Towards Highly Automated Driving: Intermediate report on the HAVEit-Joint System

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Abstract

This overview article describes the goals, concepts and very preliminary results of the subproject “Joint System” within the EU-project HAVEit. The goal of HAVEit is to develop and investigate vehicle automation beyond ADAS systems, especially highly automated driving, where the automation is doing a high percentage of the driving, while the driver is still meaningfully involved in the driving task. In HAVEit, an overarching architecture and several prototypes will be built up over time by manufacturers and suppliers. As a trail blazer, a “Joint System” prototype is under development by an interdisciplinary team of several European research institutes in order to investigate and demonstrate the basic principles of highly automated driving, which will then be gradually applied to vehicles closer to serial production. Starting with sensor data fusion, the Co-System part of the Joint Systems plans manoeuvres and trajectories, which are then used to control active interfaces and, taking into account the results of an online driver assessment, joined with the actions of the driver. While many aspects of this research undertaking are still under investigation, the concept, a first prototype and first results from a simulator evaluation will be sketched.

1. Introduction: From ADAS to highly automated vehicles

In 2010, two lines of research and development exist in the domain of ground vehicle automation: Either the automation is driving the vehicle fully automated without a human driver, as demonstrated e.g. in the DARPA grand challenge; or assistant systems warn or support the driver, while the driver is performing the driving task. Some assistant systems like Adaptive Cruise control (ACC) automate one of two control dimensions, and can be called semi-automated. These developments can be seen related as different levels on a simplified assistance and automation scale, reaching from purely manual to fully automated control (Flemisch et al., 2008). HAVEit addresses especially the region of highly automated driving, where the vehicle has the technical capabilities that it could drive fully automated, but this capability is used in a way that the driver is always meaningfully involved in the driving task (Höger et al., 2008). HAVEit also addresses the transitions between different levels of assistance and automation. Ideally, this is done in a way that the driver can be relieved in overload and underload conditions (figure 1). This task repartition between driver and automation or co-system can be dynamically influenced by both the driver and the co-system, and is especially investigated in the HAVEit horizontal subproject “Joint System”.

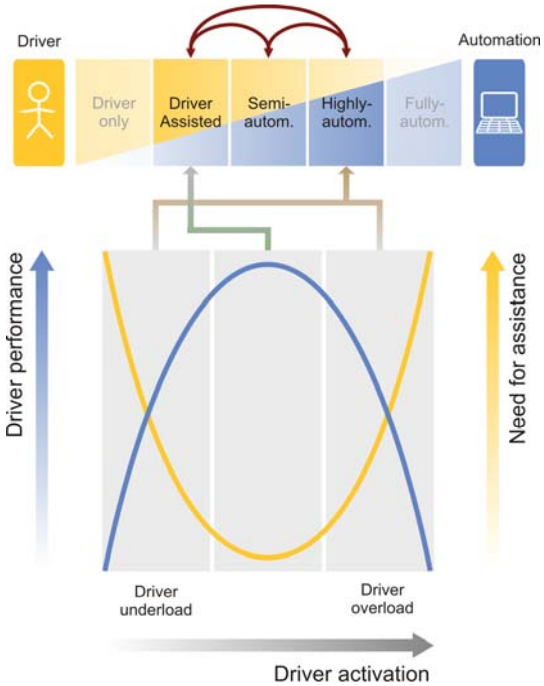

Figure 1: HAVEit assistance & automation scale and dynamic task repartition in the Joint System

2. Design and specification of the Joint System

For the design and development of the HAVEit Joint System, several different perspectives had to be brought into a dynamic balance: A more critical perspective of questioning and testing, described further down, was brought together with a constructive perspective in an iterative approach. The technical perspective, where new technical systems like the driver state camera, new vehicle sensors or a manoeuvre-based automation enable a more sophisticated way of dynamic task repartition, was brought together with the human centred perspective, where the design has to enable the driver to understand and handle the highly automated system in an intuitive way.

The starting point for the human centred perspective was the use of the theatre technique, where the not yet existing automation is played by a human confederate, mechanically coupled to the steering wheel and acceleration pedal of the driver (figure 2). System designers and potential users (initially the representatives of the car manufacturers and suppliers in the HAVEit project, later external users) were brought together in the theatre system to design and to assess alternative solutions for the system behaviour and the HMI while driving through the target use cases together. The design was then drafted in UML (Unified Modelling Language), gradually implemented in Software and iteratively tested and refined (for more details on the theatre technique, see e.g. Schieben et al., 2009, for the paradigm of balanced design Flemisch et al., 2008, for the initial use cases and design of the Joint System see e.g. Flemisch and Schieben, 2010).

Figure 2: Theatre- technique with driver (left) and confederate (right), mechanically coupled. In contrast to the original Wizard-of-Oz-technique, in the theatre technique the curtain is open, and both driver and confederate play through different use cases and system behaviours.

After a sufficient initial understanding of the behaviour and HMI of such highly automated vehicles, the technical subsystems were structured and designed (figure 3): To support highly automated driving and a dynamic task repartition, the HAVEit co-system needs to have sufficient information and knowledge about the driving environment and the driver, and sufficient actuators to influence the vehicle and the driver. Information about the driving environment is gathered by sensors, here especially laser scanners and lane detection cameras, and is fused in a Data Fusion. Based on this information, a Co-Pilot module generates feasible, alternative manoeuvres and trajectories, which are used to influence the vehicle’s actuators via a Command Generation and a Global Chassis Controller. The strength of this influence is determined in a Mode Selection and Arbitration Unit: Depending on the Driver State Assessment, based on driver input and a video camera observing the driver, an appropriate assistance and automation mode is suggested or requested, and the mode selected by the driver is activated as assistance or highly automated action. The communication with the driver is asserted via a haptic-multimodal human-machine interface (HMI).

In the Joint System demonstrator, the software is written in Embedded C, so that it can run on serial production automotive computers like the CSC (Chassis Safety Controller) from Continental.

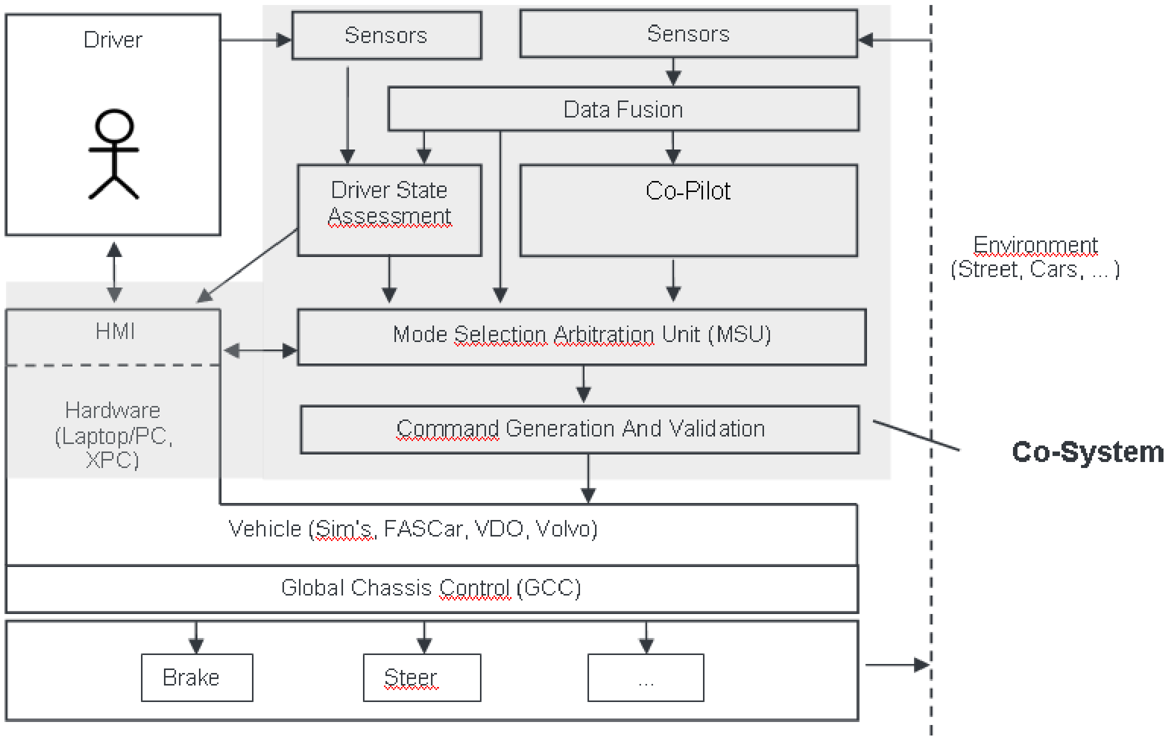

Figure 3: Technical functional block diagram of the HAVEit -Joint System

3. The Co-System: Sensor and data fusion

The sensor and data fusion (perception layer) maximizes the potential of the multi-sensor network installed in the HAVEit system and broadens the information scope that each separate sensor provides in terms of coverage, data quality and information content.

Figure 4 describes how the sensor data is processed: Radar or laser scanner data are processed by a dedicated local tracker. The local tracks are first aligned in time and space and then fused by a track fusion module. Ego Vehicle and lane detection camera data are processed by dedicated filtering modules. If map or laser scanner road data are available, then they are fused with the vision sensor data in order to improve the detection quality and extend the range of perception. The output of each processing block is then passed to the situation refinement processing where relationships between objects and additional object attributes are inferred.

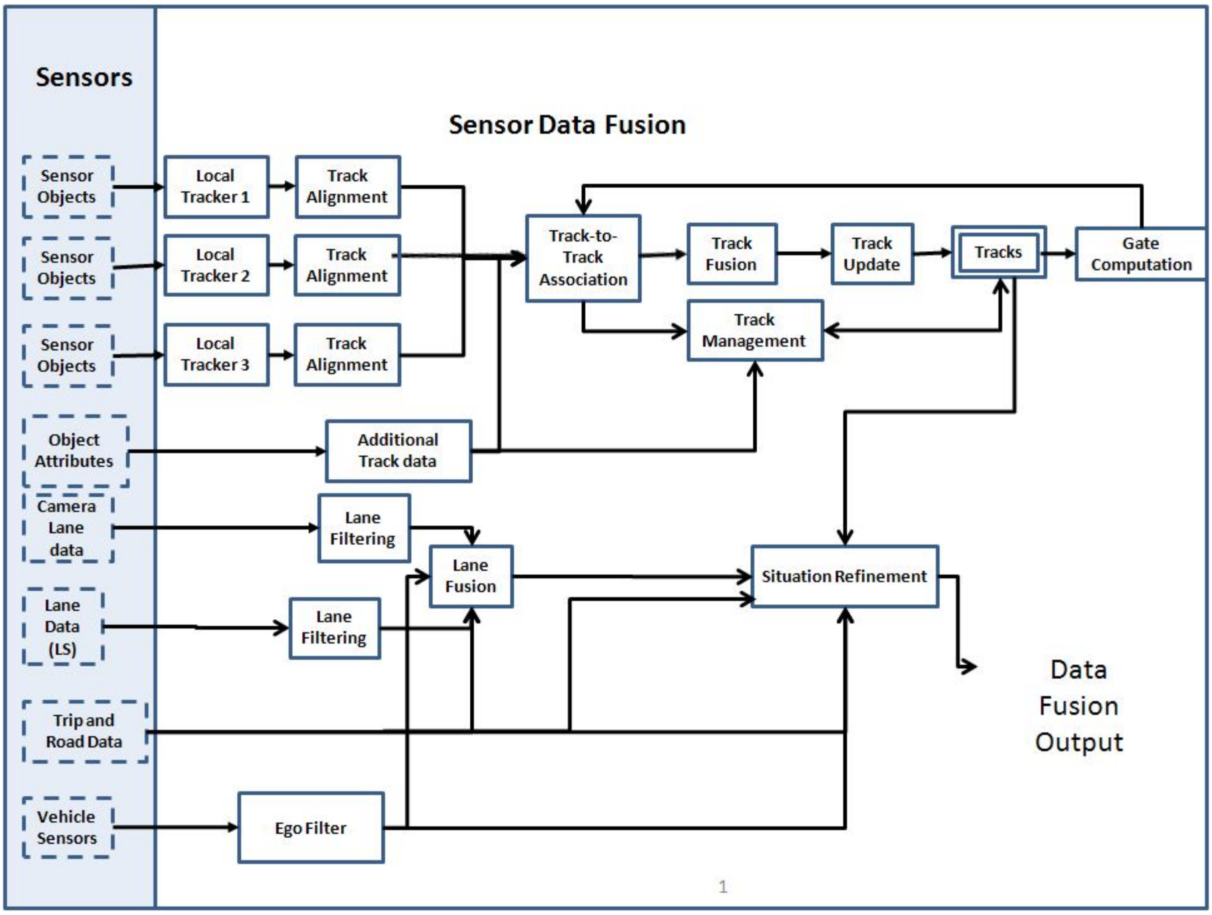

Figure 4: Sensor Data Fusion in HAVEit Joint System

4. The Co-Pilot: Manoeuvre planning with Tree and Grid

Based on the sensor data fusion, the driving strategy is generated in two modules. The manoeuvre planning module provides the first step to build up the driving strategy by defining the goals for the trajectory planner module. This includes the decision which manoeuvre should be executed next, for example to start a lane change or to stay on the lane.

For reliability reasons the outcome of the manoeuvre module consists of a fusion of the results from three manoeuvre planning algorithms which work in parallel. Two algorithms build up a manoeuvre grid, one algorithm generates a manoeuvre tree (figure 5). Within the fusion a mapping of the two representations is performed.

The manoeuvre tree offers an integrated representation of the current action of the vehicle and possible future actions regarding to the current situation, starting with the current manoeuvre as the root of the tree. Feasible manoeuvres which can possibly follow the current manoeuvre are located as leaves in the tree. A quality rating called valential is based on fuzzy logic and assigned to all feasible manoeuvres to show the preferences of the automation. If the valential of the current manoeuvre is greater than zero the automation can also continue to execute this manoeuvre. Further information about the approach can be found in Löper and Flemisch (2009).

The manoeuvre grid builds a solution space as the combination of three longitudinal actions and three lateral actions. In longitudinal direction the vehicle can be decelerated, accelerated or held in the current speed range. In the lateral direction, the vehicle can change lanes to the right, to the left or can stay in the same lane. To these nine manoeuvres, a safe state manoeuvre is added, which corresponds to stopping on the right most lane, and an emergency manoeuvre, corresponding to maximal braking till standstill.

A first manoeuvre grid algorithm calculates the risk associated with each of the eleven manoeuvres. It allows reducing the calculation time on the other modules by discarding highly risky zones of the solution space in an early stage of the calculations. A second manoeuvre grid algorithm evaluates other performance indicators on the remaining manoeuvres, such as the speed, comfort and consumption performance. The total performance of each manoeuvre is the weighted sum of the different performance indicators, with the weights allowing to tune the character of the co-pilot.

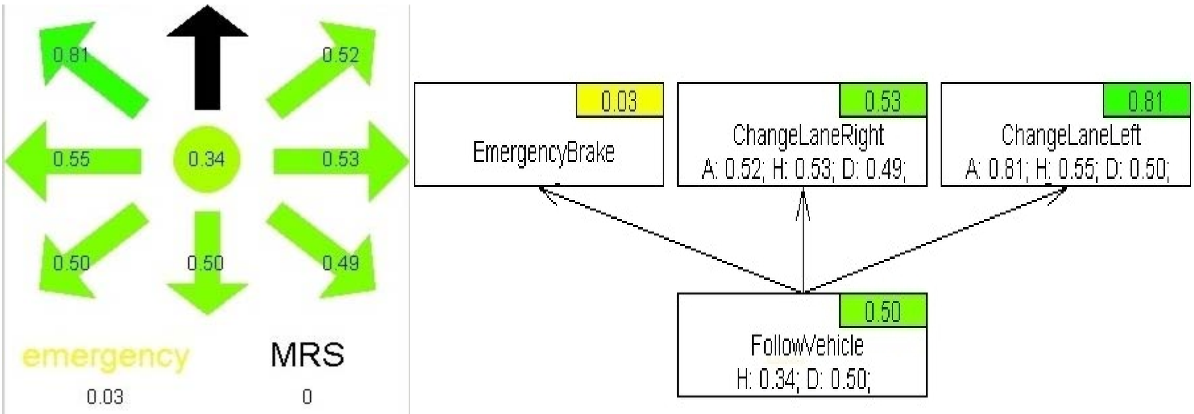

Figure 5: Manoeuvre Grid (left) and Manoeuvre Tree (right)

5. The Co-Pilot: Trajectory planning

Based on the manoeuvre planning, a trajectory planning module is determining feasible trajectories (figure 6). The *trajectory* is a sequence of desired vehicle states over time. In order to provide guarantees for the safe motion of the vehicle, the vehicle has to correctly consider its own limitations and the future movement of the other vehicles when computing the trajectory. The approach taken in HAVEit follows the works of Petti (2007), Fraichard (2007) and Benenson et al. (2008). Since the vehicle has a limited visibility, its plans can only reach a limited horizon. Since a wall (traffic jam, road blockage, etc.) could exist on the frontier of the unobserved areas all trajectories are required to stop before reaching the end of the visibility region. When the observed region is updated, the trajectory is also updated. Because of the partial nature of the provided trajectory, we call this approach *Partial Motion Planning* (Petti, 2007). In order to ensure that the trajectory is feasible for the vehicle, the trajectory generation strategy is based on a search in the command space. Given an initial vehicle state (position, velocity, steering angle), we search for the set of commands that will allow to reach the goal.in an optimal way. The model used to integrate the effect of a sequence of commands takes into account the saturation of the vehicle in steering and acceleration (Petti, 2007). Also, for any given state of the partial trajectory it is verified that the vehicle is capable of stopping without colliding.

By doing so, it is ensured that at any time the solution available will not collide with the vehicle. In order to provide this guarantee it is necessary to use a conservative prediction of the vehicle's surroundings (Benenson, 2008). Directly using a full search on a discrete commands space, using a continuous curvature distance metric to reach a specific goal and doing brute force collisions checking has been shown to provide satisfactory results (Petti, 2007; Benenson, 2008).

However, the HAVEit project presents specific needs for which previous work needed some adaptation. First of all, driving in HAVEit is modelled as operations on lanes. The goals and obstacles are defined as presence on lanes. This provides a coarser (faster) discretisation for collision checking and simplifies the distance metric to goal (how far are we from reaching the centre of the desired lane?). Secondly, instead of searching a trajectory that avoids the obstacles and reaches the goal as good as possible by any means, a simplified approach is used: The trajectory goes straight towards the desired lane and stops if any obstacle is present. The circumvention of obstacles is prohibited, this responsibility is delegated to the strategy level that will decide the sequence of lane changes required to circumvent an obstacle. These simplifications allow a more efficient implementation, in code size, memory usage and computation time.

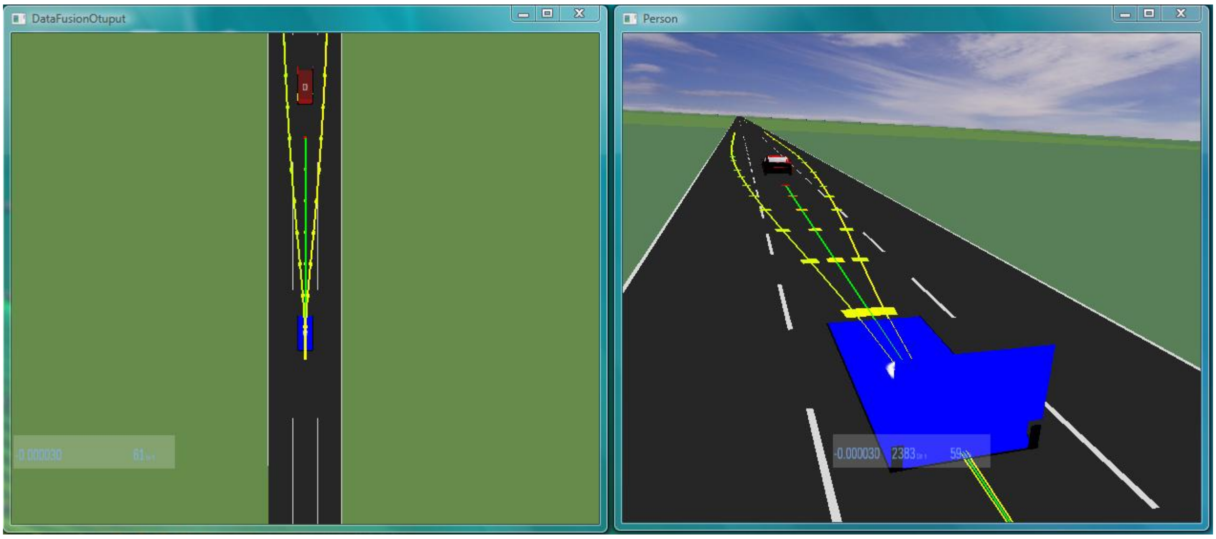

Figure 6: Trajectory planning in the HAVEit Joined System

6. Joining driver and co-system: Driver assessment

Within a highly automated system including several automation levels and transitions between those levels, it has to be assured that the driver is always able to safely manage the driving task when it is required. This is not guaranteed if the driver is either drowsy or distracted. In order to make adequate decisions about the suitable automation level with reference to the driver's need, a software component for the online assessment of the driver's state is developed. This component includes the assessment of the drowsiness level and the distraction level of the driver. The component combines two information sources: direct driver monitoring and indirect driver monitoring. Direct information about the driver is derived from a camera observing the driver's eye movements and gaze direction (see figure 7).

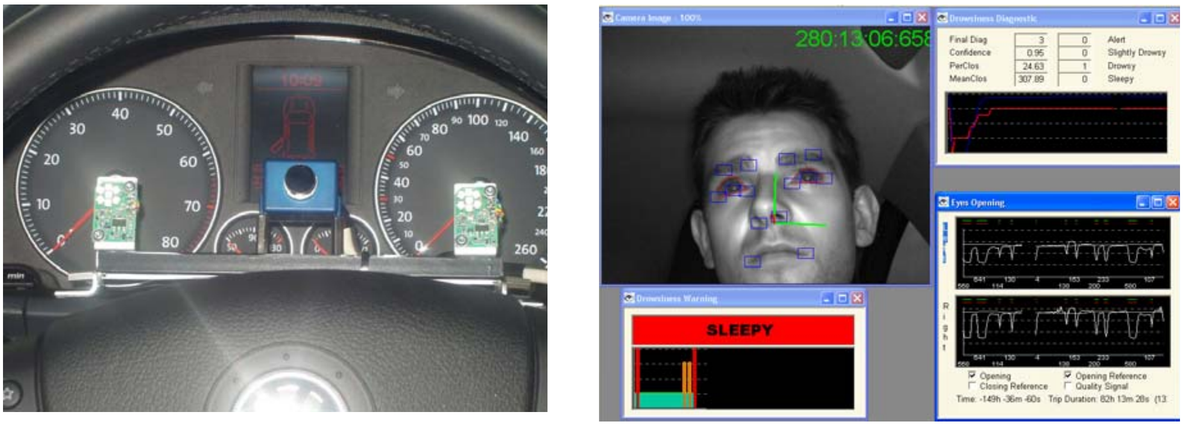

Figure 7: Conti camera for direct driver state assessment.

Indirect driver monitoring means the observation of the driver's activity (direct inputs on the steering wheel, pedals, in-vehicle information systems etc.) and performance measures (e.g. lane keeping quality). A set of signals is used to derive relevant parameters that correlate with increasing drowsiness or distraction. Most promising is the observation of driver's steering activity and lane keeping behaviour. It is known that for example the standard deviation of lateral position (SDLP) increase with increasing drowsiness. Further information on the driver assessment within the HAVEit Joint System can be found in Rauch et al. (2009).

7. Joining driver and co-System: Mode Selection/Arbitration Unit and HMI

A key element for joining the driver and the co-system efficiently is the Mode Selection and Arbitration Unit (MSU, figure 8 left). The MSU is responsible for the management of all transitions between the automation modes of the Joint System. This could be either transitions initiated by the driver (activation or deactivation of an automation mode) or transitions initiated by the automation (activation or deactivation in case of emergency or reduced system functions). To ensure that the optimal automation mode for a specific situation is activated the MSU receives information about the driver input, the driver state assessment as well as environment and vehicle related input of the data fusion and the co-pilot. Based on this information the MSU calculates all available automation modes and the optimal automation mode. In case the current automation mode is not identical to the optimal automation mode, the MSU triggers transitions to the optimal mode.

Beside this, the management of transitions comes along with the need for the management of the HMI output, which is also done by the MSU. The MSU displays all available automation modes and the current mode. In addition, all transitions either initiated by the driver or by the MSU are accompanied by a multi-modal interaction strategy that is triggered and controlled by the MSU. Most information about the automation mode and transitions is communicated to the driver by the Automation Display (figure 8, right). The display consists of three main areas: The Automation Monitor (upper left), the Automation Mode Display (right) and the Precondition and Message Window (lower left).

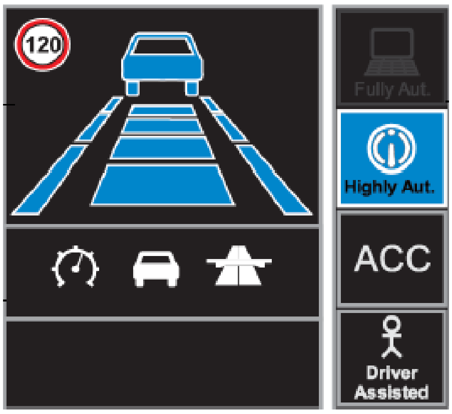

Figure 8: Automation Monitor and automation scale for the Joint System

The display information is enriched by acoustic signals and haptic signals on the steering wheel and accelerator pedal for information and warnings. The design for the HMI as well as the behaviour of the highly automated system was developed together with the other demonstrator owners in HAVEit during several design sessions in the theatre-system of DLR (Flemisch et al., 2008 and Schieben et al., 2009).

8. Controlling the vehicle and the active interfaces

The main objective of the controller is to ensure the tracking of the trajectory corresponding to the desired automation level and manoeuvre, by guaranteeing some performance specifications and stability of the vehicle with respect to internal and external perturbations. To achieve these goals, the controller needs to be sufficiently robust in order to deal with these uncertainties. The main difference to controlling a fully automated vehicle is that now a driver is in the loop, who can insert actions on the active interfaces.

Substantial simplifications in controller synthesis can be made by decoupling the longitudinal dynamic and the lateral dynamic of the vehicle. With these considerations, a linear H-infinity robust control technique is used to derive a lateral controller to keep the lateral position and the heading angle close to the desired ones (Zhou, 1998; Baghdassarians, 2001). In addition, some weighting filters are used in the design process to reject noises and limiting the steering wheel angle and its bandwidth to avoid the controller saturation and a fast variation of the steering wheel Raharijaona, 2004. In order to make the controller more reactive, to anticipate the trajectory curvature and to have better performances, it is convenient to control a look-ahead point at an appropriate front distance of the vehicle centre (Mammar, 2001). Besides, keeping the vehicle travelling velocity close to the desired value is reached using a proportional and integral controller with anti-windup action. Once the controllers' actions are computed, they will be transmitted to a lower level for an effective execution by the local controllers of the vehicle actuation systems placed on brakes, engine, and steering actuator (Figure 9).

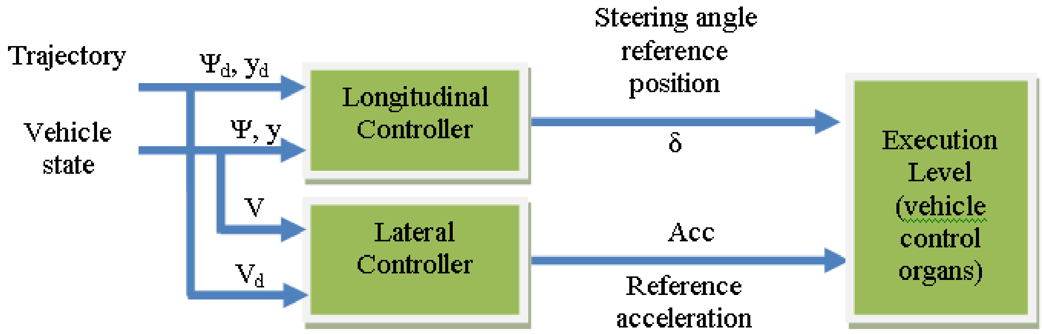

Figure 9: Simplified Control diagram of the Joint System

Steering and acceleration actuators are equipped with haptic feedback systems, so that the driver can feel every action of the Co-System. This communication is done with a mixture of continuous feedback, e.g. on the trajectory, and discrete feedback, e.g. a vibration for danger or tics/double tics communicating discrete manoeuvres, as derived from the H-Mode project (Flemisch et al, 2003; Kelsch et al., 2006).

9. First results of transition testing in a simulator

A first baseline experiment on transitions was conducted in the driving simulator of the WIVW (see figure 10). N=16 subjects participated in the study: 8 drivers in a manual driving condition (control group), 8 drivers in a highly automated driving condition (full lateral and longitudinal control). A visual interface displays the current state of the system as well as system-initiated take-over requests. The test course was a 50 minutes course on a two-lane motorway. Most of the time, the driver had to follow a lead vehicle in highly automated driving mode. In between, additional scenarios were integrated in which the environment or traffic conditions changed in a way the system could not manage. Those scenarios required the driver to take over the driving task back from the system.

Figure 10: Simulator setup for first transition experiment

To sum up the results, drivers seem to have no essential problems in reacting to required transitions of highly automated driving back to manual. Especially fast reactions are possible if the system limits are known and can be predicted. More difficult is the occurrence of sudden events which are not detected and therefore not manageable by the system. In those situations, the drivers reacted later, compared to manual driving. However, no critical situations occurred due to the take-over itself. It could not be observed that any of the drivers reacted in an unusual or critical way. Also, driving performance after a transition back to manual seems not to be negatively influenced compared to complete manual driving.

There were some critics of the subjects regarding the perceived usefulness. Drivers complain that they still have to be attentive when driving with high automation levels due to the limits of the system. Under these conditions they would prefer to be active performers of the driving task than simply watching out for situations where they have to take over the driving task back from the system. They are aware of the risk of getting drowsy or inattentive when driving on higher automation levels. This indicates that the tested version of highly automated driving might either be too much automated, with too little involvement of the driver, or not automated robustly enough, with too much attention still required from the driver. A newer version already explored alternatives with more involvement of the driver in highly automated driving, and with higher robustness of the automation, with promising results (Flemisch and Schieben, 2010).

Nevertheless, the system with highly automated driving function is, at this early stage, rated rather positive. It is evaluated as comfortable, easy to use and easy to understand. Feedback on current system state and system-initiated transitions are comprehensible. Drivers rate the acoustic feedback more necessary as the visual feedback (which is even not recognized by some drivers).

10. Next steps: Iteratively from simulator to test vehicle and back

A first, rudimentary version of the Joint System has already been integrated and tested in the experimental vehicle FAS-Car, using emulated obstacles and Differential GPS. The next steps are to extend this to real laser scanners and cameras, and to develop and integrate a new by-wire steering system. The development of this system will continue iteratively until, in addition to further simulator testing, human-in-the-loop demonstrating and testing will be done also in the test vehicle. The final demonstration of HAVEit is planned for mid 2011; final results will be documented in late 2011.

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