

Implementation of a Self-Learning Route Memory for Forward-Looking Driving

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ABSTRACT

In this paper it will be shown how a database containing information of the road characteristics of a frequently driven route can be automatically generated and continually updated in a vehicle during each drive. The contained information can be used as foresight information in predictive driving strategies. By using only drive train information, standard sensors (e.g. from ESC and ABS), and a GPS relevant road characteristics (curves, slopes, speed limits, etc) can be identified during the drive, stored in an on-board database, and used to optimize fuel consumption or driving comfort in subsequent trips along the route. The system is verified using a driving simulator with a 3D surround graphics system.

INTRODUCTION

Since the ABS (Anti-lock Braking System) became available in the end of the seventies, a variety of (assistance) systems for increased comfort, safety and fuel economy have been introduced in the vehicles. Some systems worth to mention are Adaptive Cruise Control (ACC), Lane Departure Warning (LDW), Advanced Front Lighting (AFL), systems for predictive gear shifting, electronic stability systems and curve speed warning [1][2][3]. These systems base on additional sensors dedicated for the one particular system. The sensors measure or scan the surroundings of the vehicle and together with information of the current vehicle state let the systems react appropriately, e.g. giving information to slow down before a sharp curve, automatically selecting a lower gear before a steep slope or turning the headlight to follow a bend in the road. Several research projects around the world have shown that the already impressive function of these systems could be greatly improved with information about the road ahead, i.e. foresight information for the upcoming road section [4][5][6][7]. However, the extended functionality of these systems typically bases on the assumption that the required foresight information will be available either from enhanced digital maps or through

communication with infrastructure or other vehicles [8][9]. This assumption though, has been made since the first navigation systems were introduced in our vehicles in the nineties. Nevertheless, today a great amount of this information is still lacking. The major challenge for the map vendors is the collecting of road data and keeping it up-to-date at a reasonable price for a useful support. The introduction of car-to-infrastructure communication or car-to-car networks is already a technological possibility, but the realization and use of such systems depends on the distribution of equipped vehicles, and hence the replacement rate of new vehicles. According to [10] a market penetration of at least 10% of all cars is required for inter-vehicle danger warning applications and about 5% for traffic information propagation. A 5% market penetration could be reached in 3 – 10 years, depending on the equipment rate (up to 25%) with the first equipped vehicles having no or little use of the system. In recent years a number of projects were initiated to investigate further methods to gather the required information needed. Worth to mention are methods basing on so called floating car data, or on additional sensors fitted to the vehicle, e.g. radar or optical systems such as cameras [11][12][13][14].

In this paper yet another solution for the problem of collecting road information and keeping it up-to-date will be discussed. The method bases on the fact that many vehicles repeatedly travel a certain route, i.e. commuter vehicles, public transport or commercial vehicles. The system described in the following sections, allows the vehicle to “memorize” or “learn” the characteristics of the driven route through repeated drives – just as an observant driver would do. The learnt information can then be used as foresight information in subsequent drives along the analyzed route – similar as a virtual co-driver. Possible fields of application, beside fuel efficient power train control, are e.g. improved curve speed warning, adaptive headlight control and predictive gear selection. One major benefit would be the improved controlling of the energy flow in hybrid-electric vehicles. With detailed information about the upcoming road section, regarding slopes and intersections, the full

potential of the stored electric energy can be optimally deployed [15].

The approach presented in this paper to collect the necessary foresight data claims to be cheaper and more flexible than many other systems in this category. One reason is that only sensors counting to the standard configuration in present medium class vehicles are needed. No extra sensors need to be added to the vehicle to be able to identify the relevant road characteristics discussed above. Thus no further costs arise due to costly hardware (e.g. cameras, radar). In contrast to digital maps for navigation systems which contain a fairly small amount of information but for a large geographical area (e.g. Europe, North America, etc), the route memory system described here will contain a large amount of information for a limited geographical area, i.e. the part of the road network where the vehicle is primarily moved. Hence the amount of data to be stored is limited to the, for a particular vehicle/driver combination, truly relevant information. The drawback of the system would be the necessity to travel a certain path a number of times (first investigations imply 2 – 10 times) before plausible road characteristic information can be secured. However, for commuter traffic, this would imply a maximum of 1-2 weeks of daily traveling to and from for example the work place to collect the required data for that route. The only additional sensor necessary not counting to standard equipment today is a GPS receiver. But, considering the massive demand for (portable) navigation devices worldwide these days, this does not indicate a critical shortcoming of the system [16]. Furthermore, a number of countries in Europe have committed to implement the function “eCall” (automatic emergency call) in all new vehicles as of late 2009. The eCall system bases on GPS and the mobile network and automatically makes an emergency call in case of an accident, hereby sending information about the vehicle’s current geographic position to initiate faster rescue measures [17]. Hence a GPS system will be statutory equipment.

ROUTE MEMORY SYSTEM

The *self-learning route memory* system presented here is implemented in C++ featuring a direct interface for reading the CAN bus of the host vehicle provided from Vector Informatik GmbH, Germany. The identified road characteristic data is stored in a database based on MySQL. For the communication between the route memory system and for example a driving strategy unit an interface for Ethernet communication has been implemented. A graphical display of the learnt information (similar to commercial navigation systems) is implemented with Qt® from TrollTech, Norway. The ambition is to develop a system capable of real-time application and independent of platform. The development of the system algorithms, in particular the algorithms for the situation detection, bases on real measurement data, collected during test drives over several thousands of kilometers.

SYSTEM SETUP

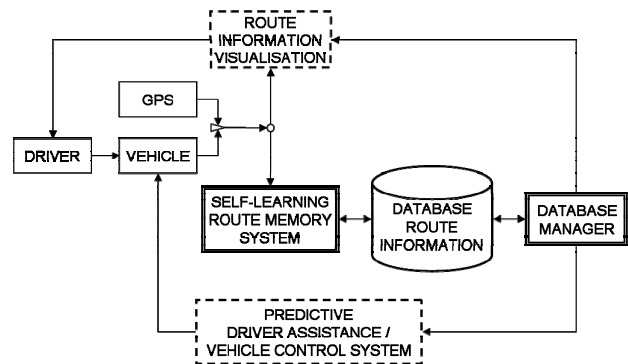


Figure 1: Schematic system setup for the self-learning route memory

In figure 1 the relations between the system’s key processes are illustrated. The self-learning route memory system is connected to the (currently simulated) vehicle via a real CAN network, both for receiving and sending data. During the drive data from e.g. yaw rate, acceleration and various drive train sensors provide information about the vehicle’s movements and actual state, and hence indirect the features of the driven road. The sensor data are together with drive train information analyzed online and features indicating relevant road characteristics, such as steep slopes or sharp curves, are extracted. Using a mathematical approach the description of each identified road attribute is simplified and compressed with regard to memory requirements. With a positioning system, such as GPS, or in the near future the Galileo system, each identified situation is associated with a geographical position along the driven route. The descriptions of the identified road attributes are written to a vehicle individual on-board database and thus available as foresight information during the next drive along the analyzed route. Based on their geographical position along the route, each recognized road attribute is used to update the from previous drives already existing and corresponding entries in the database. Finally, the database manager selects plausible road data from the database and provides various assistance, control or information systems in the vehicle with up-to-date predictive route information [18][19].

SENSOR RESOURCES AND SITUATION DETECTION

Today modern vehicles in all model ranges are equipped with a number of sensors necessary for the functionality of the vehicle, mainly for engine and transmission control but also for vehicle stability. One of the goals with this project was to use the unutilized potential of all these sensors and add functionality to the vehicle without adding further sensors. It can be shown that a number of situations relevant for predictive driving strategies can be identified using only the information already available in most of our vehicles. In this way, a number of the already

integrated sensors become a second use. The minimum requirement of systems and sensor signals for the situation detection are listed in Table 1. A graphical representation of some selected sensor signals from a number of independent test drives along the same road section can be seen in Figure 2. The measurement values show a certain degree of conformity across the different drives, even though the drives were conducted with different drivers and partly at different times of the day. Due to this fact, the road characteristics can be identified with a relative high degree of reliance, independent on driver, vehicle, and daytime.

Table 1: Required and available sensor signals for the detection of situations relevant for predictive driving

Signal	System
Wheel speed	ABS
Yaw rate	ESC
Lateral acceleration	
Steering wheel angle	
Steering wheel angle velocity	
Engine speed	
Engine torque	Power train control
Clutch activation	
Brake pressure	
Accelerator pedal pressure	

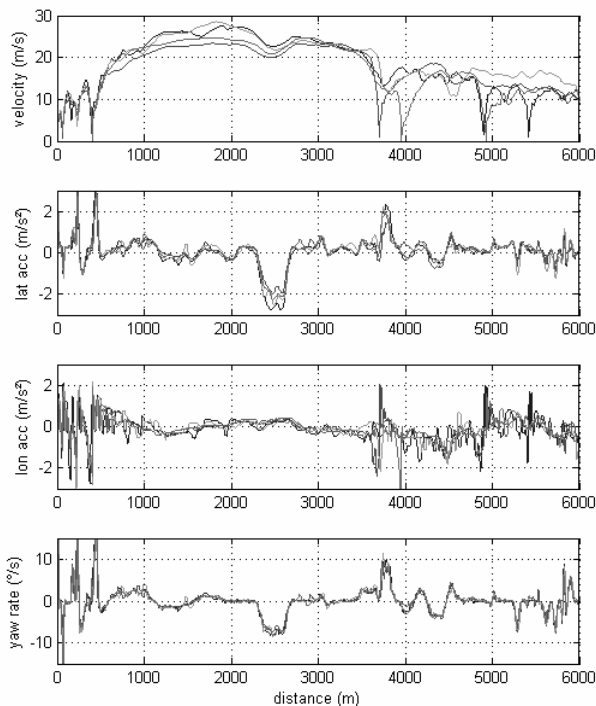


Figure 2: A selection of measurement signals collected in 4 different test drives

The sensor data are analyzed online during the drive and thus the features of each situation can be identified “on-the-fly”. The in figure 2 shown measurement data, which are used as input data for the situation identification algorithms described in the following sections, are the filtered versions of the actual sensor data. Depending on the filter used, the filtered data show a certain phase delay. However, due to the nature of the system, an identified situation cannot be entirely defined until the complete event is passed. Consequently the collected situation information is irrelevant as foresight information during the current drive. In accordance to this, the absolute phase delay of the analyzed signals is insignificant as long as the relative delay is accounted for by signal fusion and evaluation. As an extra advantage of the filtering, also the derivatives of the signals can be calculated and used for the situation detection.

Curve identification

The curvature of the driven route can be determined directly with information from the yaw rate sensor together with the vehicle velocity. By the identification of a curve, the limits for both the minimum curvature and the minimum length of the curve are set to be dependent of the vehicle velocity. In this way long curves with large radius at high speed (typically freeway) as well as short curves with small radius at lower speed (urban roads) will be accounted for.

Identification of stopping situations

Without further sensors identifying e.g. the color of the traffic light or receiving telemetric information about its control strategy, it is not possible to predict the state of the traffic light at a particular moment. However, the position of traffic lights and intersections without right of way where the vehicle in many cases comes to a full stop can be identified by considering the standstill time. By additionally taking the time of the day and the day of the week into account, it is possible to identify changes in the control strategy of the stoplights due to for example traffic load (compare daytime and nighttime traffic). Moreover also the slightly varying halting position for a specific stoplight, depending on the number of vehicles lining up, needs to be considered. Based on these factors, the probability for a halt at a certain position for a certain period of time can be determined.

Road gradient identification

A number of methods for determining the longitudinal road gradient during a drive can be found in the literature. The methods can be divided into two groups; with and without the use of a longitudinal acceleration sensor. Under the assumption that the vehicle is equipped with a longitudinal acceleration sensor the road gradient can be determined according to the sensor model in equation (1) and equation (2), where a_{sens} is the total acceleration of the vehicle, a is the first derivative of the vehicle velocity and g is the acceleration of gravity. Based on measurements of the vehicle’s suspension