# Vehicle as a Co-Driver

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## ABSTRACT
Rapid developments of sensor devices and methods for seamless man-machine interaction have provided possibilities to enrich driver's assistance in vehicles. Not only that a vehicle can contribute to a safer driving, it may also influence driver's attitude and mood by observing the driver and adapting the vehicle settings and ambient according to the driver's psycho-physiological state. The paper concentrates on new possibilities that affective computing brings and explores innovative application scenarios and the ways they can be deployed in practice. A new approach transforms a vehicle into a friendly, subtle helper. The vehicle as a co-driver system ensures that a driver is never left alone – even in single vehicle occupancy.

## Keywords
Vehicular adaptive control, Affective computing, Middleware, Automotive applications

## 1. MOTIVATION
There are many advantages of driving in company. Whether on a short distance or on a longer route, driving in company is much more pleasant, secure and effective. On a city tour or a rally drive, having a co-driver is always an advantage for a driver. According to Wikipedia, a "co-driver is the term given to the navigator of rally car in the sport of rally racing, who sits in the front passenger seat. The co-driver's job is to navigate by reading off a set of pace notes to the driver, often over a radio headset, due to the high level of noise in the car. The co-driver tells the driver what lies ahead, where and how to turn, a severity of the turn, and what obstacles to look out for. Co-drivers are also often called on to perform maintenance on the car during road sections and special stages..."

In a casual, everyday situation, a co-driver may be a friend watching the driver carefully, making a vivid atmosphere on a longer trip, or observing the angles the driver cannot see at a busy rush-hour. A co-driver, being free from a complex driving task collects other information concerning the route, road condition, vehicle, even the driver's state and assists the driver significantly.

However, often a driver is alone having no one to help him as in case of fatigue, confusion or unexpected danger. This is exactly the place where new approaches in vehicular computer systems may help. Equipping a vehicle with sensors to observe psycho-physiological state of the driver, numerous actions can be provoked by the vehicle itself to reflect the present driver's state and overcome eventual difficulties or simply improve comfort and pleasure in driving.

Recent advances in the development of in-vehicle driver-oriented technology are moving in two major directions:

- increasing and improving the information to be used by the driver (night vision enhancement using infrared, speed monitoring, etc.)
- improving adaptive automatic safety-related systems (e.g. car distance regulator).

Current safety-oriented systems are designed to warn drivers of dangerous situations, recommend actions or even assume partial control of a vehicle to avoid collisions. Representative systems are Mercedes Sensotronic Brake Control (SBC) [1] that calculates the optimum brake pressure for each wheel depending on the particular driving situation, BMW Lane Departure Warning (LDW) [2] that detects roadway markings and uses a vibrating steering wheel to warn the driver of unintended departures, or Audi Advanced Front-lighting System (AFS) [3] that takes into account both steering angle and vehicle speed to orient the headlamps to an angle that provides better night time visibility.

All these systems succeed in providing either useful information (e.g. traffic situation, vehicle to vehicle distance) or counterbalance incipient dangerous maneuvers, especially under complex driving conditions (e.g. traction and stability control) and can be seen as a step in right direction on a long road that leads to a complete adaptive vehicular control.

This approach goes a step further in a complementary direction of improving driver's mood, confidence and comfort, thus contributing indirectly to overall safety. To consider these subjective elements of a driver's condition, the following aspects need to be considered:

- psycho - physiological states (e.g. stress, excitement)
- driving attitude (e.g. poor/high driving experience, aggressive/calm driving)
- physical competencies (e.g. low/high reaction times)
- past experience (e.g. danger during overtaking, slipping)

The goal is to use sensor devices to collect this information, evaluate it and provoke actions that would adjust the vehicle according to the driver's condition.

The rest of the paper surveys principles and methods of seamless psycho-physiological man-machine interaction, explores the way how these can be deployed in vehicular adaptive control; sets and analyses innovative application scenarios and consider a possible vehicular adaptive control implementation.

## 2. PSYCHO-PHYSIOLOGYCAL MAN-MACHINE INTERACTION

Psycho-physiological man-machine interaction [4,5] is an approach that senses users and their mood and intentions by taking different aspects into account: emotional state (e.g. annoyance), cognitive engagement (e.g. high mental workload) and physical conditions and actions (e.g. temperature and movements). Psycho-physiological parameters together with human behavioral patterns form the personal awareness of the system. Additionally, information about the surroundings is gathered and used to establish environmental awareness. This kind of computing (often called affective computing), being based on unconscious indicators which are genuine, spontaneous and precise, is especially useful in supporting every day situations,

A system that deploys affective computing generally consists of:

- sensor devices used to collect information from users and environment:
  - user sensors: camera, EEG, eye fixation tracker, skin conductance , heart rate, breath rate, body temperature, location tracking, etc
  - environmental sensors: CAN-bus data (ABS, Acceleration etc.)
- sensor analyses – software for data evaluation:
  - posture, reaction time, activation
  - arousal, feelings
  - possible common focus: engagement (overload/boredom) analysis
- actuators that can be used to influence the user and the surroundings
  - power limit, temperature, lighting
  - cruise control and other car-configuration settings
  - cabin ambient (light, music, video, computer, mobile communication).

A seamless man-machine interaction [6] requires deployment of multi-disciplinary competences, such as:

- special-purpose hardware devices [7] (e.g. RFID technology, sensor, actuators, micro chip devices)
- dedicated software developments [8,9] featuring context awareness, adaptive control, self-organization, etc.
- human science know-how [10] exploring physical, cognitive and emotional states and corresponding artifacts that capture motions, body language, affections, intentions, reasoning and more complex close-loop control.

Bringing all these themes together results in pervasive adaptive systems able to silently "understand", support and affect everyday situations.

## 3. VEHICULAR ADAPTIVE CONTROL

Some recent fundamental steps have significantly changed the way of conceiving the relationship between a vehicle and its driver. While the previous vehicular research was focused on performance and reliability, progress in electronics has opened new ways to more sophisticated control. Automatic adjustments accounting for parameters the driver can not manage by himself have now become reality. Examples of this rapid evolution include automatic transmissions, power steering and adaptive suspension systems. Future research will aim at facilitating personalized tailoring, in order to overcome the limitations of manual control. What makes this problem still unresolved is the extreme complexity of the system and the objective risk to impair comfort and safety standards. Despite all the efforts, till now the optimum is achieved by looking for the best compromise in terms of safety and satisfaction. However, this general solution is improper as it does not take into account individual driver's characteristics.

The reason why the main framework of human-car interaction has remained relatively unchanged is that till recently the technology could not offer applicable solutions, tailored to individual driver's needs. Today however, a new generation of approaches is emerging allowing for the use of psycho-physiological man-machine interaction that promises radically new solution in domain of adaptive vehicular control.

The vehicle as a co-driver approach aims to bring about new vehicular services that would customize the vehicle according to the driver's mental/emotional/physical state and adapt vehicle settings and characteristics accordingly. It is a driver-centric approach that brings a vehicle closer to the driver and the current driving conditions, featuring ambient, performance and safety improvements.

### 3.1 Vehicular Sensors

To provide means for adaptive vehicular control, a number of sensor devices need to be installed and used for constant driver and environment observation, ranging from driver mental/emotional state to current vehicle configuration, and environment conditions. The observed information need to be gather, analyzed in real-time and used to provoke vehicular services that would lead to adaptive control.

There are three aspects that need a special attention:

- driver personalized characteristics (e.g. individual driving habits).
- current driver's psycho-physiological state
- external environment characteristics.

Having focus at the seamless man-machine-environment interaction, the information coming from vehicular sensors need to be collected and analyzed in real-time provoking appropriate vehicular response without driver's explicit commands.

Most of the existing vehicular sensors like:

(1) vehicle configuration sensors (suspensions, abs, e-diff);

(2) vehicle environment monitoring sensors (lighting, temperature, seat's comfort) and

(3) external environment monitoring (temperature, weather)

are going to be used for adaptive control. Recently available information derived from community services like car-to-car communication and infrastructure-to-car communication will also be deployed in a new approach.

Beside the above mentioned sensors, a new infrastructure needs to be installed measuring drivers psycho-physiological state. A camera will be used for facial/gesture recognition, steering wheel will sense the grip intensity, hands humidity/respiration etc, pedals will gather information about pressure intensity, frequency of use and the like, seat will sense the muscle tension and comfort of the driver etc.

Furthermore, the driver's behavior will be observed and split in two equally important groups: (1) personalized driving habits (e.g. slow driver during night) and (2) personalized driving attitude (usual way to perform driving tasks, e.g. going very close to the preceding car before overtaking).

## 3.2 Vehicular Services

Based on the sensor collected data and their analyses, a sophisticated vehicular services will make adaptive control possible. Adaptive vehicular services add new dimensions to current safety applications, by accounting for the driver's status, environment and vehicle performances. As safety is the primary goal, all information related to the driving behavior (e.g. reaction times, coherent use of controls etc.) have to be gathered creating an individual user's profile. The 'safety-loop' will start from a driver's profile adaptive communication and will be closed by an adaptive vehicle performance feedback (e.g. slower driving indicates that the vehicle controls should become less responsive and more comfortable). Furthermore, based on the previously collected information on driver's individual habits, the vehicular settings can be customized, thus contributing to the overall level of driver's wellness. The final step is to provide services for adaptive vehicular tuning according to the driver's present state (e.g. sport driving, lighting, colors, ergonomics –seats- and so on).

Furthermore, local solutions with respect to single vehicles can be extended to a global level due to new communication protocols (e.g. car-to-car) and future services (e.g. high speed data networks providing real time information about traffic, potential accident, or simply weather conditions).

## 3.3 Adaptive Control

To achieve adaptive control, several methods of the driver-vehicle interaction need to be revisited. Based on information collected from the driver, the environment and the vehicle itself, a series of ad-hoc services is defined and classified according to individual user's needs. In particular, direct or mediated feedback is proposed to the driver.

- Direct feedback includes adaptive warnings from the vehicle in form of conscious (e.g. visible warnings) or unconscious information (e.g. changes in lightening, acoustics).
- Mediated feedback becomes perceivable only through direct engagement of the subject in the driving experience and includes both changes in the vehicle performances (e.g. adaptive breaking distance) and in the vehicle environment (e.g. re-programmable controls).

Mediated feedback is an obvious attempt to transform the vehicle into a co—driver. With a driver-centric adaptive and pervasive control, where safety and cost barriers are of a prime concern, the vehicle not only overtakes the responsibility of a human co-driver, but also changes the vehicular settings and ambient to suit the driver's and the driving needs.

## 3.4 A Case Study

In order to show the system's potentialities at best, a well suited real-life scenario has been conceived and taken as case-study. Driving in a changing traffic conditions as a common and complex situation which causes deep solicitations both on the driver and on the car is taken as an initial scenario.

**Driving Scenario – Part I**

*On a sunny morning Silvio is driving (primary task) along a highway towards his new working place, following the instruction from a navigation system (secondary task) listening to his favorite radio station, under the light traffic conditions alternating velocity from mediate to very low speed as traffic changes…* (to be continued)

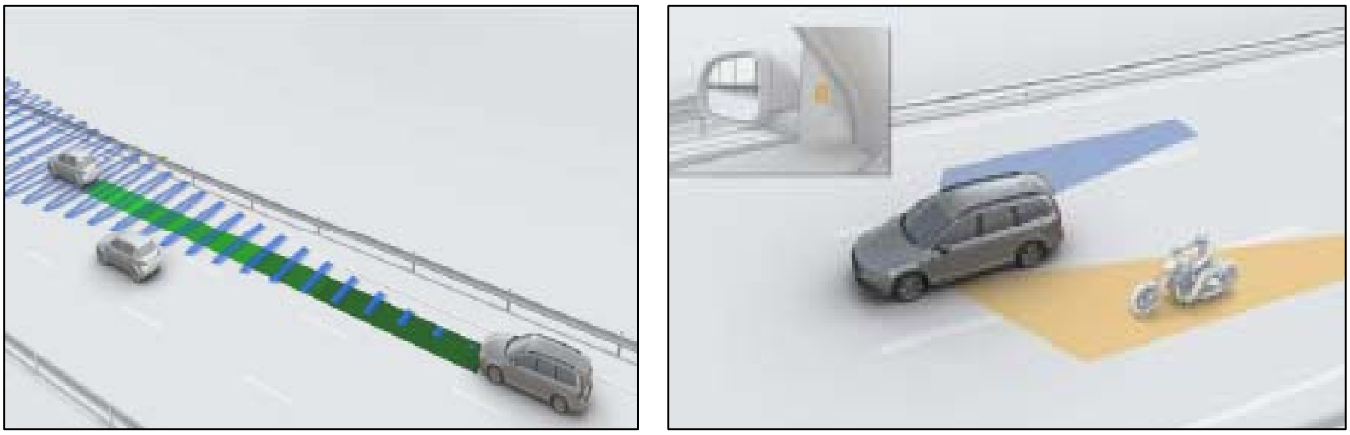
Under the assumption that the driver has been driving for a long time in these conditions, fatigue and stress will inevitably increase. Adaptive vehicular system would be able to detect changes in driver's psycho-physical state analyzing three kinds of variations:

1 gesture/movements:
- augmented frequency of changes in sitting position using measures of pressure applied on the seat;
- variations in head movements and eye blink using embedded CCD cameras [11,12];

2 controls interactions:
- prolonged time of reaction (frequency and intensity at pedals);
- increased frequency of steering wheel corrections and grip force variations;
- increased frequency of gear changes
- less coherent use of secondary devices like radio, navigator, and other panel switches;

3 psycho-physiological parameters:
- skin temperature variations;
- augmented heart rate;
- augmented skin conductivity.

All this information is gathered by the adaptive-control system forming and maintaining the current driver's and driving conditions. There already exists a number of approaching that analyze psycho-physiological parameters of the driver's state and condition [13,14].



(a) Adaptive cruise control (b) Blind spot detection

**Figure 1 Complementary ADAS**

### Driving Scenario – Part II

*As Silvio approaches the urban area, the traffic condition turns from calm to a hectic one. The vehicle immediately detects this change recognizing Silvio's firm grip at the steering wheel (using a grip force measurement sensor embedded in the steering wheel). Silvio is correcting the driving line too often with sudden movements (steering torque signal from the Can Bus) and he is no more keeping the safe distance from the preceding vehicle (radar sensor on the front and Can Bus signals from pedals). At the same time his heart rate is increasing (as indicated by the capacitive coupling electrodes ECG device in the seat) as well as his body temperature (despite a low compartment temperature). Consequently, the real time evaluating system states that Silvio is more and more aroused which implies a loss of concentration resulting in a drop of reaction time.*

Indeed, driving in changing traffic conditions causes tiredness and stress and has hence a strongly impact on road safety. This is an ideal example where a co-driver may help. In this case, the adaptive control, being able to counterbalance eventual reductions in driver's performance during suboptimal situation, overtakes the co-driver role. Ad-hoc user adaptive control (re)actions are able to mitigate driver's decreased performances on three levels:

- performance level: car response to breaks and accelerations will be smoothed, gear ratios will be remapped or in case of high stress an automatic gear modality might be set, steering wheel adjustments will be filtered
- compartment comfort: the system will act on the adaptive seat to refine and improve driver's position, on acoustic isolation to reduce disturbing noises, on adaptive internal lighting to reaching an optimal balance with the external one (whether it's sunny or cloudy)
- infotainment services: the system will warn, inform and entertain the driver in real-time driving conditions (involving audio, video and board computer equipment)

Furthermore, several other types of services can be elaborated and added to the existing ones in order to offer more comprehensive vehicular response and better assistance to the driver.

Figure 1 shows samples of two ADAS (Advanced Driver Assistance Systems) functionalities, as cited in the case-study. The left picture (a) represents an Adaptive Cruise Control, a sensor (laser or radar) based system that monitors the traffic and adapts the speed of the vehicle to the traffic flow longitudinally. The right picture (b) shows a Blind Spot Information System that helps the driver to detect vehicles in the critical area on the side just behind the car, the so called blind spot.

### Driving Scenario Analyzes

The first task of the vehicular adaptive system is to reduce any source of distraction. Hence it turns off the radio (or lower the volume) and switches the navigation system interface from an audio/visual mode to a specific audio mode (dedicated voice; indications of alternative routes to skip the traffic). Then, resorting to complementary ADAS (Advance Driver Assistance Systems, see Figure 1a), it slightly activates an adaptive cruise control to balance the car response to brakes/accelerations according to the preceding vehicle distance. It also activates the "blind spot detection system" (see Figure 1b) as the driver's lack of concentration needs a "silent" system looking out for possibly dangerous situations and coordinating feedback (e.g. vibration) on the steering wheel, only in case of unsafe lane departures. Finally, it adjusts the compartment temperature/humidity (even lighting if necessary) to carry the driver back to a comfortable condition.

In conclusion, it's important to state that even the ADAS contribution is modulated (in time) on a fuzzy psycho-physical state of the driver (more or less attentive, more or less stressed). One of the prime principles of the adaptive vehicular control is not to substitute the human control (reducing the drivers control authority) but rather to softly suggest, warn and comfort the driver

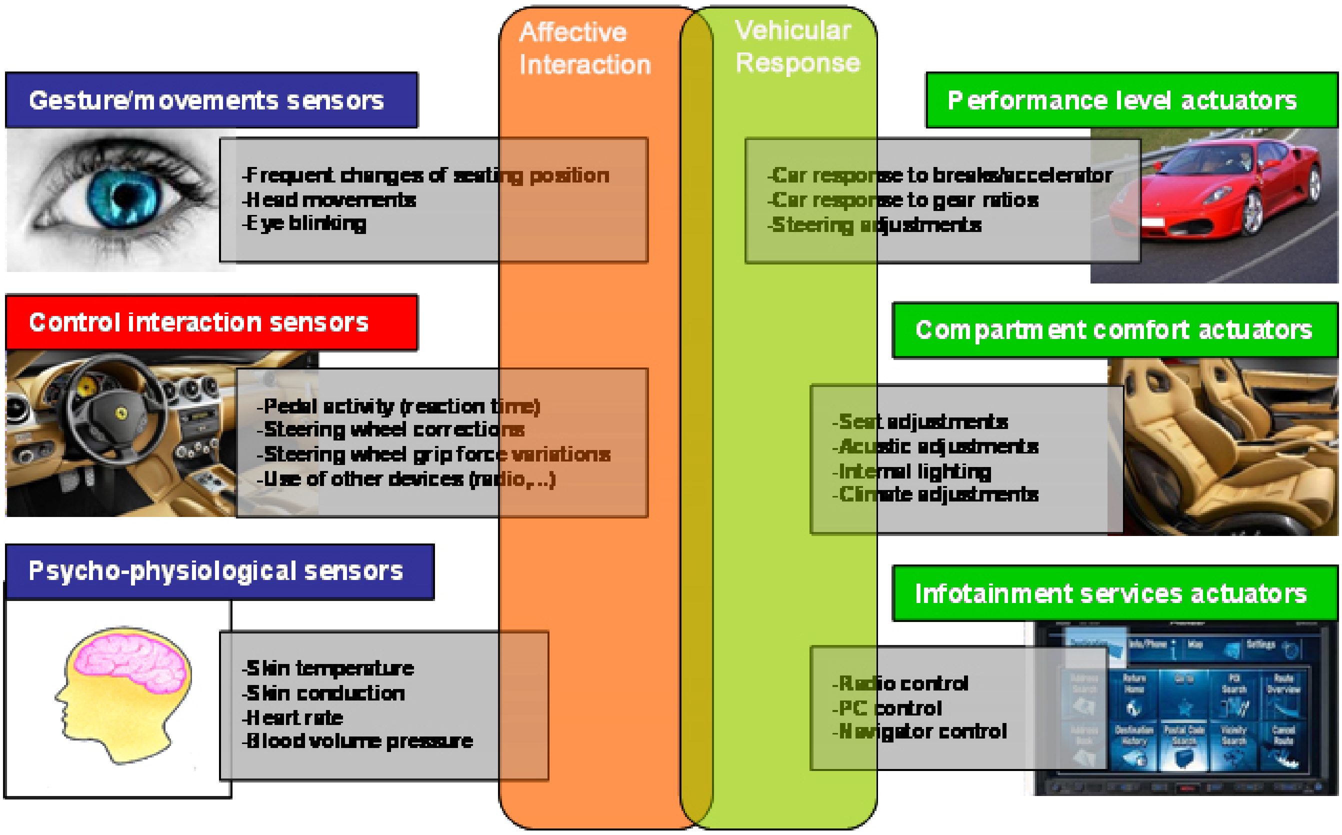



**Figure 2. Vehicular adaptive control**

providing informative, relaxed and safe ambient (even if a driver does not clearly realize the reasons for a vehicular behavior).

Figure 2 shows a graphical interface that allows probing different driver's states and proposing corresponding vehicular adaptive changes. Adapting the car response to the sport driving, adjusting the level of seat comfort or changing audio entertainment in accordance with the driver's state are some of the examples of the new vehicular adaptive control.

## 4. ADAPTIVE SOFTWARE SUPPORT

Developing software to control pervasive and adaptive vehicular system involves non trivial tasks like real-time sensor/actuator control, intelligent user and scenario profile analyses, self-organization and adaptation. To support such a complexity, a middleware architecture is being designed that through its inherently modular and distributed nature promises a dynamic adaptive behavior.

The middleware architecture for vehicular adaptive control consists of three tiers:

- Sensor/actuator tier is a low-level layer that controls sensor/actuator devices. It offers its functionality through atomic services to the rest of the system.
- Reflective tier is a central software layer that combines atomic services from the lower tier with user profiles and scenario description allowing for a more complex adaptive services that can evaluate user state (driver confused) or environment situation (danger on the road) and propose system action.
- Application tier is a high level software layer that controls the whole system by combining knowledge about environment, users' profiles and presents user state and situation.

The supporting system is under development. The service oriented architecture uses OSGI service-oriented platform [15]. The idea of service orientation allows for separate design and implementation of different devices and offers highly dynamic and reconfigurable framework. For the service management and deployment, a modified ESB (Enterprise Service Bus) concept is being developed [16].

The modified enterprise service bus contains several components that perform: transparent messaging, service registering, discovery and deployment, event propagation, user profile and scenario description analyses, situation reasoning, complex services

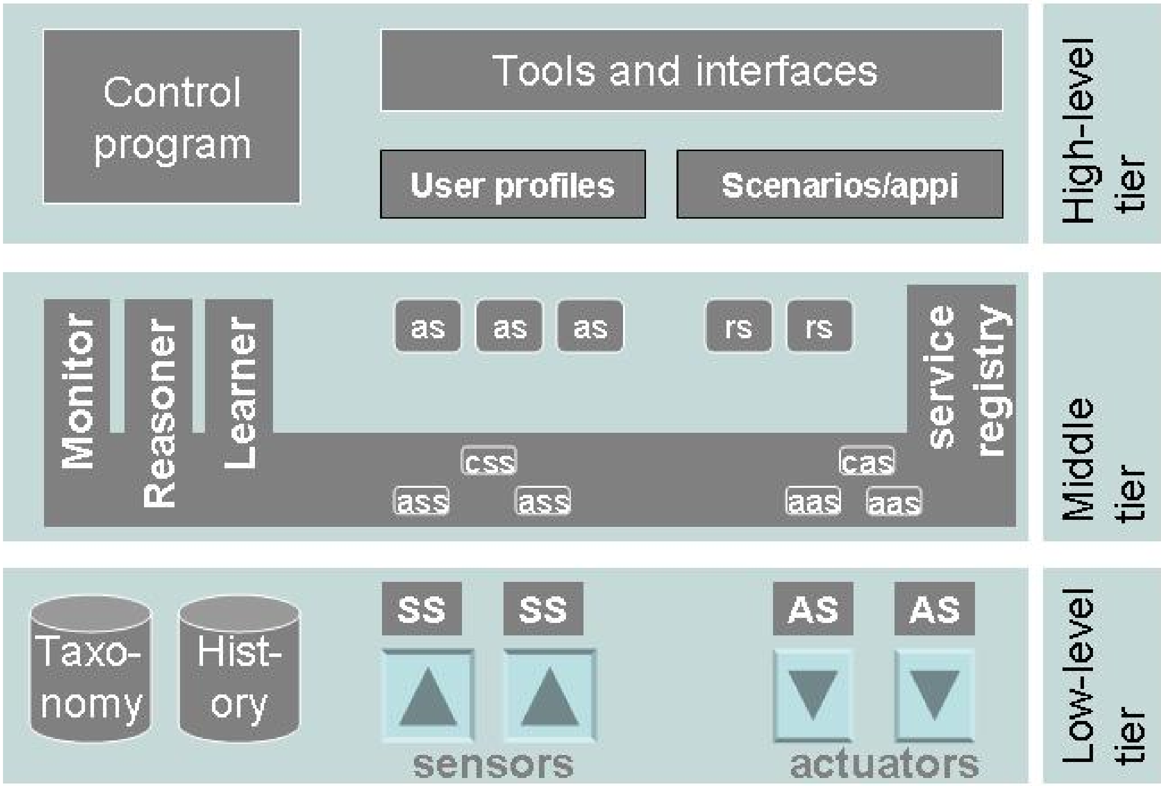



**Figure 3. Software architecture for vehicular adaptive control**

composition and deployment, system action suggestions and more.

Detailed middleware description is outside the scope of this paper. To give a hint on a complexity of the software being developed, the major software components and their structure is graphically presented on the figure above.

Figure 3 shows the software architecture that supports vehicular adaptive control. First (low-level) tier is responsible for the control of low level sensor/actuator devices, affective computing taxonomy and system history. Sensors are devices illustrated at the left-hand side of Figure 2, while the actuators are devices responsible for the vehicular response from the right-hand side of Figure2. Second (middle) tier is responsible for managing atomic sensor/actuator services (ass and css) and for learning, reasoning and monitoring. Deploying more complex (css, cas) and adaptive and reflective (as, rs) services (taking into account atomic and composite services as well as user profiles and application description) this tier plays a crucial role in achieving adaptive control. Third, high level tier contains main control program as well as user profiles, scenario/application description and development/ debugging and run-time tools and interfaces.

## 5. CONCLUSION

Vehicle as a co-driver is a novel concept that deploys affective computing techniques in order to achieve adaptive vehicular control. The envisaged vehicle of the future should observe the driver and, based on the emotional, cognitive and physical driver's state as well as vehicle and driving conditions, optimize the vehicle configuration and actively participate in a complex driving process. Vehicle as a co-driver concept aims at implementing adaptive control in vehicles achieving more secure, pleasant and effective driving.

The three major aspects that are important for the design and development of such systems are examined in the paper: (1) psycho-physiological man-machine interaction, (2) adaptive vehicular control illustrated by the concrete driving scenario and the software architecture that implements adaptive vehicular control.

Affective computing is an ideal technique deployed to transform a vehicle into a friendly co-driver. Its role is to constantly observe the driver, gather his psycho-physiological parameters and evaluate his cognitive, emotional and physical state. This, together with a personalized drivers habits and real-time driving condition information can precisely discover the possible danger and automatically undertake measures to avoid it by soft changes of the car settings and car ambient and by alarming the driver.

The central part of the paper presents the case study that vividly illustrates the functioning of adaptive vehicular control in a real driving scenario.

Finally, a software-intensive system with a service oriented platform, suited to support latest user-centric technological developments in the automotive domain has been sketched. Based on a modular and versatile architecture, a significant gain in safety, cost, and time efficiency in the development of driver-adaptive in-vehicle services is expected. Due to its generic nature, the software for vehicular adaptive control allows for the use in different vehicular application scenarios. The advantages of the taken approach can be summarized in the following:

- Separate development of affective computing principles (hidden in the lower tier).
- Separate development of the service oriented platform to support context-awareness (middle tier)
- Separate development of high level adaptive and reflective components that combine atomic services, user profiles and application scenario (hidden in the middle tier)
- Gradual development of each system module and later flexibility in extending/modifying the system (as a consequence of modular and service oriented approach)

The vehicular adaptive control system may be extended both vertically and horizontally. Vertical refinement of the higher level tier responsible for adaptivity and reflectivity should enrich the system with new functionalities and smart service compositions. Horizontal refinement is a constant task that involves enrichment of low-level tier by adding new sensors and actuators thus extending the capabilities of the system. Both extensions are transparent to the running system and may occur dynamically.

The further work will be devoted to the wider applications in various vehicular domains. Besides personal cars (present application domain) further scenarios will include the deployment of adaptive vehicular control in other types of vehicles like buses, tracks and emergency cars.

## 6. ACKNOWLEGEMENT

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