# The H-Metaphor as an Example for Cooperative Vehicle Driving

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**Abstract.** For quite a while the automotive industry has been working on assistance systems to improve safety and comfort of today's vehicles. In the course of this development combined with increasingly capable sensors, assistance systems have become more and more powerful. This whole development enlarges the role of the human, beginning from the actual driver of the car up to a supervisor of the automation state. On the one hand this leads to a relief in the drivers workload. On the other hand effects like out-of-the-loop and associated with that a loss of situation awareness can appear. Trying to solve this clash of objectives, the project "H-Mode" follows an idea of vehicle driving where the automation is capable of driving almost autonomous, but the driver is still kept active and in the loop by cooperating with the automation-system. The article describes the idea of cooperative driving and especially the H-Metaphor. Furthermore an example is given how this concept is used in the development of assistance and automation systems.

**Keywords:** highly automated driving, driver assistance, shared control, haptic feedba0063k, cooperative control, side stick.

## 1 Introduction

Functional progress in the area of advanced driver assistance and active safety systems (ADAS) enables higher degrees of automation in future cars. A comparable development has been seen in aviation and maritime scenarios. Meanwhile ADAS like adaptive cruise control, lane keeping assistant systems and collision avoidance are widespread and assist the driver partially and in given situations. But for a long time being – like in aviation – the human operator, i.e. the driver, will have to be kept in the loop due to the Vienna Convention. On the other hand the technical potentials for safety and comfort shall be gained. Therefore it is an aim to investigate ergonomic human machine interfaces that avoid typical automation effects but also increase the comfort for the user of a highly automated vehicle.

One aspect is to ensure that the interaction concept fulfills the criterion to be compatible with the driver's expectations and with the environment in which the driving task has to be fulfilled in cooperation with a very powerful cognitive enabled machine. Moreover it is necessary that as much information as possible is transferred between the person and the machine considering actual and future status of the driving task and future intentions on further driving maneuvers.

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According to this, the challenge for highly automated vehicles is to reduce a relatively high complexity of the automation into a manageable complexity for the human being. Aviation can only be a limited role model here: In most aircrafts, two well-trained pilots keep the system safe, a "luxury" in redundancy that is usually not available in ground vehicles. New concepts for an intuitive approach to automation that everybody can operate without extensive training have to be developed and tested.

One potential technique to increase intuitiveness is the use of design metaphors. In the computer domain, the desktop metaphor took a natural desktop as an inspiration for the organization of a PC user interface with folders, trash cans etc. For intelligent vehicles, the H-Metaphor takes the example of the rider-horse relationship to describe a cooperative interaction between a highly automated vehicle and a driver (H-Mode). Initially developed for air vehicles [1] [2] it is now systematically applied to cars and trucks [3].

The horse as a role model is suited with sufficient intelligence that can be used to allude the rider to changes according to the environmental setting, to influence his behavior, to widely take over control in non-critical situations and maybe even react on its own in critical situations. Transferred to the vehicle, an intelligent automation can act likewise. By becoming increasingly capable due to technical improvements automation-systems are getting more and more "intelligent" up to the point where they can actively affect the driver's behavior and release him in situations where he is overstrained.

Therefore both the driver and the automation need to interact with each other on a cooperative basis [4]. To do this an interaction concept is needed where both the driver and the automation can communicate wishes and pieces of advice to the respective partner and negotiate a common course of action. An essential aspect thereby is that the driver and the automation are simultaneously involved in the driving task, acting parallel to each other (Fig. 1).

Both perceive the environment separately, generate an intention based on this perception and try to put this intention into practice by affecting the vehicle, the driver or accordingly the automation. Following the H-Mode interaction paradigm, this communication and negotiation is primarily carried out via the manual haptic channel using active control elements. In addition to this the haptic interaction is supplemented with acoustic and visual information.

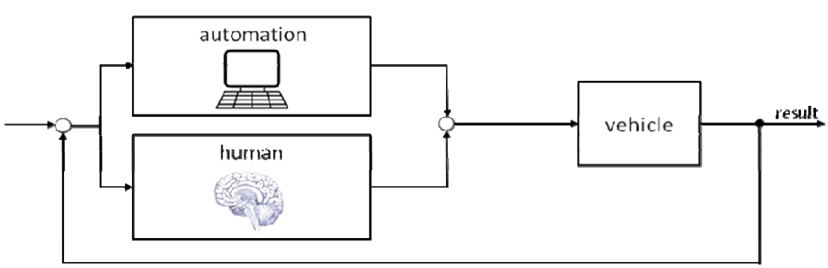


**Fig. 1.** Schematic drawing of the parallel-simultaneous interaction concept. Driver and Automation act parallel to each other and interact with each other via a summation point.

## 2 Active Control Elements for Cooperative Interaction

Active control elements in general provide a way to benefit from haptic feedback [5]. Forces which can be generated by the integrated actuators can be used to transmit vital information to the operator. Therefore the mechanical connection between the machine and the operator can be separated and replaced by an electronic one. On the one hand this decoupling makes it possible to completely redesign the interface. On the other hand the separation from the mechanical feedback may aggravate the user's ability to operate the system. The loss of information flow results from the fact that the operator can only feel the dynamics of the control element, but not the dynamic of the controlled system itself. Therefore the user has to estimate the system's behavior in order to keep the system within safety limits [6]. For technical purposes, two concepts of active operating elements must be distinguished: force and position reflective elements.

In the following these drafts are exemplified by driving a side stick based vehicle. A side stick as control element has been chosen due to the fact that from an ergonomic point of view the dimensionality of a control element should correspond with the dimensionality of the task. According to this a two-dimensional side stick should be suitable for longitudinal and lateral guidance in car driving.

For driving the vehicle the operator creates forces on the stick. The underlying spring characteristic of the force reflective operating element (Fig. 2) determines its movement as a function of the load injected by the operator. Through the stick position the user adjusts the set point settings of the vehicle.

Consequently the dynamics of the stick is autonomous and does not allow conclusions about the vehicle's state. This means for example in lateral direction that the driver manipulates the steering angle but has no knowledge about its actual state. He can only estimate the wheel position through the sensed accelerations.

On the contrary position reflective elements (Fig. 3) use the applied forces to generate the set point settings [7]. As opposed to the spring centered stick, where the position results from the balance of forces, the position reflective control element stays fixed for the operator and is only moved by the controlled system. More precisely the forces applied by the driver are measured and transformed into control inputs. The feedback information is returned as position of the element which thereby represents the actual state while its movement represents the dynamic of the system itself. Consequently the operator senses the behavior of the system/vehicle.

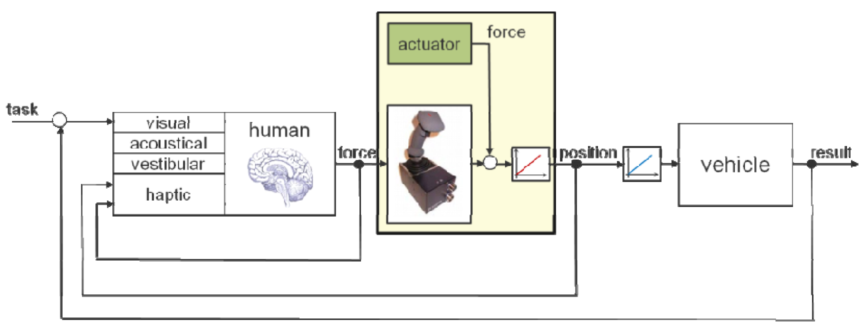


**Fig. 2.** Force reflective control element

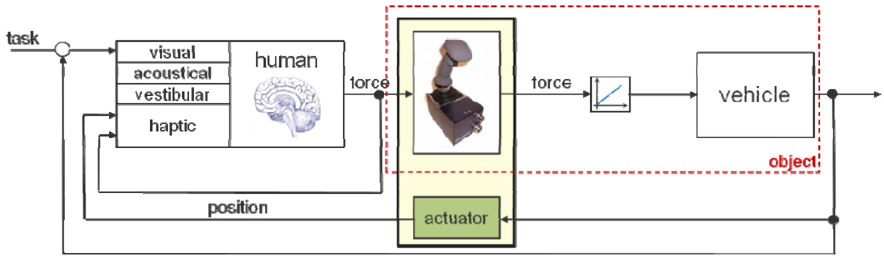


**Fig. 3.** Position reflective control element

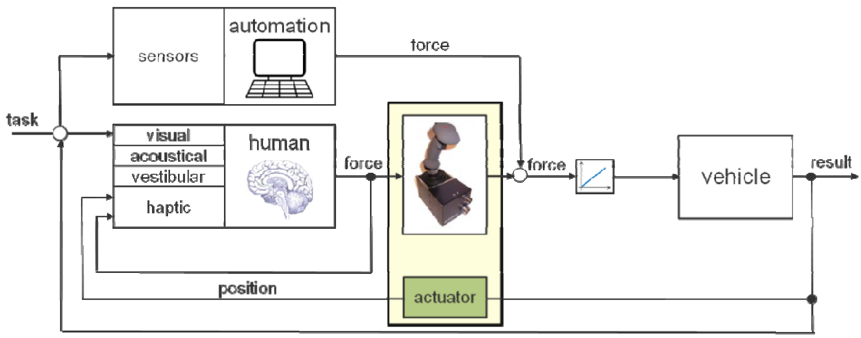


**Fig. 4.** Combination of position-feedback of the vehicle dynamics and force-feedback of automation recommendations

This configuration works similar to the direct interaction with objects and direct manipulation. By raising forces the user manipulates the item which responds with movement. As a result, position reflective elements seem not only suitable for compensating the decrease of information flow but also enable a specific feedback of essential information that supports the operator. Applied to the task vehicle driving a significant advancement in driving performance can be verified [5].

One of the essential features of the H-Mode is a bi-directional haptic-multimodal coupling with continuous and/or discrete communication between driver and automation. This communication has to be established in addition to the feedback of the system's dynamics. Thereby the driver will be kept in the loop. Status and recommendations of the automation will be communicated. This is not only a feature driving on a high level of automation but is also reasonable on low levels of automation. Fig. 4 shows the combination of the position-feedback principle with a feedback of automation recommendations [8]. In the same way the driver applies forces to the control element, the automation can influence the vehicle's behavior by generating virtual forces. Both inputs are merged in a summation point and the resulting force is used to generate the set point settings for the vehicle. Via the feedback-loop the driver can haptically sense the generated forces of the automation on the control element i.e. he can sense its recommendations.

Experiments show that the combination of both feedback principles – position feedback of the vehicles dynamics and force feedback of automation recommendations – grants a further benefit to the performance of the driving task.

## 3 Degrees of Automation

One important component of the H-metaphor is the possibility of the user to be able to change between different levels of automation from high automation to low/no automation covering the whole range of different levels of automation (Fig. 5).

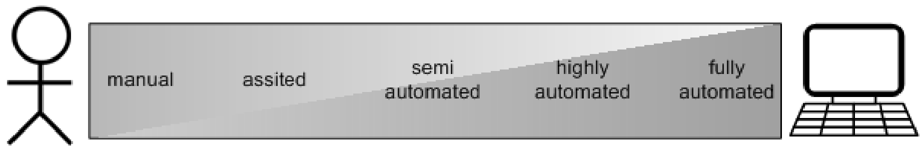


**Fig. 5.** Involvement in system control as a spectrum between fully manual and fully automated [9].

Therefore the interaction concept has to provide a possibility to switch between the degrees of automation. With an increasing degree of automation the system gains more and more influence on the driving task, thus meaning that the driver hands over authority to the automation. Subsequently, the driver gets more authority and a more direct control of the vehicle with a decreasing degree of automation. In terms of realization this corresponds with a variable weighting of the input – driver and automation – at the summation point (Fig. 2).

In the original domain, this allocation of authority is dependent on how the horse reins are used. If the rider wants to have more impact on the horse's actions, he tightens the reins and thereby vastly takes over control. In terms of vehicle driving this "Tight-Rein-Mode" corresponds with a low level of automation. For a more indirect control, respectively a transfer of authority to the horse the rider eases the reins. This "Loose-Rein-Mode" equals a high level of automation.

Based on this interaction paradigm a prototypical system has been implemented in which the grip force is used as an indicator for how much the driver wants to be actively involved in the driving task [10]. Therefore the stick is equipped with a sensor system to measure the actual grip force of the driver. Corresponding to the tight reins of the rider the driver increases the grip force applied to the control element and thereby raises his own authority in the driving task. If the driver wants to grant the automation higher latitude, he reduces the applied grip force and therefore transfers authority to the automation. This relation can be realized not only for two states but it could have the potential to be scaled on a continuum. The following chapter shows an usability-study about grip-force-measurement with three changeable degrees of automation.

## 4 Grip Force as Indicator for Driver Involvement

This experiment investigates whether grip force can be used as a nonverbal parameter to differentiate between different levels of driver involvement and serve as a switch for the level of automation. Based on the preliminary results, this experiment is performed with a position reflective side stick with steering angle feedback in lateral and speed feedback in longitudinal direction.

**Fig. 6.** Usability laboratory at the department of Ergonomics

### 4.1 Method

**Experimental Setting:** The experiment takes place in the H-Mode usability laboratory at the Institute for Ergonomics, Technische Universität München (Fig. 6). The laboratory consists of a highly variable mockup with a single projection screen. The driving simulation software SILAB TM directly receives all commands from the control elements, provides the vehicle and driving dynamics simulation and generates the information for haptic feedback at the stick. Data sampling and logging facilities are also provided by the SILAB software.

Two different concepts for the change of automation degree are compared. They differ in the method to initiate the transition of the automation degree. Whereas in the first version the shift between tight rein and loose rein can be accomplished by pressing the associated button. The second prototype measures the operator's grip force applied to the control element and changes the degree of automation accordingly. In order to measure the grip force the conventional side stick grip is substituted for a rudimentary grip with force-sensing resistors (Fig. 7, left).

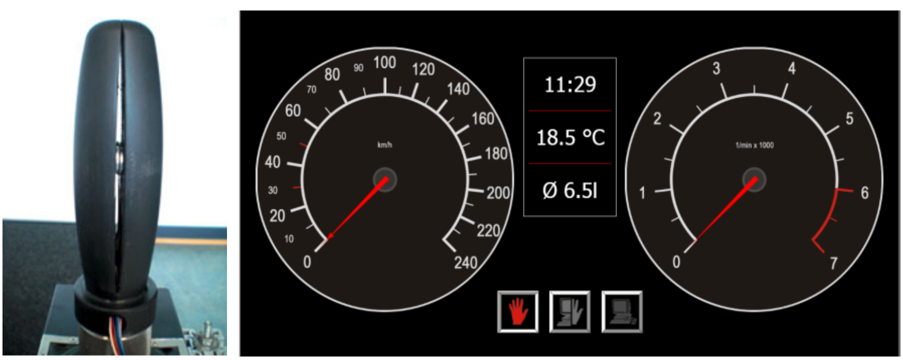


**Fig. 7.** Side stick grip with FSR sensors (left). Touch screen dashboard with buttons for completely manual, semi automated and highly automated. (right).

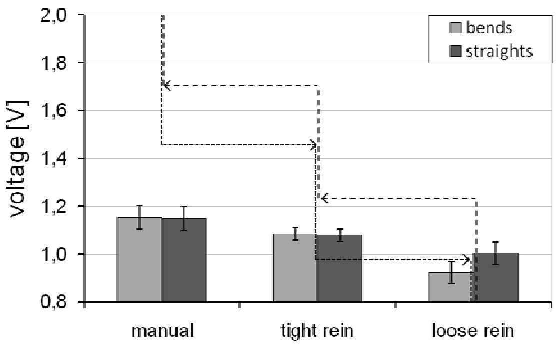


**Fig. 8.** Bar chart: measured grip force from preliminary tests (mean ± standard error, N=24), lines: realized borders for switches between automation degrees.

The voltage gradient at each of its four sensors is proportional to the pressure applied. The average of all four sensors is used as reference value for the automation degree. A high voltage thereby is equal to a high pressure, i.e. a low automation degree and vice versa. This means that a high grip force reduces the influence of the assistance while loosely holding the side stick grants the automation the possibility to take major control over the vehicle. For alternative experimental conditions the virtual dashboard which is based on a touch screen, was extended with three buttons providing an interface for initiating transition in the automation spectrum (Fig. 7, right).

The automation thereby consists of three levels: completely manual, semi automated and highly automated. The difference between the two automated levels is mainly based on the forces the automation may apply to the control element. Based on a preliminary test a system with grip force induced automation shift was implemented. In order to alleviate the intentional shift of the automation degree the force levels have been elevated . To prevent a continuing alternation of the automation state at the border between two defined states a characteristic hysteresis curve has been added (Fig. 8).

**Participants:** 16 subjects (13 male, 3 female) with an average age of 29.5 years (standard deviation: 5.3 years) participate in the experiment. All subjects have a driving experience of at least 5.000 km/year and normal or corrected-to-normal visual acuity.

**Experimental design:** The experiment is set up using a within-subjects design with the switching method as independent variable and different items of subjective acceptance as dependent variables. For the assessment a semantic differential consisting of various Likert-type bipolar rating scales is used for the assessment of subjective acceptance covering a range from -3 (strongly disagree) to +3 (strongly agree). As this experiment is only thought to show the potential and subjective usability of the grip force measurement only subjective data are statistically assessed. Therefore the different items are compared pairwise with a t-test. The level of statistical significance is set at $\alpha = .05$.

**Experimental procedure:** As most of the subjects have never participated in a driving simulator study before and as none of them has had any experience driving with a side stick, the experiment starts with a training session of about 20 minutes in which the subjects can get used to the simulated environment and to the unfamiliar control concept (including side stick and changeable degrees of automation). After this training run, two trial runs are performed in permuted order during where subjects have to change the degrees of automation either by pressing buttons or by varying the grip force (depending on the run). The subjects are instructed to change to the automation mode according to the mode presented beside the road on traffic signs. Both runs are performed on the same test track (30 kilometer road, partially winding). Every run is accompanied by a questionnaire regarding the subjective acceptance.

### 4.2 Results

The evaluation of the subjective questionnaire regarding 5 different items of subjective acceptance is presented in Fig. 9. The results of the items comfortable ($t(15) = -0.436$; $p = .669$) and simple ($t(15) = 0.000$; $p = 1.000$) show no significant effect. Regarding the items feasible ($t(15) = 2.298$; $p = .036$), attractive ($t(15) = 4.162$; $p = .001$) and even sportive ($t(15) = 1.986$; $p = .047$) the grip force measurement is rated significantly better.

Summarized it can be said that the grip force measurement is not rated significantly worse in any of the items but is rated better in three of five. This result seems promising regarding further investigations on this topic.

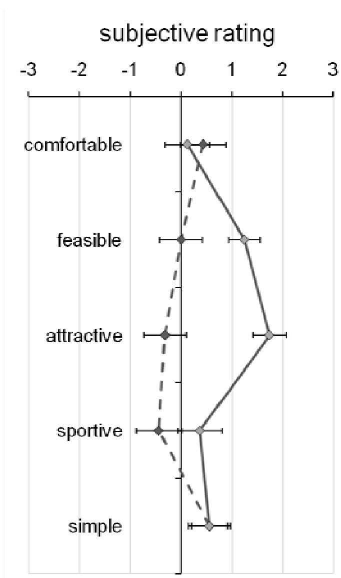


**Fig. 9.** Subjective rating of the different transition modes (mean ± standard error, N=16). Dashed line: buttons, continuous line: grip force

## 5 Conclusion

In the long run completely autonomous cars are not very likely to be on the market due to technical restrictions (e.g. sensor range) as well as the Vienna Convention which says that the driver must be kept in the loop. Nevertheless the increasing number and quality of driver assistance systems enables the feasibility of a highly cooperative vehicle. One potential implementation of this idea follows the H-Mode interaction paradigm as a parallel-simultaneous interaction concept. Taking this parallel interaction as a basis, the question arises, whether conventional control elements are conducive and if there might be any considerable alternatives, especially regarding the human-automation-communication.

The experiment shows how design metaphors can be used to generate and develop new and unconventional interaction ideas. Its focus is a usability test to assess the idea whether grip force can be used as a parameter to differentiate between different levels of driver involvement and therefore serve as a switch for the level of automation. This method is compared to a touch screen with three buttons providing an interface for initiating transitions in the automation spectrum. The comparison shows positive results throughout all attributes. Therefore the initial idea seems to have potential and will be further pursued. However many questions remain especially how does the grip force work in situations of surprise, stress or shock. The apprehension arises that in such situations humans show a tendency to hold onto the control elements and thereby increase their grip force. If this were the case, the relation "high grip force – low assistance" would be extreme counterproductive, as the driver would especially need more assistance in these situations. Nevertheless should be further investigated if the potential of grip force measurement can be used as a nonverbal additional information in combination with other channels (multimodal fusion).

More experiments regarding different control elements besides the side stick and the steering wheel will also be conducted. Conventional elements of driving cannot be substituted overnight by side sticks. Thus other possibilities have to be explored. Alternatives suitable for migration might already exist in other domains but have to be found.

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