sections allows the execution of tests in simulation. Subsequently, the test environment can be used to validate the developed driving functions. The overall system can be regarded as an iterative cycle, which is shown in Fig. 1.

3.2 Traffic Detection Concepts

HDV-Mess aims to build mobile ITS-Ss, equipped with two 128-layer LiDARs and two 4K monocular PTZ camera sensors each for flexible data recording at various locations and different environments. Each ITS-S stores its raw measurement data via a local Wi-Fi connection to a mobile data collection server. The data is then copied and processed on a stationary high performance server after the recordings are finished.

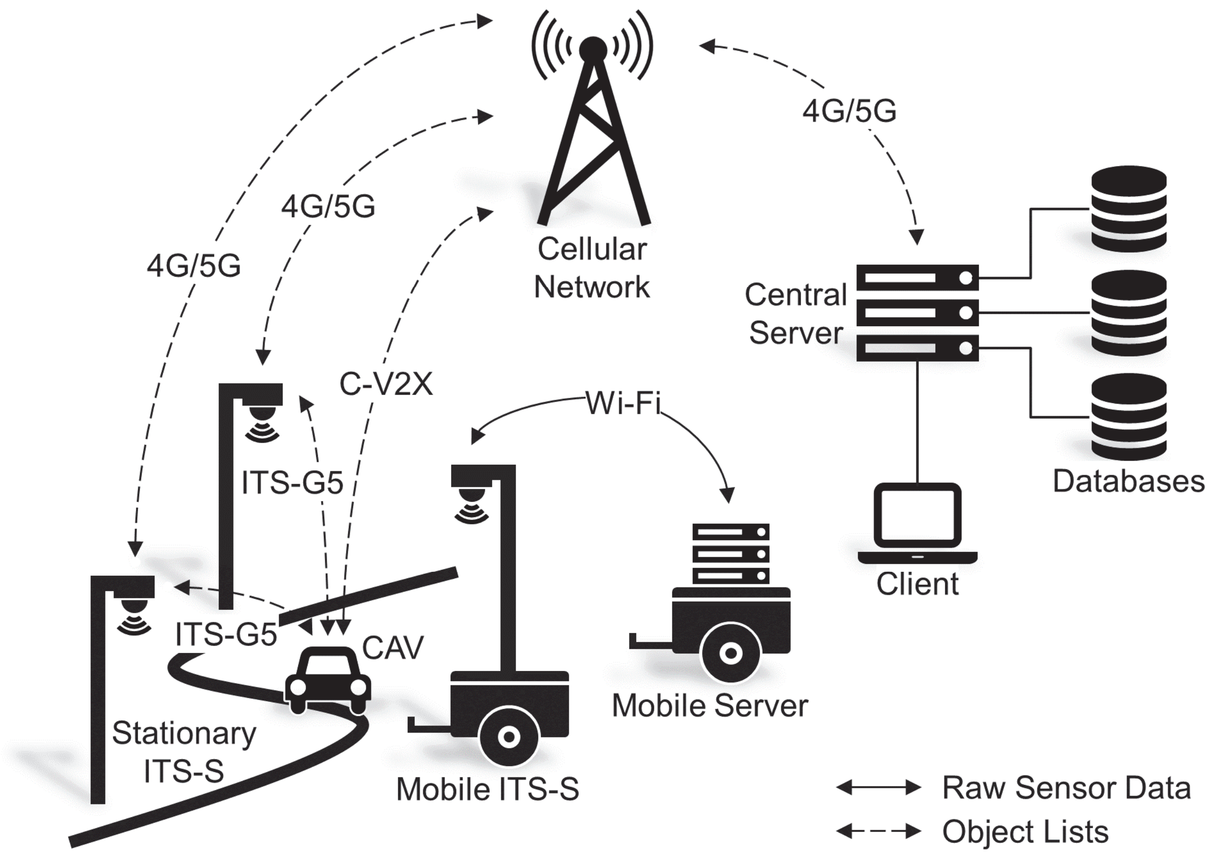

Fig. 2 Traffic detection concepts using mobile (HDV-Mess) and stationary (ACCorD) ITS-Ss.

In contrast, in ACCorD we mount the same sensor setup at fixed places in urban and rural areas, next to a highway as well as on the CERMcity testing site of the ATC. Each ITS-S already extracts the perceived objects from the raw sensor data and sends them to a central fusion server, which estimates their trajectories in real-time. An extraction node combines these data with the known environment to store specific scenarios relevant for further research and development. Additionally, the live data can be visualized in a digital twin and used in various client applications such as vehicle-to-everything communication (V2X). For this purpose, ITS-G5 is used for the communication between vehicles and the ITS-Ss, whereas the central server distributes its data via cellular V2X (C-V2X). All components of the traffic detection concept are shown in Fig. 2.

3.3 Data Processing Pipelines

The concept of HDV-Mess allows the use of an offline pipeline in which the raw sensor data is first recorded and then processed at a later time. In contrast to this, the goals of ACCorD make an online approach necessary, which is able to process the raw data at real-time. Fig. 3 gives an overview of the two processing pipelines.

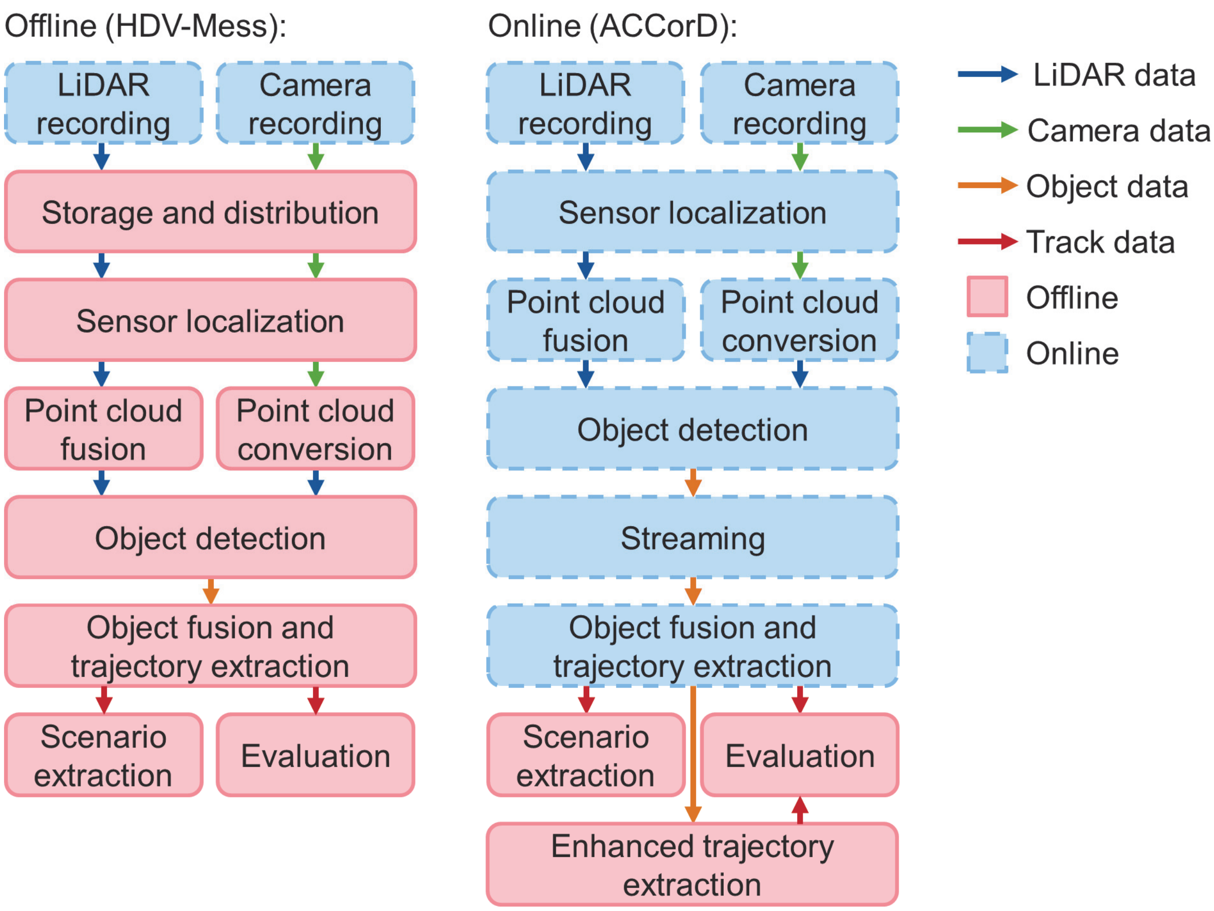

Fig. 3 Offline (HDV-Mess) and Online (ACCorD) Data Processing Pipelines.

For offline processing, the data recorded by the LiDARs and cameras are stored on a mobile data server. After the recordings are finished, the data is distributed to one or more high performance servers, which perform the further processing steps. At first, we use the information of optical features, inertial measurement units (IMUs) and global navigation satellite systems (GNSS) to precisely localize each sensor in a global coordinate system. This is necessary for each time step, since environmental influences such as wind cause unwanted movements of the sensors. Based on the calculated positions and orientations of the LiDARs, both LiDAR point clouds of each ITS-S are fused. This increases the density of the resulting point cloud compared to the unfused point clouds, which allows us to achieve a higher detection accuracy. To extract 3D-information from the monocular cameras, a convolutional neural network (CNN) converts each image to a pseudo-LiDAR point cloud. In the next step, another CNN performs an object detection on the fused point cloud of the LiDARs and the two pseudo-LiDAR point clouds of the cameras. A bayesian filter then fuses all generated objects from all ITS-Ss of the same test field section. By taking advantage of the fact, that not only past but also future data can be used to calculate the object state at each time step, highly accurate trajectories are generated for each road user. We further use these trajectories to extract interesting driving scenarios such as lane changes or near collisions. For evaluating the accuracy of the road user tracking, we carry out reference measurements with a drone. Drones deliver high quality reference data, so that a good assessment of the accuracy of the infrastructure measurements can be made.

The online pipeline of ACCorD differs from the offline pipeline in two major points. First, most of the steps are done online, as the name suggests. This leads to the issue that no data from future time steps can be used for the extraction of road user trajectories. Therefore, the accuracy of the online-generated trajectories is slightly lower than that of the offline trajectories. To compensate this, another trajectory extraction runs offline to avoid drawbacks in offline use of the recorded data. The second difference is that the recorded data from the sensors is not directly distributed to the main server(s), but all steps up to the object detection are done directly on the ITS-Ss. This results from the fact, that the sensors generate a huge amount of raw data. Transmitting them via mobile communication would exceed the capacity of the network channels. Alternatively, using wired connections would require to install cost intensive fiber cables to each ITS-S, which is only possible in rare cases. Therefore, converting the raw data to object lists initially drastically reduces the required network capacity, so that mobile communication can easily be used. The drawback of this method is that the electric power required to perform these calculations is needed at the ITS-Ss. The power must either be provided by a permanently installed power line or it must be generated by a self-sufficient supply, such as wind or solar energy. Ultimately, the reduced bandwidth due to the ITS-S based processing also leads to a reduced latency, which is critical for V2X applications.

3.3.1 Simulation and Digital Twin

Before the measurement hardware is available, we use simulation to collect data for several purposes. Its main objective is to represent an accurate copy of the real sensor setup together with its environment, as shown in Fig. 4. The extraction of both raw measurements and ground truth object positions allows the development and training of all algorithms used in the entire toolchain. Additionally, the simulation enables to selectively test the algorithms on rare scenarios, which can contain, for instance, partially occluded vehicles or pedestrians.

Furthermore, a digital twin of all ACCorD test environments is set up for investigating the traffic in real-time. Beneath the raw visualization of the scenes, it serves as a key component on the path to highly automated driving. In this context, it can be used by a control center to monitor the state of CAVs and to interact with them, e.g. maneuvering them through difficult scenarios.

Fig. 4 Design of the digital twin based on a real scenario.

3.3.2 Data Transmission via V2X

The object data extracted from the raw sensor data is sent to the receivers using two different data transmission methods. It is up to the receivers (e.g. a CAV) to decide which technology they intend to use. In general, a distinction is made between the automotive WLAN standard IEEE 802.11p [9], which is referred to as ITS-G5 by the European Telecommunications Standards Institute (ETSI) [10] and the cellular C-V2X approach, which uses 4G/5G technology. The main difference between ITS-G5 and C-V2X in general is the transmission range. ITS-G5 relies on the use of infrastructure-side Road Side Units (RSUs) and vehicle-side On Board Units (OBUs). If an OBU is within the WLAN range of an RSU, it is capable of receiving its data. C-V2X, on the other hand, interacts within the known ranges of cellular networks. With regard to the use of infrastructure sensors for highly accurate traffic detection, our work is limited to the standardized ETSI message types Cooperative Awareness Message (CAM) [11] and Collective Perception Message (CPM) [12]. CAMs contain information about a transmitting traffic participant, such as position, speed, heading, etc. CPMs basically contain the same information as CAMs for all perceived objects, but the values of a CPM must be extrapolated due to the time delay compared to a CAM sent directly from a CAV. This comes at the cost of increasing the inaccuracy of successive coordination transformation processes. Furthermore, a CPM provides additional parameters, which are not provided by a CAM. These optional parameters are the vehicle orientation angle, pitch angle, roll angle, vehicle weight and trailer data.

The infrastructure sensor technology used in ACCorD sends both CAMs and CPMs, depending on the needs of the receiver. Parallel transmissions are carried out via multiple channels. One CPM per measuring station or one CAM for each road user per measuring station is broadcasted both via ITS-G5 and C-V2X. In addition, all ITS-Ss send their object lists for each time step to the central fusion server, which in turn broadcasts correspondingly fused CAMs and CPMs of all road users per test field section via C-V2X.

4 Conclusion and Outlook

This paper shows that the use of high-performance modular infrastructure sensors can serve as a data basis for highly automated and connected driving. With an increased computational, power and cost effort, it is possible to output highly accurate fused road user object lists from stationary infrastructure sensors to CAVs in near real-time with low latency. Although the initial effort for the installation of a comprehensive infrastructure sensor system is very high, an equipped test field continuously provides measurement data for live applications or offline development purposes. CAVs benefit from the infrastructure sensor technology by expanding the CAVs' sensor fields of view and providing CAVs with additional safety-critical traffic data. These data might not have been recorded by the CAV's sensor system due to object occlusion. In addition to the use of stationary real-time capable ITS-Ss, the use of mobile non-real-time capable ITS-Ss is also well suited. The mobile design allows flexible access to additional measurement cross-sections, at which long-term recordings can be carried out. In turn, this results in large traffic data sets, highly relevant for the development and safeguarding of automated driving functions.

In future, we will test the use of 5G to evaluate the latencies achieved with this technology in comparison to 4G and ITS-G5. We also plan to develop field programmable gate arrays (FPGAs), which will be utilized in the measuring stations to significantly reduce their energy consumption.

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