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A Vehicular Environment Perception Platform for Safety Related Applications

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Abstract

The aim of this paper is to present a perception platform developed for vehicular safety applications. The work described here is part of the work carried out in the interactIVe project and more specifically inside the PERCEPTION sub project. InteractIVe is a large scale integrating project co-funded by the European Commission as part of the FP7-ICT for Safety and Energy Efficiency in Mobility. One of the main objectives of this project is the implementation of a reference perception platform with a general purpose interface to the applications.

Keywords: perception platform; automotive safety; data fusion; sensors; actuators

1. Introduction

The interactIVe project addresses the development and evaluation of next generation safety systems for Intelligent Vehicles, based on active intervention. Safety technologies have shown outstanding capabilities for supporting the driver in hazardous situations. Despite their effectiveness, currently available systems are typically implemented as independent functions. This results in multiple expensive sensors and unnecessary redundancy, limiting their scope to premium-class vehicles. The project is based on the concept that by integrating applications together, vehicle components may be shared among the

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various safety systems. This is accomplished in interactIVe by discrete architectural layers that are common to all applications. This paper focuses on the perception layer. Therefore, significant effort is devoted in interactIVe to the enhancement and integration of the perception layer. This is done by taking into account the results from the PReVENT project.

The perception of the environment, using a variety of sensors and information sources, is a challenging task which plays a central role in Intelligent Transportation Systems (ITS). Actually, the perception platform collects data from all available sensors installed on the vehicle and from other information sources such as wireless communication and digital maps, processes this data using advanced fusion techniques, and then provides its output to the applications using a dedicated interface called Perception Horizon. The Perception Horizon is one of the innovations of the interactIVe project since it is the first time that all clusters of information (incl. sensors, maps and communication nodes) are combined in one common output.

Another important aspect of the platform is that the interfaces of the input sources are also specified in the framework of the project, based on the experience of the collaborating partners. This means that for each sensor type or information source a common interface structure is defined and the solution for attaching different sensor types and products is the plug-in concept.

A variety of sensors and information sources will be available inside the interactIVe system. This data is fed into the perception platform which performs the low and high level data fusion through the different perception modules which are included in the platform. These modules are related to object perception, lane detection, road geometry extraction, object classification, trajectory calculation etc.

The remainder of this paper is organized as follows. In section 2, the different layers of the interactIVe architecture are briefly described. In the following section, the perception platform which is the central component of the interactIVe system is presented. Finally, conclusions are drawn and future work is outlined.

2. System architecture

First of all, a brief description of the system architecture is essential to understand the significance and the role of the perception platform within interactIVe. An overview of this architecture is illustrated in Figure 1. This architecture consists of four discrete layers, namely sensor, perception, application and information, warning and intervention (IWI) layers. A short description of these layers will be given below, where the focus is on the perception layer which will be implemented as part of the perception platform.

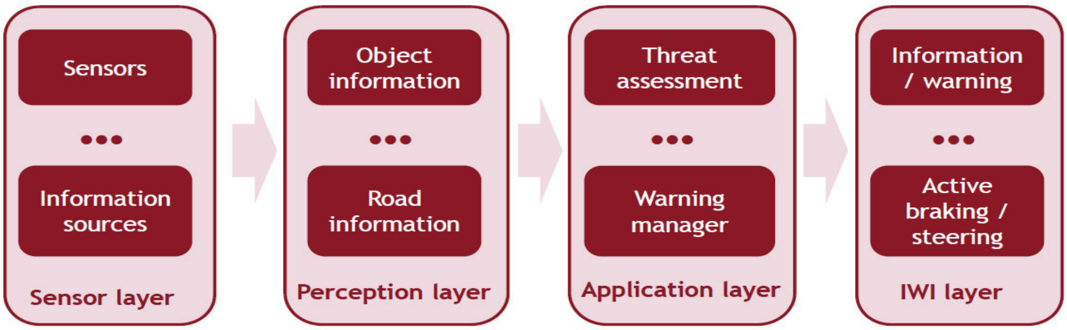

Fig. 1. interactIVe layered architecture

2.1. Sensor layer

This layer includes the sensors which will be used for the perception of the road environment as well as other information sources, such as digital maps, that will be directly connected to the perception platform. The perception platform will use general interfaces defined for each sensor type, which allows transmitting all necessary sensor information. Each new individual sensor connected to the interface will require a small software plug-in that converts the sensor output to the perception interface module format.

The generic senor types supported by the platform include the following: environment sensors, digital map, GPS, vehicle sensors, camera, lidar, radar, ultrasonic and vehicle-to-X (V2X) nodes, where X stands either for vehicle (V) or for infrastructure (I).

2.2. Perception layer

The perception layer collects the data from all available data sources (sensors, map, etc.) installed on the vehicle, processes this data using the perception modules, and then sends its output to the application layer via the Perception Horizon (the perception output interface). The sensor layer transmits all available input data to the perception layer which performs the low and high level data fusion. Instantiations of this low and high level data fusion are the perception modules which together with the Perception Horizon form the perception platform which lies in the heart of the perception layer, and will be described in detail in the following section.

Example perception modules include the following: vehicle state filter, frontal near range perception, frontal and side/rear object perception, moving object classification, enhanced vehicle positioning, lane recognition, road data fusion, vehicle trajectory calculation .

2.3. Application layer

The application layer contains the functions which are needed to build the applications, ranging from threat assessment and path prediction to warning strategies. It does not process data from individual sensors or other inputs, but all relevant data is coming from the perception layer through the Perception Horizon. The output of the application layer is “signals” to the IWI units for execution. The IWI units themselves only execute the commands from the application components.

2.4. IWI layer

The IWI layer contains the human machine interface (HMI), i.e. the input and output devices that enable interaction between the driver, the automation, and the base vehicle. The IWI layer further contains the related functions to optimize this interaction.

It is evident that the interaction does not only take place via outputs from automation towards the driver (e.g. via displays or sounds) and inputs from the driver towards automation (e.g. settings by buttons or stalks). Instead, there can also exist an interaction via haptic devices such as the pedals or the steering wheel, where automation and driver act together to influence the movement of the vehicle. Furthermore, the automation could also intervene directly, e.g. by braking, and thereby implicitly interacting with the driver, since the driver will perceive changes in the vehicle’s movement.

3. Perception platform

As mentioned in section 2, the perception platform lies at the "heart" of the perception layer, which in turn is the central layer in the interactIVe architecture. In this section, the input to the perception platform, the perception modules running inside the platform, as well as the perception output (namely the Perception Horizon), will be presented. An overview of the perception platform is depicted in Figure 2.

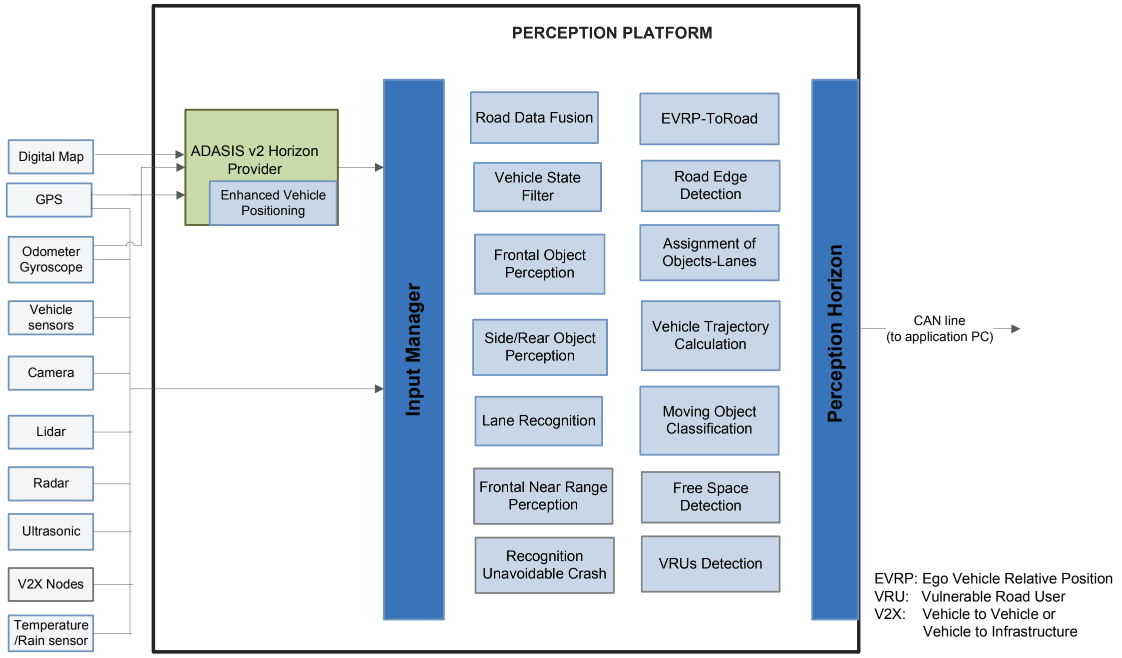

Fig. 2. Perception platform overview

3.1. Perception input

The input to the perception platform are the sensors and information sources which belong to the sensor layer. One of the innovations of this project, and especially this platform, is the well defined interfaces for generic sensor types, which allows different sensors of the same type (e.g. two different radar sensors) to connect to the platform using an appropriate adaptor module. The perception inputs which are highlighted in Figure 2 are also listed below:

- Digital map
- GPS
- Odometer, Gyroscope
- Vehicle sensors
- Camera
- Lidar
- Radar
- Ultrasonic
- V2X nodes
- Environment sensors (temperature, rain)

3.2. Perception modules

A short description of each perception module will now be given. Some of these modules are applicable to several demonstrator vehicles, whereas others are developed specifically for a certain demonstrator. The interconnection of these modules is not depicted in Figure 2 because the focus in this paper is on their functionality.

Vehicle State Filter

The vehicle state filter will filter the state representation of the vehicle derived by the production vehicle sensors, and additional gyroscope and GPS sensors. An Extended Kalman Filter (EKF) with appropriate model will be used to filter the signals and derive associated uncertainties.

Furthermore, additional parameters will be derived, such as yaw rate offset and velocity scale compensation factors. Vehicle acceleration will be derived if this is not directly measured by any sensors. Velocity signals will still be derived even when wheel slip occurs, and similarly, vehicle heading will still be derived when the GPS is temporarily unavailable.

ADASIS Horizon

The purpose of the ADASIS (Advanced Driver Assistance Systems Interface Specification) Horizon module is to provide the system with the following information:

- Absolute position of the ego vehicle (longitude/latitude)
- Relative position of the vehicle with respect to the digital map
- Detailed information about geometry, topology and attributes of the road ahead.

Note, the Enhanced Vehicle Positioning module is intended to increase or refine positional precision derived by the ADASIS Horizon module.

Enhanced Vehicle Positioning

The Enhanced Vehicle Positioning (EVP) module will enrich the absolute vehicle position message by the information about the current lane on which the ego vehicle is actual driving. This current lane information is coming from the lane recognition camera sensor. The Lane Recognition module also will determine vehicles current lane position and provide this information to EVP module as input. The EVP module will integrate this information into the vehicle position messages of ADASIS V2 protocol.

Frontal Near Range Perception

Frontal Near Range Perception is intended to deliver the environmental description of the near field area in front of the host vehicle. The main goal is to report all relevant obstacles that can be detected by the sensor platform. To realize comfort and safety applications on the basis of the resulting information the detections of single sensors have to be fused and filtered in time to stabilize the environment description and derive stable additional information describing e.g. dynamic parameters of each object. Special focus of this module is the support of time critical functions also during high dynamic maneuvers required by the recognition of unavoidable crash situations perception module.

Frontal Object Perception

The objective of the module is to detect every relevant obstacle in the front area of the ego vehicle including stationary and moving objects and provide information about these objects (e.g. detection confidence value, ID, position, static/moving flag, moving direction, velocity, acceleration and estimated object size). Sensor data fusion and advanced filtering techniques should be taken into account in order to obtain a more reliable perception result and provide additional information not directly observed from sensor (e.g. estimation of object velocity from lidar data). In contrast to the Frontal Near Range Perception module this module is more general taking into account also the far range which is closer to continuous support and safe cruise functions.

Side/Rear Object Perception

This module detects and delivers objects in the rear and side area of the ego vehicle including also the blind spot. Regarding the side area at least the two adjacent lanes are covered (one on the right side and one on the left). Sensor data fusion techniques will be used to achieve a stable and accurate representation of the environment in the rear and side area sensed by the sensors. Measurement data from sensors are processed with filtering algorithms to achieve noise reduction, overcome short term missing sensor detections and estimate state information not measured directly by the sensors. The identity (ID) of the tracked object is maintained while the object is traveling through the field of views of the sensors (that requires that sensors mounted on the vehicle should have at least partially overlapping field of views) and a detection probability is assigned together with a flag indicating if the ID is maintained from a previous detection. There is also a flag indicating stationary/moving object.

Lane Recognition

The Lane Recognition module outputs the position and geometry of high-contrast lane markers of the ego lane on the road. The model behind the output values are a second order polynomial, i.e. distance between ego vehicle and lane markers, angle between ego vehicle and lane marker, and curvature of road.

The lane index of the ego vehicle (e.g. “in lane 2 of 3”) will (usually) not be calculated by this module (but, for completeness, it is foreseen in the output interface).

This module uses a camera as sensor input, and optionally an input indicating urban / non-urban situation (e.g. from map). An inertial sensor can help to improve the recognition results.

It is possible that the functionality of this module is also realized by internal processing within the camera sensor. In that case, this module will just pass-through the lane information coming from the camera sensor.

Road Edge Detection

The Road Edge Detection module estimates the road boundary using different sensors. Thereby the main attention is turned on image processing techniques for the detection of the road boundary. The raw image is analyzed by different features that are fused within a stochastic filter and a street model in order to identify road surface from non-surface.

Additionally, a radar sensor is used for supplementary information like the detection of street surroundings like guardrails.

Since image processing tasks are computationally expensive, a pre-located lane recognition system delivers the information about the ego lane. This is used to narrow down the search space.

The ego vehicle information improves the module results significantly, because camera projections are sensitive to pitching of the vehicle.

The output of this module is geometrical description of the road in form of clothoid parameters (curvature, curvature rate), the road width and lateral offset of ego vehicle to road boundary.

Road Data Fusion

Road Data Fusion module aims at increasing the accuracy of the road attributes provided by the individual sources of information as the vision based lane detection and map data. Road features are extracted from the image processing units (Lane Recognition and Road Edge Detection modules) and are fused (first segment) and extended (remaining segments) using the map road geometry. Additionally it increases the availability and robustness of the system i.e. lane information should be always available even if they are artificially reconstructed in absence of visible lane markings using only map data.

The output of the module will be a list of road segments. Every segment will be described from the following attributes:

- Equation describing the geometry of the segment; Alternatively, attributes: segment initial point coordinates, segment length, curvature, curvature rate
- Road width (fused)
- Lane width (fused)
- Quality flag

Road geometry is delivered with respect to the ego-vehicle local coordinates system.

Recognition of Unavoidable Crash Situations

The purpose of the Recognition of Unavoidable Crash Situations module is the assessment of the actual situation and the prediction of the likely development within a certain time frame in the future. Result of the prediction is the estimation of a crash probability and severity with the aim of a secure forecast with very low false alarm rates and a high probability of crash detections. In general the module should serve as a source of information for safety applications that have the goal to trigger various actuator systems inside or outside the ego vehicle.

Relative Positioning to the Road of the Ego Vehicle

This module aims at providing the relative positioning of the ego vehicle with respect to the road combining information from road geometry and from vehicle motion vector. A more accurate position of the ego vehicle is given, assigning a lane index and a lateral offset along with a heading to the lane marking. Moreover, a confidence value is provided.

Assignment of Objects to Lanes

This module uses the positions of the detected objects and the available lane geometry and assigns a lane index to each one of them. The lane index is extracted using the relative distance of the detected objects from the lane markings. For each detected object this module provides a lane assignment index together with a confidence value with respect to the ego-vehicle's predicted trajectory or alternatively with respect to the road geometry as this is provided by the Road Data Fusion module depending on the application needs.

Vehicle Trajectory Calculation

This module will provide the future trajectory of the ego vehicle as a list of points. The aim of it is to predict driver's intention in a short term (some few seconds in the future) by estimating the future path of the ego vehicle and its dynamics with respect to a given fused road geometry. The module takes into account the ego vehicle dynamics and the fused road geometry in order to estimate the future trajectory of the ego vehicle in the local ego vehicle coordinates.

Moving Object Classification

The Moving Object Classification module will classify different types of moving objects into several predefined categories. This module is intended to work complementarily along with the Frontal Object Perception (FOP) module providing information about object class of moving objects detected and returned by FOP. For the module inputs, not only object-level information obtained from FOP is required (refers to the outputs of FOP interface specification), low-level sensor data (e.g. raw images from camera) is necessary as well. Furthermore, predicted future trajectory of the ego vehicle could be also used to help focusing the classification process on the more threat-relevant areas.

Detection of Free Space

The objective of the module is to detect the free/drivable on-road/off-road space in front of the ego vehicle in order to provide information about where the vehicle can go in a short term (e.g. a few seconds). The module will take raw data from lidar and the ego vehicle dynamics as inputs to output the most relevant drivable region.

A free/drivable region which represents the region where the ego vehicle can go is delivered relative to the coordinate system of the ego vehicle

Vulnerable Road Users

This module is responsible for detecting, classifying and tracking vulnerable road users (VRUs), i.e., pedestrians, bicycles and motorcycles, in front of the host vehicle. The module fuses information coming from a forward looking radar sensor, capable of accurately measuring the range to the object, and a vision sensor providing classification capability and accurate lateral positioning of the object. However, the module also works in degraded mode if one of these sensors are unavailable, especially the vision sensor shall deliver both position and classification information that is accurate enough to support limited functionality. The output consists of position and velocity estimates of all VRUs detected by the sensor system.

3.3. Perception horizon

The Perception Horizon is the output interface of the perception platform. The Perception Horizon module is considered as the union of the following three elements:

- The synchronized subset of the outputs of the perception platform modules
- Configuration files for each demonstrator vehicle defining which sensors are available and in what mounting position, plus which signals are needed for each application function
- Output manager functionality (software module translating Perception Horizon data to the communication line between perception platform and applications).

The Perception Horizon module sends the output from all available perception modules to the applications. The advantage of sending each module's output to the Perception Horizon is that a modular handling of the data is promoted. Duplicate structures or passing through of information from one module to another is minimized.

Finally, it is worth mentioning that the perception horizon data will be transmitted in Controller Area Network (CAN) format to the application layer.

4. Conclusion and future work

In this paper the perception platform being developed within the intreractIVe project was described. A short overview of the architecture of the system to illustrate the role of perception inside interactIVe was also given. The perception input, the Perception Horizon as well as the perception modules which are the main components of the perception platform were described.

Work on vehicle perception inside interactIVe has entered now the creative phase, where sensor data fusion research is realized and its outcomes are transformed into the perception platform development and engineering. Work on the data fusion modules comprises processing of heterogeneous data from different sources like radars, cameras, lidars, vehicle sensors and digital maps. Cutting edge multi-sensor online data fusion approaches as grid-based fusion, attention-focused fusion, object classification and road edge detection are part of the future work. In this direction, active intervention envisioned within interactIVe applications, poses hard real-time requirements for perception data processing and fusion modules.

The perception platform can serve multiple safety applications and has been designed to work on different sets of sensors, thus being close to a "plug and play" approach. The specification of general sensor type interfaces makes the insertion and adaptation of a new sensor to the perception platform (as long as it belongs to one of the general sensor types accommodated by the platform) a relatively easy task. The interoperability will be demonstrated by fitting the platform on the different demonstrator vehicles equipped with different sensors.

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