

Smart Roadster Project: Setting up Drive-by-Wire or How to Remote-Control your Car

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Abstract. Since research in intelligent autonomous road vehicles gets more and more popular, many interested researchers are confronted with the needs to setup a commercially available vehicle with drive-by-wire. Up-to-date road vehicles contain many mechatronical components, sensors and driver assistance systems, which can be interfaced and thus reduce the needs of expensive modifications and additional actors to a minimum. This paper describes how to interface steering, throttle and brake as well as built-in sensors, and shows an inexpensive way to provide a safe research platform for road traffic.

Keywords. Drive-by-Wire, Autonomous Vehicle, Vehicle Control, Driver Assistance, ABS, ESP, Electric Power Steering

1. Introduction

In the last decades, vehicles have been equipped with more and more mechatronical components. Starting with conventional cruise-control over first safety systems like Anti-Blocking-System (ABS) or Electronic Stabilization Program (ESP) towards higher-level assistance systems such as adaptive cruise control (ACC), lane change warning systems or semi-autonomous parking assistants.

Development of such intelligent assistants also rose interest of various research labs and universities, and established a connection between robotics area and automotive industry. Recent events like the Grand Challenge show this trend of applying the experiences gained from mobile robot research to road vehicles. It can be expected, that traditional robotics research topics like computer vision, object recognition, situation estimation, decision control as well as knowledge extension and learning will be included in future driver assistance systems. With integration of cognitive capabilities, such systems will be able to understand and evaluate traffic situations and derive reasonable and safe behaviors, which will be the basis for fully autonomous road vehicles.

Where automotive industry sets their focus of research on applying existing technologies to new driver assistance systems, universities and research centers



Figure 1. Experimental Vehicle

are able to deal with more complex problems that do not need to result in products in the near future, which means 4-5 years. It will be their major task to perform basic research in the field of cognitive road vehicles. This includes finding answers to questions of how traffic situations and vehicle knowledge can be represented, which learning algorithms qualify for these systems, and, how safety of autonomous vehicles can be verified and numeralized.

To apply the experience gained in the fields of mobile and humanoid robotics to road vehicles, the Institute of Computer Science and Engineering [1], and the group Interactive Diagnosis- and Servicesystems [2] started a collaborative project, the Smart Roadster Project, to extend their research towards this area. A Smart Roadster (see Figure 1), which was donated by the Smart AG, will serve as experimental vehicle.

Aim of this project is to setup a fully autonomous road vehicle, and to equip it with cognitive abilities to negotiate in road traffic environment. While autonomous lane-following or lane-changing maneuvers on highways were performed by various research groups [3,4,5], the emphasis of this project is to develop a cognitive platform with understanding for a wide variety of traffic scenarios, including inner-city and interurban driving. Even if this goal seems to be very far, and it cannot be expected to see autonomous vehicles in traffic within the next two decades, it is clear that the trend goes towards this direction. Therefore, research in this area is necessary and will be very helpful to improve assistance systems on the way to a fully autonomous vehicle.

Figure 2 shows the architecture which is going to be used in Smart Roadster project. The interaction with the physical world occurs through a *Sensor/Actuator Level*. A camera-head with stereo and tele-cameras is going to be used as main sensor. Even though other sensor concepts like Lidar or Radar devices might be added in the beginning, the authors think that in the long term non-invasive sensors need to be preferred.

At the next level, sensor data is processed to obtain information about infrastructure like signs, street course and other static obstacles, as well as pedestrians, cyclists, other cars and moving objects. The control part in Figure 2 generates control values for throttle, brake and steering according to higher-level input, taking into consideration the vehicle dynamics.

The third level from the bottom contains the database and behavior execution. The database contains spatiotemporal information about recognized objects, their state and behavior as well as the own vehicle state. All capabilities of the vehicle are stored in a behavior execution net. It has an internal structure that consists

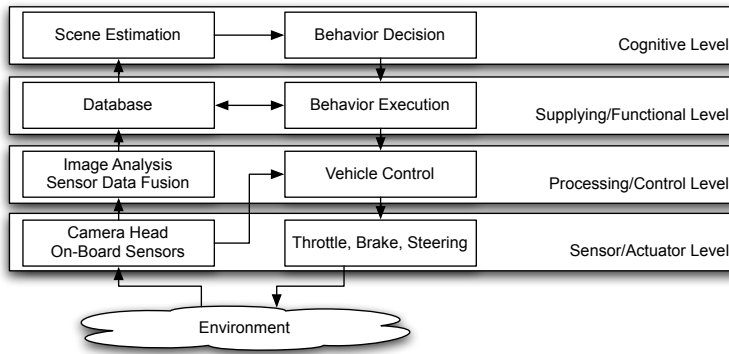


Figure 2. Smart Roadster Control Architecture

of different layers of behaviors, which have a pre-defined coupling and progression as they are active.

The cognitive level contains the most important components: The scene estimation to understand and to evaluate a traffic scenario, and the behavior decision to trigger an appropriate vehicle movement. It is obvious that all possible situations can neither be identified nor stored. Also, there are many different ways of executing behaviors and reacting in situations. Therefore, the questions of how to learn unknown situations, how to improve the behavior, and how to assert safety for this extended knowledge will be the key task in this level.

According to the architecture described above, the development of our cognitive car can be divided into the following phases:

1. Phase: Setting up drive-by-wire capabilities
2. Phase: Implementation of sensor data processing and vehicle control to provide basic features
3. Phase: Integration of simple situation estimation to perform low-level driving behaviors
4. Phase: Extension of situation estimation to wide area of traffic situations and derivation of complex tasks
5. Phase: Evaluation and integration of safe learning algorithms to improve cognitive abilities

In the first phase, the goal is to provide a complete drive-by-wire ability for the system, and to make necessary modifications to guarantee safe operation. Where in former times researchers had to make expensive modifications to setup a fully controllable road vehicle, up-to-date cars have included many assistance systems and mechatronical components. These systems include various sensors and actuators, and provide interface options which reduce modifications to a minimum.

This paper describes an inexpensive and effective way to setup a commercially available car for drive-by-wire. Special regulations concerning safety are considered, against the background of obtaining a later permission for use in road traffic.

2. Built-In Assistance Systems

2.1. Anti Blocking System (ABS), Electronic Stability Program (ESP)

Nowadays, almost every new car comes with ABS, which prevents wheels individually from blocking in case of heavy braking. The main advantage in contrast to conventional braking systems is a shorter braking distance and the conservation of tractability. To determine the wheel speeds, four sensors are connected to a control device via a Controller Area Network (CAN). This CAN-bus is usually referred to as Motor-CAN.

ESP keeps the vehicle dynamically stable in critical skidding situations by braking wheels individually, and by counteracting understeer or oversteer. The existence of a critical situation is computed by a control box by comparing driver's intention (steering angle, brake pressure) with information on the state of the vehicle (wheel speeds, engine speed, lateral acceleration and vehicle rotation) [7]. This sensory information is again available on the Motor-CAN-bus (except the brake pressure, see Section 3.3) and provides the ability to use this on-board information.

2.2. Electric Power Steering (EPS)

Electric Power Steering is used in more and more new models instead of Hydraulic Power Steering. The smaller and lighter electric motors can be attached directly to the steering rod and need no lines, valves or hoses like hydraulic systems. They are less power consuming and thus much more efficient, as well as easier controllable. To be able to support the driver, the steering control box needs to measure the applied torque. Therefore, a torque sensor is directly connected to the steering control box, instead to the Motor-CAN-bus, since no other component needs this information and fail-safe operation is easier to guarantee.

3. Vehicle Modifications

3.1. Power Supply, Motor-CAN Interface and Safety Modifications

The vehicle itself does not leave much space for voluminous power supply devices like additional batteries, alternators and large converters. These restrictions seem to hardly qualify the car as a research vehicle. On the other hand, the vehicle is equipped with many power-consuming components like power windows, windshield defrosters and seat heating, so that a comparatively strong alternator with 900W or 75A is used.

Disabling seat heating, rear window heating and fog lights save up to 40A which can be used to supply additional control equipment. This will be sufficient to run up to six PCs and three DSP boards with maximum 30A and an DC/AC converter for TFT-monitor and notebook supply.

To be able to read the internal Motor-CAN-bus, it was extended from the instrument board towards the control rack. From this bus, cyclic and event-triggered messages are read to derive the sensor values described in Section 2. Since auto-

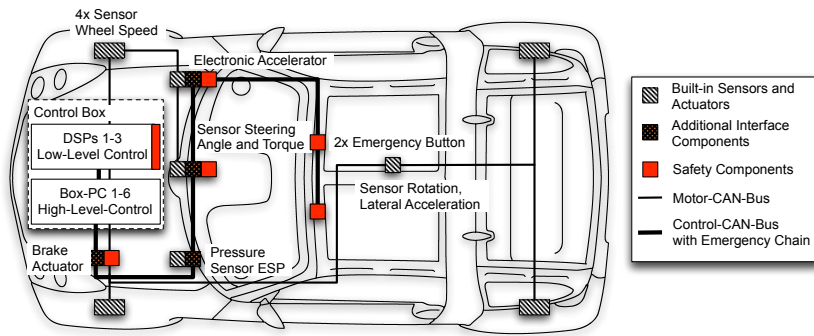


Figure 3. Interface and Safety Components (Base Drawing: Smart AG)

motive manufacturers usually are very reserved in terms of disclosing communication protocols, recording sets of CAN-bus messages in specific situations and reverse-engineering the data was the only, but overall quite enthralling, solution.

As software framework for the control, the open-source Modular Controller Architecture [6] is used. This framework provides CAN and Ethernet communication routines, supports real-time Linux to realize time-critical control tasks on PCs, and provides the ability to setup a graphical user interface based on QT. Due to various control devices listening at this CAN-bus, it is not possible to insert additional messages with unknown IDs. This means listening is the only option and CAN-communication between own devices needs to occur on a second Control-CAN-bus.

To meet safety requirements, it must be possible to electrically switch off all components that interface throttle, brake and steering, and to immediately set the vehicle back into the origin state. Since having any logical parts within this safety chain makes a evidence of safe operation very complicated, a separate circuit was added to the Control-CAN-bus. All emergency components are connected to this circuit, and only in case of proper operation (High signal), throttle, brake and steering are contacted.

To implement redundancy, all DSP modules check correct functioning of both Motor-CAN-bus and Control-CAN-bus as well as activity of other DSP modules and PCs by sending ping-pong messages. If any of the safety criteria is violated, each DSP can cut the emergency circuit and hand vehicle control back to the driver. Driver and Co-driver have the option to take over control at any time by hitting emergency buttons. Figure 3 illustrates the integrated sensors and additional components to interface throttle, brake and steering, and their connection to the control box.

3.2. Steering Interface

As described in Section 2.2, the torque applied by a driver is measured by a sensor and amplified from a control box by driving an electric motor. This mode of operation leads to an obvious idea of separating the sensor from the control box and generating imaginary torque values, and to force a resulting steering movement. After several tests and measurements, a circuit was built (see Figure 4)

to switch between Control-CAN-bus and regular sensor as input for the steering control device. The state of the relay depends on the emergency circuit, namely on the level of *NOTAUS_SENSE* line.

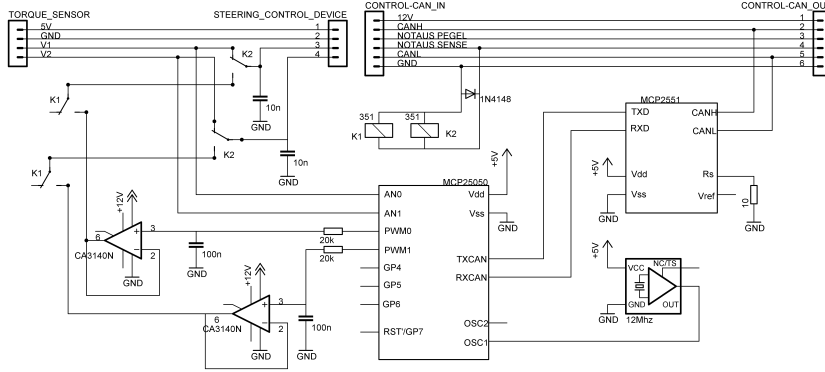


Figure 4. Control Circuit to Interface Electric Power Steering

This solution to interface existing power steering is cheaper, less complex and less vulnerable than mechanical constructions. Good emergency behavior is guaranteed since the driver gains immediate control over the vehicle, and no additional actuators are able to interfere with his decisions.

One problem of this practice is the amplification behavior of the steering control device. As discussed earlier, steering support changes according to vehicle speed. The faster the car drives, the less support is given by the electric motor, even if it would be strong enough to do so. This makes sense in practical use so that drivers are unable to make a hard turn when driving fast. But this means on the other hand that automatic steering works only for low speeds (until 60km/h with Smart Roadster). A possible solution to this problem would be to add the missing torques to the supporting torque by using different amplification characteristics in autonomous mode. Since such different sets of characteristics are used to run different car models (which need different steering support) with the same electromechanical component, another EPROM of the particular manufacturer will help. This drawback has also a good point: Using pre-defined characteristic curves from manufacturers in original control devices simplifies the lateral control since nonlinear friction is partially considered, and also limits the lateral movement to a safe level no matter what the higher-level control computes as set-point.

3.3. Throttle and Brake Interface

Interfacing throttle was done almost exactly the same way as interfacing electric steering, described in the previous paragraph. A throttle position value is given through Control-CAN-bus and is adjusted to the corresponding electrical interface by a circuit as in Figure 4. Connection between CAN node and motor control device is double protected and only established if level of *NOTAUS_SENSE* is high. Setting up braking-by-wire is probably the most critical part of interfacing

vehicle components. Several solutions seem possible, so could perhaps the existing ESP module be told to brake. Since ESP is only designed to brake individual wheels, it would not be strong enough to decelerate the entire vehicle. Interfacing an active brake booster could be an option, but is unfortunately not available in our testing car. Modification of the hydraulic system might work, but needs valves and pumps and probably causes unmeant interaction with existing ESP and ABS modules.

Therefore, the easiest way to interface the brake is a mechanical connection to the brake pedal. A drum, connected to a gear motor is pulling the brake pedal over a steel cable, and adjusts to a desired brake pressure. The brake pressure sensor is interfaced through another Control-CAN-bus module, which converts the value and puts it on the bus. The steel cable connection is able to transmit force only in one direction, so that is is not possible to counteract the driver's wish to brake. In a second step, the brake actuator will be extended through a possibility of pre-stressing the cable. This will allow completely unmanned driving since the system is able to brake automatically in case of emergency or power loss.

4. Results

Figure 5 shows the converted passenger compartment with touchscreen, camera head, concole and emergency buttons (left), and a screenshot of the MCA2 interface displaying sensor values (right). The result is a very slim system, in terms of power consumption, complexity and price.

First experiments with steering and throttle interfaces circuits showed that it is possible to apply a virtual torque, which causes the steering unit to run autonomously, and to set the throttle position via joystick. Figure 6 (top) shows steering angles as a result of applying a constant virtual torque of 6.2Nm at different speeds of the vehicle. At higher speed, the resulting angle is lower due to the velocity-dependent characteristics of the amplification curve. The bottom diagram of Figure 6 shows, that it is possible even without a torque applied by the driver and, with standard amplification characteristics, to drive a slalom parcours at a speed of 20km/h. Using an emergency button to switch between real sensors and interface circuits was possible at any time.

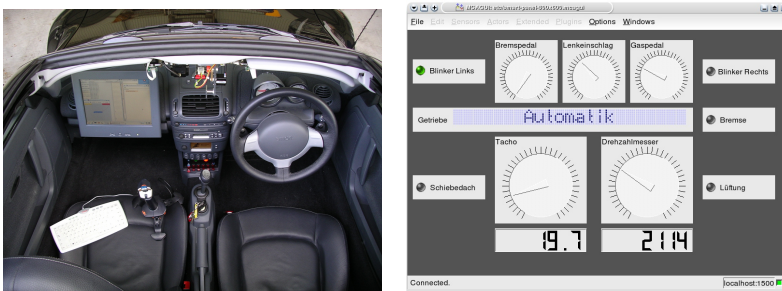


Figure 5. Display and Camera Head (left) and MCA2 Screenshot (right)

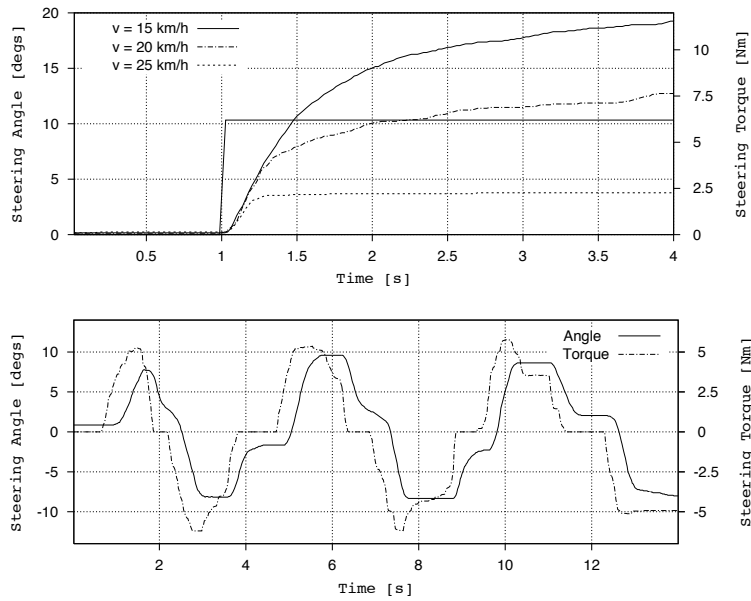


Figure 6. Velocity-Dependant Steering Support (top) and Slalom Test Drive (bottom)

5. Conclusion

This paper showed that it is possible to setup an actual vehicle type with drive-by-wire capabilities very easily without severe changes to the system. It was pointed out, how integrated sensors and actuators can be used and interfaced, and how existing control devices have to be combined with additional units to not interfere with their usual mode of operation. The next steps will be to put the brake actuator into operation, and to implement a longitudinal and lateral control to be able to perform basic vehicle movements, and lay the basis for further research.

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