Highly Accurate Map-based Path and Behavior Planning for Automated Urban Driving

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***Abstract*—To overcome challenges of automated driving in inner-city scenarios, this paper's approach is to realize a robust behavior and path planning based on highly accurate maps combined with localization and communication methods. The main idea is to build up the model based on an existing modular automated driving architecture which was initially developed for highway use cases. This should enable a possibility of implementation with an significantly reduced effort.**

Keywords–Automated Urban Driving; Behavior Planing; Connected Driving; Highly Accurate Maps; Localization.

I. INTRODUCTION

Automated driving is undoubtedly one of the most important technological development components for the automotive industry. For example, the first series applications of individual Society of Automotive Engineers (SAE) Level 3 systems are now almost ready for market launch [1]. However, their range of functions is still rather low and the scope is limited to the highway.

On the other hand, a number of complex challenges have to be overcome in order to realize automated driving in the inner-city area. Therefore, the high complexity of the static and dynamic environment within cities leads to increased requirements to the robustness of in-vehicle behavior planning.

This is where the following papers approach is focusing on. Based on a high-precision digital map, additional information about the static environment is provided to the vehicle's planning modules. This is complemented by additional information from communication infrastructure to the dynamic environment.

At first, in Section II, an exemplary use case is presented in which the concept can be applied. Section III is focusing on the key elements of the concept and their purpose as well as the connection among them. In Section IV an overview about the integration in an existing architecture is given. The paper is concluded by a summary of the current work status and the outlook for upcoming activities in Section V.

II. MOTIVATIONAL USE-CASE

The problem given is the approach of an automated driving vehicle on a road with two lanes to an inner-city intersection with three lanes branching off into three direction - one lane for turning right and going straight, one lane for going straight and one lane for turning left. Regardless of other dynamic object vehicles, some really big challenges come up to the automated driving vehicle in such a complex scenario [2].

The correct localization on the approaching road and the high precise localization within the intersection area is difficult to handle. Based just on Global Positioning System (GPS), it is almost impossible to localize within a required tolerance for automated intersection crossings [3]. At this point, this paper's approach to use map and communication data combined with vehicle sensor data is set up. After the data fusion, it is possible to locate the ego vehicle with high precision within the right lane and on the right spot, e.g., the stop line of a traffic light on the lane for left turning.

The localization is followed by the behavior and path planning model, which provides the vehicle with the necessary intelligence to deal with for example complex intersection scenarios. Therefore, in addition to this, the planning model needs information about the traffic lights, other crossing object vehicles, e.g., the opposing traffic on the straight lane or pedestrians crossing the target road. This can be solved by different communication methods, e.g., road-side-units, backend-server communication and is work in progress.

III. CONCEPT

The basic idea to overcome the challenges of the inner-city area is to expand the information sources of the behavior planning of the automated vehicle to high-precision map data and communication.

For this purpose, a tool chain is developed, which is initially dedicated to the processing of map data in the online vehicle application. In the first step of preprocessing, a map is parsed into the structure of the framework. Thus, in the next step, an interpretation can be made, which provides the logical and geometric information of the map.

The proposed architecture offers the possibility to integrate different map formats and extract specific information from them. Thus, on the one hand, behavior planning purposefully receives information about, e.g., the change in the road cross-section and the associated logical assignment of tracks, which then in turn lead to an adequate behavior decision.

On the other hand, geometric information of the lane course is used to support and optimize path planning. For example, complex lane courses at inner-city intersections can be taken into account in a timely and precise manner in the planning.

The extraction of the information can be done in two ways. On the one hand, a predefined route can be stored on the basis of which, in combination with the current vehicle position, specific information can be forwarded to the planning level. On the other hand, it is possible to provide information by means of a virtual horizon during free driving. The former, of course, offers the higher precision, since the route is known in advance.

The localization within this map is realized by a combination of different data. First, a rough assignment within the map is achieved via the GPS of the vehicle. This was done by comparing the current vehicle position and the global reference stored in the map. Next, a track accurate assignment of the vehicle is supplied. This is calculated by a model which processes information of the vehicle camera and matches these with the GPS data.

If a higher accuracy is required in individual situations, this is also anticipated in the model. A comparison between specific landmarks within the map and the scenario perceived by the vehicle provides additional potential for this. In particular, this can also be used to support the localization during a lack of GPS signal quality.

The model is also supplemented by external dynamic information. On the one hand, there is the possibility to provide data from a backend server. Here, individual events or specific information can be collected centrally and transmitted to the behavior model. Thus, a timely and targeted response of the automated vehicle can be realized on, for example, a construction site with a lane closure without a critical or uncomfortable situation arises. Situations of these types classified by the vehicle itself are correspondingly reported back via this interface and can in turn be made available to other vehicles.

IV. INTEGRATION IN EXISTING AUTOMATED DRIVING ARCHITECTURE

An important point for the design of the concept is the practical feasibility. In doing so, particular attention was paid to the modularity of the individual elements. This is particularly important with regard to the integration of the model in an existing vehicle architecture.

Figure 1 illustrates the relationship between the individual modules, as well as the general structure in the overall overview.

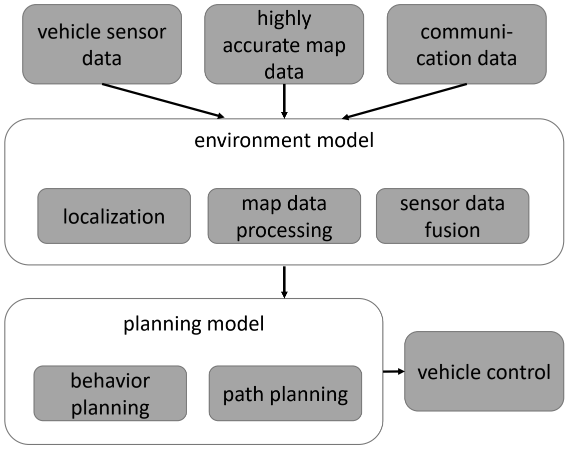

Figure 1. Relationship between the environmental model, the planning model, the vehicle control as well as the map and the communication data set on the same level as the vehicle sensor data.

The first level shows the provision of the most important input information for the model chain. Here, the existing vehicle sensors are extended by the highly accurate map data and the communication data. The latter are therefore considered in the overall context as an additional source of information at the sensor level. These data form the basis for the extended environment model. At this level, the processing of map data is integrated. In combination with the localization module, information is passed on to the planning level from there. The communication data are also processed and linked here.

At the planning level, this additional data can now be used directly to enhance the behavioral planning, as described in Section II, or as additional support in path planning.

For this purpose, the existing planning module is extended so that specific information can now be extracted. This can be done on the one hand in addition, in which, for example, information about speed limits can be adapted in advance. On the other hand, additional information which is not yet detected by the vehicle sensors, such as the distance to a stop line is taken into account.

Furthermore, the path planning model is edited, so that, in addition to the information of the existing vehicle sensors, now also information from the map are directly considered. These are for example the exact course of tracks within complex intersection scenarios.

The finally planned vehicle movement is then transferred to the vehicle control level. The advantage at this point is that the existing control algorithms do not have to be edited but can persist. This is possible because the existing interface can be adopted here unchanged.

V. CONCLUSION AND OUTLOOK

The paper proposes a new approach for a highly accurate map-based path and behavior planning for automated urban driving. In summary, the presented approach realizes a model that can contribute to overcoming the specific challenges of inner-city automated driving. One of the main advantages of the model is that the individual components can be integrated into the existing vehicle architecture due to the modular design. Consequently, on the one hand, the implementation effort is significantly reduced, and on the other hand, extensions can be added easily.

The next step is to complete the hole practical implementation. In particular, the communication data processing model and its complete integration into the planning level are currently still under development.

Following this, a comprehensive evaluation of the overall function is planned. For this purpose, specific test cases have to be carried out in simulation based on an existing test methodology [4]. This is followed by integration into a test vehicle and the execution of tests on a test site.

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