Ilka Zöller, Roman Bechmann, Bettina Abendroth

Institute of Ergonomics and Human Factors, Technische Universität Darmstadt

Otto-Berndt-Straße 2, 64287 Darmstadt, Germany

abendroth@iad.tu-darmstadt.de; +49 6151 1623123

# Possible applications for gestures while driving

## Abstract

The ongoing trend of integrating new comfort and entertainment functionality into cars is leading to an increase in the number of controls operated by the driver. In order to position as much functionality as possible within optimum reach of the driver, complex control designs such as rotary buttons and touchscreens are increasingly being implemented to guide the driver through multi-level menus. However, this also increases the mental effort, hand-eye coordination, visual distraction, and time required to operate these controls. Touch-free gesture control represents an innovative control design with the potential to improve the efficiency of human-machine interactions while driving. The *Institute of Ergonomics & Human Factors* (IAD) at the Technische Universität Darmstadt is currently researching which gestures could theoretically be implemented, based on the criteria of distinguishability, intuitiveness, and efficiency of operation. This paper presents the first results of a preliminary study, as well as a comprehensive catalogue of gestures that meet the criteria identified thus far that should be met by any efficient gesture-based control design.

## 1 Motivation

As technical possibilities expand, the number of driver assistance systems and entertainment/comfort functionality intended to improve driving safety and positively influence the driving experience rises with them. But this growing functionality, especially that offered by vehicular infotainment systems, also increases the number of controls, which negatively affects the driver's comfort when operating them.

In response to the increasing number of controls, the automotive industry has invested in the development of new control designs (Bubb 2015). These designs do indeed reduce the number of controls by using more haptic rotary buttons and touchscreens, but they require deep menu structures in order to compensate. This creates higher mental and visual strain for the driver, which is for example reflected in the increased amount of time required to operate these functions.

The additional strain placed on the driver while operating these on-board systems not only compromises the comfort gain, but can also overburden the driver, ultimately leading to a considerable increase in the accident risk (Chiellino et al. 2015). One solution might be to supplement conventional control designs with touch-free gesture control for certain functions, as is currently implemented in the BMW 7 Series. A gesture may be defined as "a motion made with the body that has some meaning for a person or their communication partner" (Franz and Schader 2008, p. 3). The IAD is currently studying two research questions relating to gesture control:

1. Does gesture control provide the desired benefits of more efficient control (e.g. in terms of operating time, input errors) and less distraction (e.g. motor, visual) for the driver?
2. How many gestures are drivers capable of distinguishing, and how must these gestures be designed in order to achieve more efficient operation?

## 2 Gesture control as an efficient control design – results of a series of empirical tests

The first research question has already been studied at the IAD in a preliminary study. In a static driving simulator at the Institute, the influence of gesture-based control on distraction was compared to conventional haptic control. In a total of 13 test subjects, the time required to operate the controls, eye motion, and distance variations from lateral lane markings (distance between the lateral side of the vehicle and the lateral road markings) were recorded. The driving simulator used in the study was a realistic vehicle mock-up with force-feedback, a high-resolution simulation view spanning nearly 360°, and a surround sound system (Figure 1, left). Silab 5.0 was used as software.

**Fig 1** IAD driving simulator (left); Section of the driving simulator mock-up during the test drives (right)

The subjects drove along a two-lane motorway track with varying volumes of traffic and different speed zones. While driving, they received a total of five instructions from the test instructor, asking them to perform a control task. The type of control was also specified (gesture based or conventional haptic control). For touch-free gesture control, the subjects completed the operation by executing a one-handed gesture (see Figure 2, right column "touch-free") near the central console. The Wizard-of-Oz technique was then used for the implementation of the gestures. For this the instructor observed the gestures from the back of the vehicle and performed the corresponding operations on the infotainment system using a remote system (so that the subjects did not recognize that the instructor performed the operations). Relating to the conventional haptic control tasks, touch controls were performed on a Samsung tablet mounted on the central console, displaying a radio control panel (Figure 1, right). Figure 2 shows the five control tasks associated with the infotainment system and an overview of the corresponding control options.

**Fig. 2** Control tasks and control options in the driving simulator study

The control tasks "music on" and "music off" could be completed via touch by tapping the corresponding on/off icon on the touch display, and touch-free by pointing an outstretched index finger towards the touchpad. The tasks "volume up" and "volume down" could be accomplished via touch by executing a two-step motion; first toggling a dial above the speaker icon, then turning it left or right to adjust the volume (touch). Alternatively, the tasks "volume up/down" could also be completed by turning the dial mounted directly on the vehicle (dial). To complete this task touch-free, the subjects needed to execute a circular motion with their outstretched index finger. The "next song" could be activated touch-free by performing a swiping motion with one hand from left to right, or alternatively by tapping the corresponding arrow button on the touch pad to activate it by touch. Before beginning the driving in the test, the functionality of the instrument panel displayed on the tablet was explained to the subjects, as well as the corresponding gestures. After this introduction, each subject had another opportunity to memorise the control instructions in association with the gestures before beginning to drive. The driving session began with an introductory phase designed to allow the subjects to familiarise themselves with the simulator.

## Gaze aversion

How often drivers look away from the road is an important indicator of the extent to which they are visually distracted by a control design. To compare the time spent looking away from the road across subjects, fixed start and end times were chosen to define an observation period. Since the subjects were already looking in the direction of the central console before beginning to execute each hand motion, the start time of each control task was defined as the moment when the instructor began to give the task. The end time was defined as the moment when the driver's hand returned to the steering wheel.

Figure 3 shows the average gaze aversion times of the subjects when they executed the tasks by touch and touch-free. Noticeably, for three of the five gesture control tasks, the drivers did not look away from the road at all. They only looked away from the road when executing the tasks "music on" and "music off" touch-free, with an average gaze aversion time of 147 ms. Three of the subjects looked away from the road when executing the task "music on", and one subject for the task "music off". When using touch control, the subjects looked away from the road for significantly longer, namely 949 ms and 1324 ms on average, respectively. Statistically verifying this difference with a one-tailed t-test shows that it is significant with a 5% significance level ("music on": $t(11) = 7.381$, $p < .000$; "music off": $t(11) = 4.350$, $p = .001$). The differences in the other three tasks were also significant ("next song": $t(11) = 8.540$, $p < .000$; "volume up": $t(11) = 7.750$, $p < .000$; "volume down": $t(10) = 5.909$, $p = .001$).

**Fig. 3** Average gaze aversion times with touch and touch-free control

## Operating time

The time required to operate a control was evaluated as an indicator of the efficiency of the control design. Longer execution times lead to an increase in the strain and hence create visual and mental distraction for the subject. Here, the operating time was defined as the period between when the steering wheel is released and when the hand returns to the wheel.

Figure 4 shows the operating times measured when the tasks were executed by touch and touch-free. Here, it was also found that the operating time for touch-free control was significantly lower than for touch control. Statistical verification confirms this; all five tasks were executed significantly faster touch-free ("music on": $t(9) = 1.869$, $p = .047$; "music off": $t(9) = 2.713$, $p = .012$; "next song": $t(10) = 3.796$, $p = .002$; "volume up": $t(10) = 4.507$, $p = .001$; "volume down" $t(9) = 3.153$, $p = .006$).

**Fig. 4** Average operating times with touch and touch-free control

## Lateral distance variations

The lateral distance variations, which were measured using the standard deviation of the lateral position on the track, represent an important indicator of visual and motor distraction when operating controls. Analogously to the operating time, the moments of releasing and re-gripping the steering wheel were chosen for the start and end times of the observation period.

After averaging over the operating time and over all subjects, it was found that, although the lateral distance variations during touch-free gesture control did tend to be lower than for touch control (see Figure 5), the difference was only significant for the "volume up" task ($t(10) = 2.994$, $p=.007$), which required two steps to be carried out by touch.

**Fig. 5** Average lateral distance variations with touch and touch-free control

## Error rate

The error rate is a good way of assessing the intuitiveness and intelligibility of a control design. Since touch-free gesture control cannot be self-explanatory, unlike controls with labels, its execution requires the subject to demonstrate the mental capacity to memorise the association between gestures and specific functions and reproduce these functions faithfully. This can be facilitated by assigning intuitive gestures to each control function. For gesture control, the 13 subjects performed a total of 65 touch-free gestures during the trial. Two subjects made errors when performing three gestures with two functions. Interestingly, the only gesture that was executed incorrectly during the tests was the pointing gesture corresponding to the execution of the tasks "music on" and "music off". In all three cases, the pointing gesture, which should involve a relatively static execution, was instead executed with a swiping-like motion. The other eleven subjects executed all touch-free gestures corresponding to their instructed tasks without any errors.

## Subjective perception

Surveying subjects to establish their impressions of new control design can also yield important insight. If a subject feels that the control design is too complex or too cumbersome, his or her attention will be negatively affected. Even if objective parameters such as the gaze aversion time and operating time indicate that distraction is reduced, a control design with these issues would likely struggle in terms of acceptance. In order to describe subjective opinions, the System Usability Scale (SUS, Brooke 1996) was used to assess the usability. On average, the usability of the gesture-based control design scored 90.96 points out of a total of 100 (corresponds to the best evaluation) on the SUS.

## Conclusions

In answer to research question 1 ("Does gesture control provide the desired benefits of more efficient control (e.g. in terms of operating time, input errors) and less distraction (e.g. motor, visual) for the driver?"), the consistent findings of significantly lower operating times and lower input error rates confirm that gesture control does indeed represent an efficient control design. But the results require a more nuanced interpretation of the effect on distraction, which was also considered by the analysis.

The fact that the gaze aversion time was significantly lower with touch-free control than with touch control indicates that touch-free control creates less visual distraction. On the other hand, if we consider motor distraction, evaluated here in the form of lateral distance variations, we cannot definitively conclude that the effect on distraction is lower. Given the low number of test subjects, this result should only be viewed as indicative for now. The question of whether the type of gestures affects their efficiency has not yet been resolved. A prior study conducted by Geiger (2003) showed that certain types of gesture offer advantages compared to others. The subjects of this study predominantly chose dynamic gestures that simulate a direction of motion. This direction of motion was strongly correlated with the representation of the controls. In the preliminary study presented in this paper, this was reflected in the gestures associated with the functions “next song”, “volume up”, and “volume down”. Previous studies have also shown that subjects only have a limited gesture vocabulary, characterised by high inter-individual and intra-individual overlap (Zobl et al. 2001). The type of gesture therefore seems very relevant to the efficiency of a gesture-based control design. Accordingly, we present a catalogue of gestures below.

## 3 Classification of gestures

Primary gestures intended for communication can be theoretically divided into hand gestures and gestures made with other parts of the body. For gesture control in vehicles, hand gestures are used, which according to Geiger (2003) can be further subdivided the categories of static and dynamic gestures (Figure 6). The distinction between static and dynamic gestures is not necessarily binary. Each gesture is assigned to one category or the other depending on whether a static pose or a dynamic motion is predominant.

**Fig. 6** Classification of primary gestures (systemisation of dynamic hand gestures according to Geiger 2003)

Dynamic gestures can be again subdivided into discrete and continuous gestures. In the case of a discrete gesture, the information content is transmitted by fully executing the gesture to elicit a specific system reaction. By contrast, the information content of a continuous gesture is not limited to the simple completion of the gesture, but depends on the way that it is executed. By adjusting the direction and speed of motion with the body part performing the gesture, system parameters can be varied continuously. One example of this type of gesture is the operation of a Wii remote, which moves a target point on the screen, following the hand motion precisely.

Discrete gestures can be subdivided into mimetic, kinemimetic, symbolic, and deictic gestures. Weidinger (2011) and de Ruit (1998) define deictic gestures as pointing gestures oriented towards a certain location or in a certain direction. They are very intuitive and are therefore viewed as relevant to human-machine interaction. Kinemimetic gestures imitate a direction of motion, and are therefore considered to be oriented gestures (Geiger 2003). One example is performing a swiping motion with the hand from left to right in order to switch to the left within a menu. Symbolic gestures have a specific defined meaning (Weidinger 2011) that must be learned. One example is forming a circle with the thumb and index finger as a gesture indicating “everything is okay”. The information content of these gestures is therefore self-contained, and they can serve as a possible substitute for language. Mimetic gestures are used to describe objects, and are somewhat pantomimic in nature. Due to their complexity, they are not suitable for driving and are not considered here.

Static gestures can be divided into symbolic and deictic gestures. The classical example of a static gesture with a symbolic meaning is a thumbs-up to communicate the information “everything is okay”.

In the IAD study presented above, deictic and kinemimetic gestures were used. For the tasks “music on” and “music off”, a deictic gesture with a static character was used, whereas the functions “next song”, “volume up”, and “volume down” were controlled using kinemimetic gestures. It is not currently possible to definitively conclude whether certain types of gesture are more useful than others based on the study conducted so far, as only a limited population of subjects was considered, and only one single deictic gesture was used for one specific function. Further research is required to substantiate any statements about the influence of the type of gesture on the efficiency of the control design, and thus before an answer can be given to research question 2 (“How many gestures are drivers capable of distinguishing, and how must these gestures be designed in order to achieve more efficient operation?”) To support the systematic development of an innovative control design based on touch-free gestures as an alternative to haptic control with complex menu structures, the IAD first compiled a comprehensive catalogue of gestures appropriate for use in vehicles. On the basis of this catalogue, the IAD is currently conducting further systematic research on the suitability of these various types of gesture while driving.

## 4 Creation of a gesture catalogue

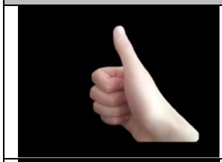
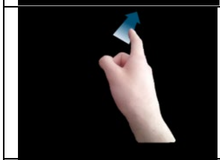
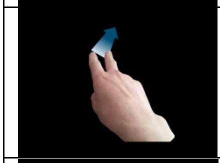
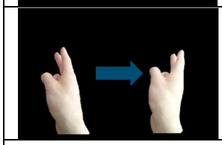
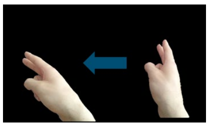
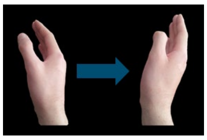
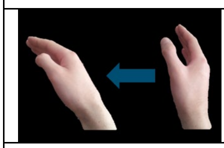
Both dynamic and static hand gestures were included in the compilation of this catalogue, which lists intuitive and differentiable gestures that can be used to operate various functions within a vehicle. Since one of the objectives of gesture control is to reduce distraction, only discrete gestures were used from the category of dynamic gestures, excluding any continuous gestures, which require continuous visual monitoring of the current system state. Within the category of discrete gestures, three subcategories are suitable for use while driving: symbolic, deictic, and kinemimetic gestures.

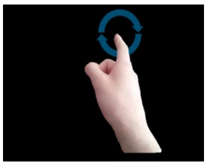
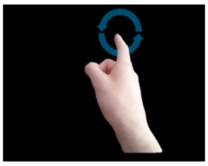
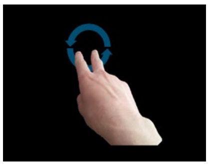
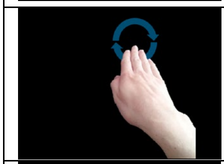
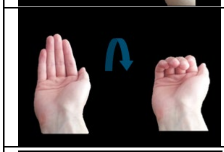
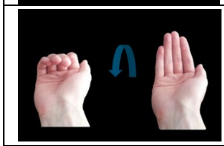
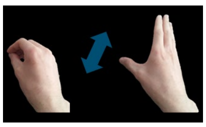
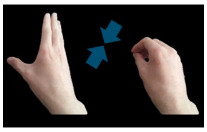
Each gesture included in the catalogue is designed so that it can be executed with one hand, with the other hand continuing to operate the steering wheel. Furthermore, potential user experience of gestures in other areas of application (e.g. smartphones or gaming) was taken into consideration. Starting from a basic gesture, additional gestures are obtained by executing this basic gesture in different directions, or changing the position of the hand and fingers. Hand and finger positions that were considered to be unnatural or overly complex, e.g. gestures with three spread-out fingers, were excluded from the catalogue.

As well as compiling a list of suitable gestures, control functions were suggested for each gesture. To do this, a selection of relevant vehicle functions was established by a workshop of experts. The primary selection criteria were the frequency with which the function is used while driving, and the typical arrangement of the controls corresponding to that function in the space spanned by the driver’s reach within the majority of vehicles. In order to create a positive user experience, assigning suitable gestures to each function and ensuring that these gestures are unambiguously distinguishable is critical. The gesture control associated with each individual function must be sensibly chosen within the context of the control design as a whole, and must be easy to integrate into existing vehicle operation.

Table 1 shows an excerpt from this gesture catalogue, listing a symbol, description, and classification for each gesture, as well as suggested example functions based on the expert survey.

**Table 1** Gesture catalogue (excerpt): Classification of gestures into categories and example functions

| Gesture symbol | Gesture description | Gesture category | Example functions |
|---|---|---|---|
|  | hand position (thumbs up) | symbolic | • general-purpose confirmation<br>• begin navigation |
|  | hand position (fist) | symbolic | • activate hazard warning system |
|  | hand position (spread thumb and little finger) | symbolic | • accept call<br>• initiate call |
|  | hand position (palm) | symbolic | • mute (phone/GPS) |
|  | pointing forwards with one finger | deictic | • radio on/off |
|  | pointing forwards with two fingers | deictic | • enter navigation destination |
|  | swipe right with two fingers | kinemimetic | • next radio station/song |
|  | swipe left with two fingers | kinemimetic | • previous radio station/song |
|  | swipe right with full hand | kinemimetic | • decline call<br>• next (saved) radio station |
|  | swipe left with full hand | kinemimetic | • previous (saved) radio station |
|  | swipe right with hand held flat | kinemimetic | • end navigation |

| | | | |
|---|---|---|---|
|  | clockwise circles with one finger | kinemimetic | • volume up |
|  | anticlockwise circles with one finger | kinemimetic | • volume down |
|  | clockwise circles with two fingers | kinemimetic | • temperature up (air conditioning) |
|  | anticlockwise circles with two fingers | kinemimetic | • temperature down (air conditioning) |
|  | clockwise circles with hand held flat | kinemimetic | • change media (radio/CD/USB) |
|  | anticlockwise circles with hand held flat | kinemimetic | • change media (radio/CD/USB) |
|  | close fingers or beckon | kinemimetic | • close sunroof |
|  | open fingers or reverse beckon | kinemimetic | • open sunroof |
|  | spread fingers | kinemimetic | • zoom in (navigation) |
|  | close fingers | kinemimetic | • zoom out (navigation) |

## 5 Summary & Outlook

The objective of this study is to evaluate the possibilities offered by touch-free gesture control when driving. The hope is to use gesture-based control to design human-machine interactions that are easy to implement because of their intuitive nature and which reduce visual and mental distraction for drivers.

After evaluating the selected gestures, the assumptions about distraction in terms of operating time and gaze aversion time were confirmed. The results of eye-motion analysis showed particularly clearly that visual distraction can be fully eliminated by gesture control. It was also shown that communicating information to the machine via gestures can significantly reduce the operating time compared to manual input controls. These measurements were further supported by the subjective impressions of the test subjects, who reported that they felt less distracted with most of the considered gestures.

In terms of the effect and influence of touch-free gesture control on driving, the advantages of gesture control over touch control were less clear. At first glance, this result seems contradictory, since both the operating time and the gaze aversion time were lower when executing gestures than when operating the controls by touch, and the deictic and kinemimetic gestures were perceived to be simple and intuitive.

The reason that the effect of gesture control on driving was less unambiguously positive when executing the gestures considered in this study may lie in the nature of these gestures, which could plausibly create motor and cognitive load, since they require two-handed coordination. In order to draw more detailed conclusions about the influence of different gestures on driving, further studies with more gestures are required.

Around half of the subjects felt that the gestures were not completely intuitive as a control design, which is not surprising, since the association of the gestures chosen from the gesture catalogue with control functions has not yet been evaluated by “normal drivers” (this is the subject of further research at the IAD). However, the overall effectiveness of touch-free gesture control was nonetheless perceived by the test subjects to be significantly better.

Based on the results obtained by evaluating the selected gestures, the use of touch-free gesture control while driving can clearly be recommended. Gestures, or at least those considered here, are intuitively understandable and easily distinguishable, enabling good usability to be achieved in human-machine interaction, and as such satisfy the requirement that the driver should benefit from their implementation.

The IAD is conducting further studies to determine the extent to which the potential applications of gesture control can be expanded without negative consequences on driver distraction. These studies will focus on the second research question (“How many gestures are drivers capable of distinguishing, and how must these gestures be designed in order to achieve more efficient operation?”). The previously developed gesture catalogue will serve as the basis for this research.

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