

Adaptive cooperation between driver and assistant system

Abstract. The introduction of assistant systems has two main drawbacks. First the technological limit obviates the realization of full autonomous vehicles and makes mandatory the actions dangerous from the driver in complex situations such as in urban places. Second the driver shifts more and more his/her task to the monitoring and stays just as a back-up for the technological solution. Unfortunately he/she does not master adequate request as the human leaves quickly out of the control loop. Moreover, the lack of practice may influence negatively their actions with respect to complacency risks.

Therefore it is necessary to change the interaction design of the couple driver–vehicle. Hence the machine-centered design has to be replaced by an integrated human–machine approach, which may give better global results. Instead of automating as much as possible, the strategy will be to automate just the necessary tasks at the right moments. The assistant systems will be combined to define a virtual driver. Its cooperation with the driver will be adapted in real time depending on both situation awareness, the driver’s needs of cooperation and his/her activity level.

First of all the vehicle architecture based on a vertical layering (direct link of a dedicated sensor to an ECU for one single actuator) has to be changed radically. Therefore, the first action will be to re-organize this architecture by using a horizontal layering where all the functionalities are integrated within the main domains. Hence it will be possible to add new functionalities within the different layers without having to modify the overall architecture.

2.1 Vehicle architecture matching the driver cognition flow

As today, a dedicated electronic control unit is allocated per functionality in a vehicle. This approach, corresponding to the actual suppliers’ business model, may not be the best solution. Indeed the addition of the new functionalities

will make the integration of the devices more complex and less reliable (compromises between cost and efficiency). That is why an extensive re-design of the architecture should be done by splitting the hardware and the software. The system architecture will handle the shifting from hardware connections to software integrations.¹ For a clear integration, the software architecture can be inspired from the driver cognition, since it is the most compliant architecture for cooperation with the functions within the driver.

The set of primary tasks defined first by Rasmussen in [106] and improved through works of Suetomi [121], and Stanton [118], splits the intellectual activities of a driver in three main tasks levels (Fig. 2.1). The first tasks are driving related and, thus, safety relevant. It goes from vehicle stabilization up to navigation as described hereafter. The second task level is related to the improvement of the driving tasks, e.g., a driver needs to switch on the upper beam when he/she is driving into a tunnel. These tasks are not mandatory but they improve the driving reliability. Differing from the first two levels, the last tasks are not driving related at all, they are related to all the disturbances. They can be technology disturbances such as changing the radio channel or non-technology disturbances such as discussions with passengers. All in all, the driver has a maximal activity level capacity, which cannot cover all the tasks. Therefore, the driver focuses automatically on some tasks, those which are the most relevant in his/her opinion. It is possible to automate partially the second level tasks such as automatic beams or to manage technology disturbances such as radio when dangerous situation arises. Hence it is possible to get the driver more concentrated more on the most relevant tasks: the first level tasks.

The first level task as depicted in Fig. 2.2 integrates the driving related tasks. First a strategy function defines the road sections to reach a destination. Then a tactic function determines an adequate maneuver relative to the situation. Finally this action is transformed in terms of acceleration and

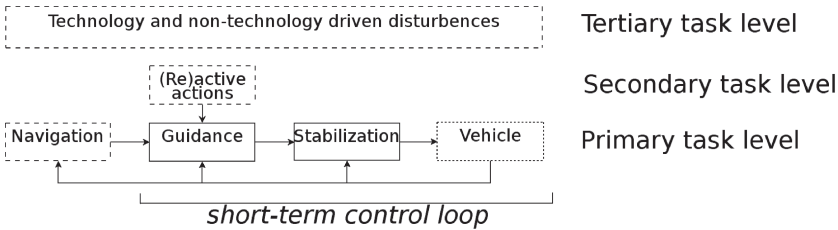


Fig. 2.1. Improved cognitive model for the driving tasks

¹ Moreover the costs of such architecture will be cheaper and more reliable because of the savings of wiring, connectors etc.

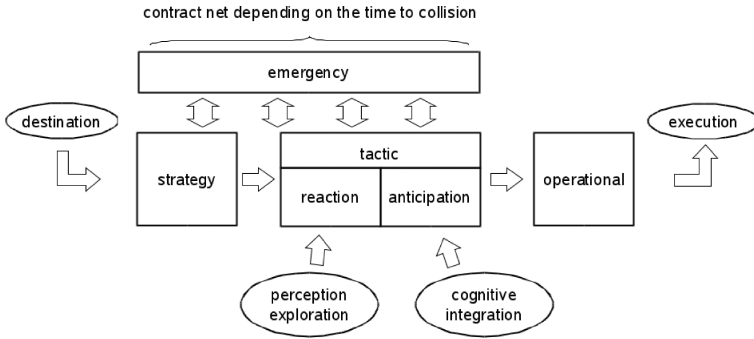


Fig. 2.2. Improved cognitive model for the driving tasks

steering angle, which will be transferred as a physical command to the vehicle through an operational function. A right integration of the assistant systems as a virtual driver has to be done in parallel to ensure a safe vehicle command even if the driver fails.

Two major points need to be improved to create an optimal human integrating architecture. First an emergency function is working in parallel to the strategy and tactic functions. This module will take the initiative to gain a hold on the other modules as soon as the driver perceives a danger. In this case the driver downsizes unconsciously his/her perception range and focuses only on the source of danger. That is why it is necessary to postpone the non-guidance functions while dangerous situation occurs.

Secondly the tactic function has to be improved through a split into two modules. The driver first has a look at all the possible maneuvers that he/she can perform as a reaction to the surrounding environment, and after that he/she will choose one of the maneuvers. Thus an advanced assistant system needs to deal with multiple maneuvers to get the capacity to react to the different needs of the driver. Moreover the driver can also face a dilemma as he/she has to anticipate situations such as an incoming curve. The driver will have to consider if overtaking is recommended, as the incoming curve requires speed degradation.

Two additional elements will be integrated into this cognitive flow even if their influence is low. On one hand humans have the capacity to remember locations and situations encountered earlier. On the other hand a driver can get information from other people, e.g., through radio (jamming etc.). This is referred to communication between vehicles or infrastructure (C2C/C2I). These two ways of sensing are indirect possibilities to get additional second-order information about the incoming environment.

2.2 Horizontal layering integrated into the vehicle

The integration of new layers into the vehicle must always be reverse compatible in case of failure and still give the possibility to add features without any modifications on this layer. In such cases, it will be possible to inhibit the controls based on the layer, which is posing difficulties without corrupting the rest of the architecture. It will then become possible to downsize the level of intelligence of the full platform just below this element. This is why the architecture has to be clearly horizontally layered as explained by Brooks in [20] and shown in Fig. 2.3. This concept has also been used in serial vehicle production such as the Vehicle Dynamic Control by Toyota.

When a vehicle is not equipped with this kind of systems, the driver's command is directly sent to the actuators. If layers have to be integrated, the control of some actuators will first have to be done autonomously. Indeed the gear shift has to be automated to give a direct control to the engine, the brakes and the steering unit. Moreover when a differential has been locked, it cannot open autonomously without specific braking torque to compensate its torsion. Therefore, the steering angles will have to be disabled to avoid mechanical defects of the differential and the vehicle will have to stop as quickly as possible.

The first layer named *reactive safety* corresponds to the operational function. It can also integrate the functionalities corresponding to the reactive safety such as braking control, yaw control etc. This layer is based only on the difference between the command and the vehicle state. It will provide a correction if necessary. The connection with the layer below can be either done mechanically by using epicycloids on the steering wheel [71] or a second valve for the baking units. This connection can also be done fully electronically with the integration of a drive-by-wire technology [117].

The second layer named *predictive safety* corresponds to the tactic function. At this level all the possible predictive assistant systems will be inte-

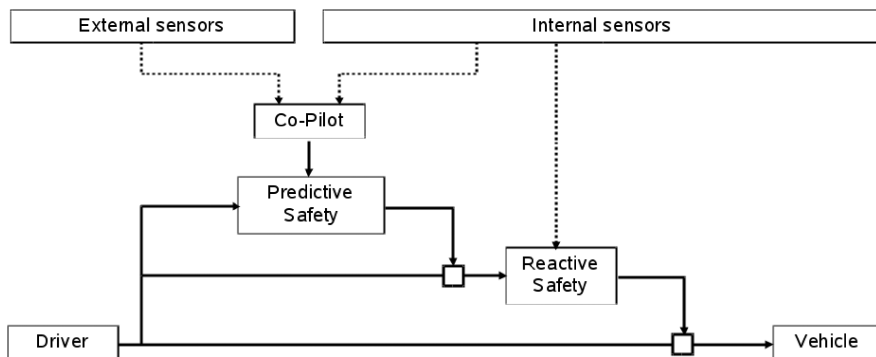


Fig. 2.3. Layers for the vehicle platform

grated in a virtual driver. This deliberative level requires also an access to the driver's command to intervene while an optimization is required. Theoretically three possibilities exist: first a limitation of the driver's command to stay within the safety limits, second a correction or third a decision to realize one of both commands. Since the second method is purely reactive, it can only bring collision mitigation. Thus the innovation will be the combination of the two other methods. Here the connection to the lower level is done electronically such as in [11]. It would be also possible to do it mechanically by adding and moving mechanical limits to the steering wheel and pedals, but the complexity of such devices presents singular systems like the devices such as the German society Paravan.

The strategic function into the cognitive model will not be integrated as an additional layer in this architecture. Actually the strategy function is not relevant for the safety of the vehicle in a short time range; it is more focused on the driver comfort. Moreover the information coming from this layer, typically based on old data of the navigation platform are seldom upgraded (less than 5% for the Blaupunkt navigation platform [22]). Thus the use of such devices as safety input is not appropriate, but it can help the external sensors to perform their tasks. So the connection of these two layers can be a stream delivering the data from the navigation platform.

Moreover an external trigger of the navigation platform is required while danger occurs. Indeed the use of the navigation platform at such moments will disturb the driver, whose brain switches from normal mode to emergency mode and it will skip automatically the strategy function.

2.3 Overall presentation of the new concept

In this chapter a new methodology for the cooperation between the driver and a virtual driver will be presented. The part II defines the new vehicle platform required to design an adaptive virtual driver. After that, this virtual driver is integrated on those platform (part III) and finally the intervention process is developed (part IV).

The innovation of the vehicle platform is the capacity of instability anticipation which enable the assistant systems to pre-compensate hazards. Thus, the use of real-time models of the actuators to extrapolate the vehicle capacities during the next instants will be described in chapter II.4. However, the use of drive-by-wire components will require an energy management to look at the influence of the battery state on the actuators' capacity (section II.4.2). The road-tire friction coefficient will also be estimated (chapter II.2) as it influences directly the single link between the vehicle and the road. Once the vehicle dynamics are modeled, it will be possible on one side to realize the vehicle command with a predictive adaptation (chapter II.5) and on the other side it will be possible to send a feedback to the command level related to the vehicle capacity. On top of that, reactive assistant systems such as ABS and

ESC will be used with a predictive configuration (section. II.5.4) as they may be required anyway.

Once the vehicle dynamics are made available at the command level, the virtual driver begins to bring the tactic level within the vehicle. As the integration of assistant systems reaches an exponential level of complexity, a multi-agent platform (chapter III.1) will be developed to give the possibility to plug these functionalities in parallel. A blackboard will store the outputs of the smart sensors and it will combine them to improve the reliability of the environment models. To improve the level of availability, a redundancy mechanism has been used by integrating algorithms from the robotic field such as potential field method or dynamic window method (chapter III.2) parallel to the event-based algorithms from the automotive world such as the distance control or the lane keeping control (chapter III.3). As they bring different control dynamics, their outputs require a combination on the acceleration–steering space to define the safety envelope of the vehicle command.

When the virtual driver is ready to act in parallel to the driver, its cooperation capacity can be used. In the last part, the different levels of cooperation which are used as degradation modes will be described in details. The first level of cooperation will be purely binary: once the driver’s command has reached the safe limit of a maneuver, the system will intervene and align the command with the corresponding safe maneuver. This kind of intervention is only an extension of the emergency brake to the synchronization of longitudinal and lateral directions. Thus, a first required task will be to understand the driver’s command in terms of maneuver (chapter IV.2). After that, a transition path can be planned when the intervention kicks in. The confidence values of both driver and virtual driver were not taken into account yet. Thus, another task will be in charge of the driver monitoring to determine his/her drowsiness (chapter IV.3). Hence, a fuzzy intervention can be performed depending on their confidences. Finally the level of assistance required by the driver will be estimated to enhance the cooperation process (chapter IV.4).

2.4 Presentation of the concept of adaptive cooperation

For airplane ergonomics and nuclear power plants, adaptive cooperation has already been investigated since the early 1980s. Norman [95] proposed the idea of cognitive engineering to answer to the increasing complexity of the systems. In 1984, Sheridan defined for the first time the different levels of automation and their inherent risks [111]. From this enumeration, Boy defined 6 years later in [16] the properties of integrated human–machine systems and he/she has shown clearly the performance of cooperation using of real tests in the space shuttle for the landing control. Following this, he/she focused more on the interaction processes [15] and especially how to bring the most relevant information to the human during decision–making process. A derivated concept dedicated on ground vehicles came later from Flemisch in [40]. In his/her

approach the trio—human, intelligent assistant system and machine—is fused into one sequential two-level architecture with a driver and an intelligent vehicle. This approach focuses more on the transfer of driving tasks and the ergonomics related to this transfer, by giving the possibility to amplify the driver's request. The limitation of these different approaches comes from their global vision of the acting tasks; and hence they try to provide an intelligent assistant system as one single entity.

Besides taking into account the driver cognition model as dataflow, the approach presented here will also modify the former trio driver, virtual driver and vehicle platform by adding a module involved into the cooperation and the dispatch of its results, see Fig. 2.4. The cooperation will be split independently into strategy, tactic and operational skills. Therefore the driver and virtual driver will have the possibility of bringing their knowledge on different levels only for some specific tasks, for which they get the advantage. For example, the driver gets good capacity for the anticipation and the tactic when he is concentrated; it remains difficult today to have a good anticipation with intelligent systems. On the positive side, assistant systems are fast with repetitive capacity even if the driver has to monitor their actions. For each function, the optimum of the cooperation is continuously evolving depending on their knowledge on the environment. On one hand, if the driver tends to be an expert, the optimal solution will tend to shift generally to his/her side. Even if the environment is well known without risk of unanticipated situations, the assistant system will rarely have to correct the driver's intentions.

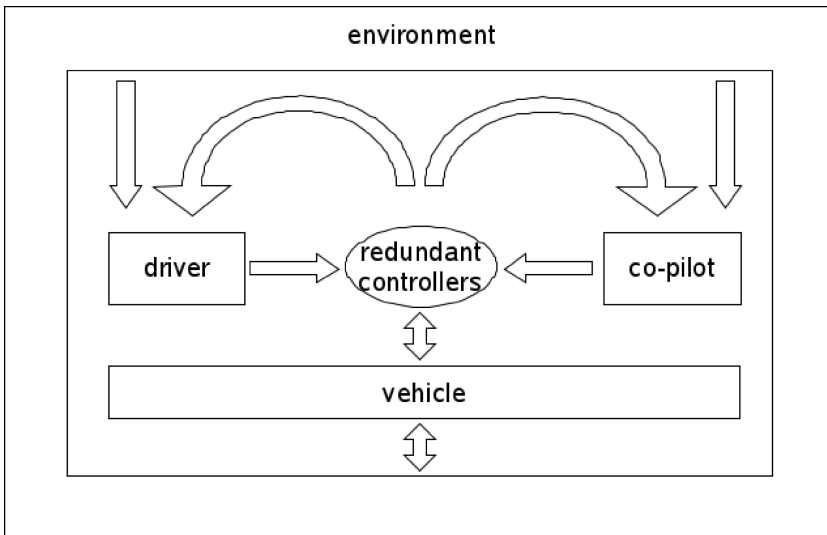


Fig. 2.4. Concept of adaptive cooperation with parallel elements in the command level

On the other hand, the shift to the assistant system can be done for inexperienced drivers or inattentive drivers so that the assistant system can perform mandatory actions without overriding possibilities up to autonomous driving.

The intelligent assistant system has to first understand undoubtedly what the driver goals are, not only in terms of vehicle command but also in terms of destination and maneuver to perform otherwise it does not know how to support him/her. Following this it can determine how to cooperate with the driver. This means it has to determine how much support the driver expects, and how much support it can bring to this person. This difference of capability is also important for the driver, since he has to know how far the assistant system can support him/her. For the functions not related to the short-term control loop, its help is always punctual as events do not come continuously. However, as already explained before, this help may be disabled during dangerous situations to avoid disturbing the driver. For the tactic level, help for the anticipation task is also rarely given and only when the driver will be missing relevant information, such as *what is happening after the driven curve*. For the reactive task, the continuous cooperation requires from the cooperation module to know the driver's acceptance level for the feedback. Depending on the cases, this information will just describe the dangerousness of the maneuver, showing the risky zones for a maneuver change (depending on the driver's own confidence), or describing the source of dangers at a later time. In the worst cases, the assistant system will have to disagree with the maneuver changing and the cooperation module will have to explain to the driver the different reason (e.g. dead angle). Last but not least, the operative level gets a wide range of possibilities, from completely passive assistant system to continuous optimization of the driver's maneuver by means of autonomous driving. The level of delegation may be contested from the cooperation module anyway if the driver's fitness goes down, since the driver may leave the control loop after that. The highest problem here will be to determine the difference between the support requirement and possible support reserve.

Next, if the cooperation is analyzed over the time during crisis resolution [73], three steps will be defined: anticipation, interaction and recovery. The anticipation time is almost the most common level and it corresponds to the case described just before. Potential hazards have to be detected as soon as possible and the dangerousness lowered. An easier interaction for the crisis solving will depend mostly on the human competences and the usability of the interaction process with the assistant system. If their solutions are converging, the resolution will be faster and with less stress for the driver [140]. However, in some cases, their solutions can be conflicting due to lack of information or knowledge for at least one of them. To solve this conflict as fast as possible, the role of the feedbacks to the driver and to the virtual driver are fundamental. Indeed, assistant systems can do mistakes like humans if they would have sensing failure, problems with situation categorization, or control not adapted to the situation. The assistant system can modify its strategy after verification if some elements have not been detected correctly. However,

if the outputs stay incompatible, it will be necessary to choose the source of command, which has the highest probability to achieve the recovery, and the other one will be set out of the control loop temporarily. This choice will correspond to a passive recovery if the assistant system has to intervene, or it will correspond to an active recovery if the driver achieves the recovery by himself.



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