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Tracking down the intuitiveness of gesture interaction in the truck domain

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Abstract

Touchless hand gesture control potentially leads to a safer, more comfortable and more intuitive Human Vehicle Interaction (HVI)if relevant ergonomic requirements are met. To achieve intuitive interaction and thus to favor user acceptance, the gesture interface should be conform to user expectation and enable the users to apply their prior knowledge. This particularly concerns the gestures used for input. The conducted experiment investigateswhich gestures subjects tend to use for various functions of a truck and how these gestures are affected by the subjects' prior knowledge. In total, 17 potential functions were considered for this purpose. Within the experiment, 74 subjects performed gestures for each of these functions while being recorded on video. The video data showsa variety of gestures differing in hand pose, execution space, and palm orientation. Nevertheless, several interindividual similarities in gesturing can be observed, which made it possible to analyzethe gestures in terms of the prior knowledgeapplied. The results show thatgestures differ according to the sources of prior knowledge like culture and instincts. Depending on the function, the gestures observed within the experiment are based on gestures ofquasi-direct manipulation, emblematic gestures, instinctive gestures, standardized gestures and gestures expressing the users' mental model. However, the applicability of these gestures is limited by capabilities of gesture recognition and is depending on how the user interface will be designed.

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*Keywords:*Human Vehicle Interaction; Truck domain;Touchless hand gestures;Gesture control; Gesture interaction; Intuitivness; Prior knowledge

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1. Introduction

In recent years, much research work has been conducted concerning the application of touchless hand gesture control for automotive user interfaces [1]. By now, using hand gestures for Human Vehicle Interaction (HVI) is feasible and quite realistic due to the development of sensor technology and pattern recognition.Several OEMs already introduced prototypes and concept cars demonstrating that gesture control has reached the stage of practical applicability for in-vehicle secondary controls [2,3]. The potential advantagesofgesture control are numerous.By maximizing eyes-on-the-road and hands-on-the-wheel times [1], gesture control potentially reduces visual and mental distraction [4] and therefore leads to higher safety.Beyond that, gesture control could enable a more comfortable, natural input and a more intuitive interaction [4].

With regard to current concept cars, gesture interfaces are gaining relevance.However, the truck domain is rarely addressed by gesture research. But in the sense of ergonomics, trucks offer manifold possibilities for a reasonable application of gesture controls. First of all, the average truck driver spends much more time behind the steering wheel than the driver of a passenger car. As a consequence,truck drivers might domore input while driving.Thus, the advantages of gesture control concerning the above mentioned safety issues may bemuch more beneficial. Secondly, reachability and accessibility are more of concern regarding the dimensions that trucks have. This affects functions inside the truck, but also functions outside the truck, e.g. adjusting the roof spoiler or air suspension.Thirdly and particularly with regard to dirty environments trucks are partially run in, touchless hand gesture control helps to prevent the driver's hands getting dirty while e.g. handling closures on the outside of the truck.

When developing gesture control applications, various aspects have to be considered [5]. Regarding human factors, gesture-based interaction should be geared to characteristics that can be found within human-to-human communication [5]. Because users do not have a natural affinity for a “gestural language” [6], conformity with user expectations is of central importance. Ideally, gestures should already be familiarto the user (consciously or subconsciously) and should be retrieved easily. This will finally lead to an intuitive HVI and therefore favors user acceptance.

2. Theoretical background

According to Schmidt et al. [7], there are two main factors on the intuitiveness of gesture interaction: the context of use and the user's prior knowledge. The context is preset by the task the user has to perform and bythefunctionality of the truck. The user's prior knowledge,however,needs to be further investigated. In the first line, prior knowledge is decisive for the conformity with user expectations. It highly depends on the individual and includes the awareness of existing predefined standards. By enabling the user to applyprior knowledge by means of appropriate interface design, an intuitive interaction can be achieved.

Prior knowledgecan be specified more precisely by the continuum of knowledge [9]. According to this model, there are four different sources of prior knowledge (Fig. 1). On the lowest level of the continuum, there is the source of innate knowledge which is responsible for instinctive behavior. One level above, the sensorimotor knowledge is located. It is acquired through interaction with the world and e.g. applies to concepts of gravitation, speed and motion. The third level describes cultural knowledge, which depends on the culture an individual lives in. It may have an influence on how people approach technology. The uppermost level of knowledge finally is expertise, which is specialist knowledge acquired in one's profession. In addition to these four levels,there might be knowledge about using tools or technologies, which can be located on each of the latter three levels.

The frequency of encoding and knowledge retrieval is highest on the lowest level of the continuum, the level of innate knowledge. It decreases along the continuum, from sensorimotor knowledge over cultural knowledge unto the level of expertise. The further down the continuum, the more universal the knowledge and the larger the number of users potentially having this knowledge [9]. However, intuitive interaction can occur on each level of the continuum.

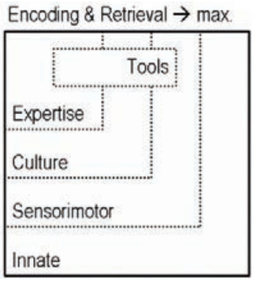

Fig. 1. Continuum of knowledge [9].

In the truck domain, standardized gestures already exist within human-to-human communication [8]. Most of these gestures are mainly used by persons assisting the driver in maneuvering or loading and unloading the truck. Therefore it can be assumed that truck drivers are aware of such gestures and have specific knowledge which is probablylocated on the level of expertise. This expertise as well as additional occupational knowledge may affect user expectations on gesture control and thusmay have an impact on the intuitiveness of gestural HVI in trucks.

The following experiment investigates, if truck drivers have particular user expectations on gestures used for gesture control applications intrucks. By gathering and analyzing gestures for a variety of potentialfunctions, it is examined, which levels of prior knowledge aredecisive for user expectations andthe intuitiveness of gesture-based interaction, and how these levels of prior knowledge differ according to profession, cultural background and age.

3. Methodology

The experiment is guided by the procedure proposed by Nielsen et al. [10] for finding an appropriate set of gestures when developing a gesture interface. Such a set of gestures also can becalled “gesture vocabulary” [10]. The procedure originally consists of four steps [10]:Finding functions, collecting gestures from the user domain, extractingthe gesture vocabulary, and benchmarking the chosen gesture vocabulary.

Finding relevant functions will be the first step when developing gesture control applications. For this study,17potential functions are taken into account (Table 1). The authors agree with otherresearch work pointing out that the size of the gesture vocabulary should be as small as possible [4,10]. However, developing anexplicit gesture interface is not the ultimate objective of this study.So, for this particular experiment, the amount of functions was intentionally set rather high in order to collect many, potentially different gestures.

Since no gesture interface has to be developed, the extraction and benchmarking of the gesture vocabulary will not be part of this study. Instead, the focus lies on collecting gestures and analyzing them with regard to the levels of prior knowledge. In order to allow comparison, not only truck drivers were taken into accountfor this experiment, but also personsnot having a link to the truck domain and persons with different cultural background. The following subsections will describe the conducted experiment in detail.

Table 1. Function commands.

Truck cabin	Infotainment	Audio	Navigation
open window	confirm	next title	zoom in
close window	cancel	previous title	zoom out
light on	more	volume up	move map to the left
light off	less	volume down	
answer phone call			
reject phone call			

3.1. Subjects

Altogether85 subjects took part in this experiment. In order to achieve homogeneous groups regarding cultural background (on the basis of nationality), eight subjects were excluded from further dataanalysis. Additionally, three subjects had to be excluded due to corrupt video data, so results finally are based on 74 subjects. On the basis of age, profession, and nationality, subjects were divided into four groups. Table 2 describes these four groups in detail.

Table 2.Subject groups along with sample size and age.

		Age			
Group	Sample size	Mean	SD	Min.	Max.
Truck drivers, German	15	48.5	12.8	28	65
Germans, age ≥ 30 years	13	40.0	12.3	30	63
Germans, age < 30 years	31	22.1	2.8	17	28
Chinese	15	24.9	2.5	20	31

The percentage of women within the sample is 17.6%, 69 subjects (93.2%) are right-handed. 32test persons (43.2%) have experience with gesture control in the field of consumer electronics, especially in the field of gaming consoles. 17 of these persons are within the group of Germans younger than 30 years, eight within the group of Chinese. Oneperson even states that she is familiar with gesture-based HVI. However, only 15 subjects (20.3%) are aware of established gesturesbeing used for assisting the driver when maneuvering a vehicle. Six of these persons are truck drivers. All truck drivers are holding their driver’s license for at least five years and for 26.0 years on average (SD = 12.8 years).

Subjects were acquired randomly at the campus of the TechnischeUniversitätMünchen and at a highway service area near Munich. All subjects participated on a voluntary basis and didnot receive any reward for participation.

3.2. Experimentalprocedure

During the experiment, the subject saton the driver’s seat of a MAN TGX truckwherethe function commands shown in Table 1 were presented to the subject. For this purpose, a screen was mounted behind the steering wheel displayingwritten function commands in a random order.Subjects were instructed to perform a gesture for each function command. They were told to spontaneously perform the first gesture that comes to their mind as soon as they read the current command. While performing gestures, subjects were recorded via video camera. In order to enable unambiguous and fast comprehension, function commands presented to the Chinese subjects were written in Chinese characters. Subjects were told to use only one hand when gesturing, as gestures later are intended to be performed whilst driving.Before starting with the first function command,the numbers 1 to 5 were presented to the subjects. Subjects performed gestures for these numbersin order to get familiar with gesturing and to reduce their potential inhibitions in gesturing.

3.3. Data acquisition and processing

At the beginning of the experiment, subjects filled in a questionnaire. Apart from socio-demographic data,subjects were asked about their driving experience with passenger cars and trucks,as well astheir familiarity with the above mentioned gestures for assisting the driver when maneuvering. Additionally, regarding subjects’ technical affinity, subjects were asked which electronic mobile devices they use frequently, how muchexperience they havewith touch-based interaction and which gesture-controlled devices they used previously.

Gestures performed by the subjects were recorded with two video cameras.Onecamera was positioned at breast height and was adjusted frontally towards the subject, whilethe second camera also recorded subjectsfrom the front, but was positioned higher than the firstone.

After recording all gestures, a second questionnaire was handed out to the subjects. In this questionnaire, subjects had to answer how easy it was for them in general to find gestures for the function commands, as well as which functions in particular were especially easy or hard to find an adequate gesture for. Furthermore, they were asked which functions they would notapply a gesture for and which other functions not being part of the experiment they would like to apply a gesture for. Beyond that, subjects rated the importance of the following aspects:

- Application of gestures which can be learnedquickly
- Enabling the users to applytheir own gestures
- Application of a gesture recognition which is error tolerant
- Application of gestures which arecountry-specific
- Application of gestures which are consistent across different applications

Based on the taxonomy for describing gestures used by Zobl et al. [11], each gesture shown in the video datawas described qualitatively by the following properties:

- Use of left or right hand
- Occurrence of motion [11] and main link of motion [11]
- Pose of hand (if dynamic, both at the beginning and at the end of motion)
- Direction of palm and fingertips (if dynamic, both at the beginning and at the end of motion)
- Execution space [11] and direction of motion

4. Results

This section describes the most frequently used gestures for the function commands. Figure 2 shows the hand poses and theunderlying taxonomy used to describe these gestures.Numbers in brackets below indicate how many subjects statements are basedon.

The gesture mostly observed for the function *'truck cabin: open window'* is characterized by a 'flat hand' moving downwards (39) with the palm facing down at the end of the movement (37). This gesture occurred within every group, but shows interindividual differences regarding the direction of the palm at the beginning of the movement as well as the main link of motion, the execution space and the hand which was used. However, for this function the left hand was used more frequently than for all other functions. Apart from that, some subjects (4) pointed at the side window of the truck with the index finger and then moved the fingertip downwards. Other subjects (4) gestured in a similar way, but pointed towards the camera first instead of pointing at the side window. For the function *'truck cabin: close window'* subjects basically performed an opposing movement.

For the function *'truck cabin: light on'*, one gesture was frequently observed within each group. Characteristic of this gesture is an initial fist (29) that changes to the hand pose 'splayed out' (29). While within the group of older Germans the palm mainly faced down when performing this gesture (5), for most of the subjects within all other groups the palm was facing the camera (21). Regarding execution space, no distinct similarities could be found. For the function *'truck cabin: light off'*, basically an opposing movement was used starting with the hand pose 'splayed out' (24) and changing to a fist (17) or to the hand pose 'fox' (7). Other gestures for *'truck cabin: light off'*varied completely regarding hand pose, direction of movement, and orientation of the palm.

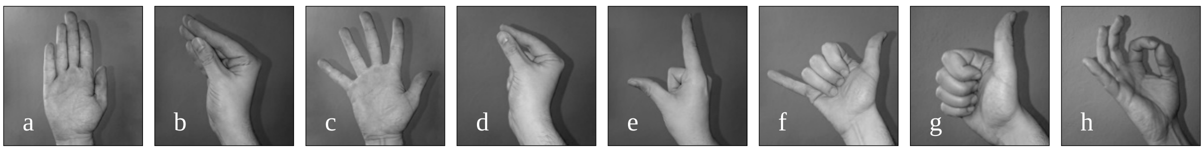

Fig. 2. Hand poses: (a) flat hand; (b) fox; (c) splayed out; (d) pinch closed; (e) pinch open; (f) phone; (g) thumb up; (h) okay.

Regarding the function *‘navigation: zoom in’*, the gesturemostfrequentlyused is characterized by an initial hand pose ‘fox’ (20),where the palm is facing the camera (20) and from where the fingers were moved into the hand pose ‘splayed out’ (20).Another gesture similar to this one is the so-called pinch-to-zoom gesture (11). Here,the initial hand pose was‘pinch closed’ (9), which then changed to ‘pinch open’ (9). Some subjects additionally used the middle finger (2) when performing this gesture. A third gesture that was observed frequently is characterized by a flat hand pose (10),the palm facing the subject(10) and the hand approaching subject’s upper body (10).When it came to the function *‘navigation: zoom out’*, in most cases subjects performed an opposing movement again.

The most frequently used hand pose for *‘navigation: move map to the left’*is ‘flat hand’ (38). In most cases, the hand was moved from right to left (30) after the palm faced the camera initially (26). Other subjects moved their hand in the same direction, but instead of a ‘flat hand’ they pointed towards the camera with their index finger (11).

For the function *‘infotainment: confirm’*, several gestures were observed. The most frequently used gesture was the static hand pose ‘thumb up’ (32), which interindividually differed in orientation of the palm and execution space. However, only a few Chinese (3) performed this gesture. Instead, the Chinese more often usedthe static hand pose ‘okay’ (5), which everyonediddirectly in front of the breast. Within other groups, the hand pose ‘okay’ occurred sporadically (3). Beyond that, also dynamic gestures were performed. The most frequently used dynamic gesture was a movement of the hand and an index finger pointing approximately in direction of the camera(10).

Gestures for the function *‘infotainment: cancel’* mainly came along with the hand pose ‘flat hand’ but differed in execution. Most subjects moved the hand laterally outwards while the palm faced down (26). Others gestured in a way in which the palm is facing forward at the end of the movement (13). In this case, however, the orientation of the hand at the beginning of the movementis interindividually different.

The gesture most often observed for the function *‘truck cabin: answer phone call’*is characterized by the hand pose ‘phone’ (40). In most cases, this gesture was static (37). The hand was mainly held at the side of the head (35) while the back of the hand faces the camera (28). Other subjects (4) used a fist instead of the hand pose ‘phone’ but also put the hand alongside the head. For the function *‘truck cabin: reject phone call’*, the gestures partially were similar to the gestures which were used for the function *‘infotainment: cancel’*. The gestures are characterized by the hand pose ‘flat hand’, where the palm faces the camera (5) or where the hand is moved laterally outwards (20). Other subjects gestured in different ways. Some subjects made use of the hand pose ‘phone’ (18) again but without any further distinct similarities.

Regarding the function *‘audio: next title’*, there are mainly two hand poses subjects used when gesturing. The first hand pose is ‘flat hand’ (29), while the second one is characterized by an outstretched index finger (23). Except for most of these gestures being dynamic, there are rarely any similarities that can be found. Indeed, most of the gestures showed a movement of the hand from the left to the right (21) or vice versa (15), but they vary extremely in orientation of the palm and main link of motion. The same was observed for the function *‘audio: previous title’*.

For the function *‘audio: volume up’* gestures differed a lot. Nevertheless, one gesture occurred relatively often in each group. It is characterized by the hand pose ‘flat hand’ (26) and by an upward movement (26). In most cases, the palm is facing up (12) or down (12). Gestures observed for *‘audio: volume down’*can be described by a downward movement (33) instead. Here, the palm is either facing down for the whole movement (12) or is first facing the camera before facing down afterwards(20).

Regarding the function *‘infotainment: more’*, gestures observed are mainly identic to the gestures described for *‘audio: volume up’*. These gesturesare characterized by an upward moving ‘flat hand’ (22) and a palm facing up (15) in most cases. Other gestures performed on this function are highly varying in hand pose, execution space and direction of movement. Gestures observed for the function *‘infotainment: less’* are mainly characterized by the hand pose ‘flat hand’, too, and a downward moving hand (30). Here, the palm faces down in most cases (26).

In total, the function *‘infotainment: more’* was the function the most people found the hardest to create a gesture for (14). On the contrary, the two functions it was easiest to find a gesture for are *‘truck cabin: open window’* (16) and *‘navigation: zoom in’* (16).In total, no subject rated finding gestures as very difficult. Instead, 71.6% of all subjects stated that this was easy (48) or even very easy (5). Finally, table 3 shows, how subjects on average rated the importance of diverse aspects concerning gesture-based interfaces.

Table 3. Aspects of gesture-based interfaces and their rating: 1 = very unimportant; 5 = very important

	Mean	SD
Application of gestures which can be learned quickly	4.50	.81
Enabling the users to apply their own gestures	2.86	1.12
Application of a gesture recognition which is error tolerant	4.33	.74
Application of gestures which are country-specific	3.01	1.36
Application of gestures which are consistent across different applications	3.90	1.22

5. Discussion

As Table 3 shows, the learnability of gestures is veryrelevant for user acceptance. This emphasizes once again, how important it is to chooseunderstandable gestures for the gesture vocabulary. In the context of this study, appropriate gestures are characterized by conformity to user expectations and thus by enabling the user to apply his prior knowledge. From this point of view, the gestures gathered within this experiment will be discussed.

The above described gestures for *‘truck cabin: open window’* and *‘truck cabin: close window’* all have in common that they indicate the desired movement of the side windowpane. Although some of these gestures differ in execution, the basic idea is to move the windowpane up or down in order to open or close the window. This requires knowledge of the operating principle of the side window, which is – regarding the continuum of knowledge – located at the level of cultural knowledge. Although cultural knowledge has certain specificity, in this case the required knowledge is very common in the addressed user domain andindependent of users’ nationality. So what finally can be observed is a quasi-direct manipulation of the windowpane while being in the know that the windowpane has to be moved down to open the window and vice versa. Similar facts seem to apply for *‘navigation: move map to the left’*. By moving the hand in the desired direction, a quasi-direct manipulation of the navigation map is intended. Generally, in this context speaking of quasi-direct manipulation means that actually there is no direct manipulation due to the spatial distance between the operating hand and the object being manipulated. But in fact, the spatial distance is bypassed by means of gesturing. As observed in the experiment, subjects refer to the object by pointing at it, virtually touching it with the palm or performing the gesture in spatial proximityto the object. The latter is shown for example by the fact, that subjects often used the left hand in order to open or close the side window on their left hand side.

The gestures observed for the function *‘infotainment: confirm’* can be divided into two groups of gestures. The first group consists of so-called emblematic gestures [6], which come along with the hand poses ‘thumb up’ and ‘okay’. These gestures vary between nationalities and are based on cultural knowledge. Within the experiment, emblematic gestures were performed relatively often, probably because they are used consciously [6]. But due to the fact that the observed hand poses can vary extremely in meaning dependent on the culture they are performed in [12], they are rather inappropriate for gesture-based HVI. The second group of gestures observed for *‘infotainment: confirm’* consists of pointing gestures with the index finger. In this context, these gestures might be an adequate alternative for emblematic gestures, as they derive from the level of innate knowledge. Already in early infancy, children point out objects of interest with the index finger. Later on –although being used subconsciously –pointing gestures still occur in human-to-human communication. So it is assumed that when applying this kind of gesture to an interface, intuitive interaction can be achieved quickly. This effect is also expected for those gestures observed for the function *‘infotainment: cancel’*, as they derive from the level of innate knowledge, too. Things that are unwanted are put aside by a correlative movement;somebody can be stopped nonverbally by a wave of the hand. As it can be seen from the function *‘truck cabin: reject phone call’*, these gestures can be applied generically, as subjects used the same gesture for *‘infotainment: cancel’* and *‘truck cabin: reject phone call’*.

For the function *‘truck cabin: answer phone call’*in most cases subjects imitated the movement of lifting a telephone handsetwhile the hand pose ‘phone’ expresses the shape of the handset. This hand pose is also used in sign language to express “telephone” [13]. Also the gesture observed for *‘truck cabin: light on’*, which consists of a fist changing into the hand pose ‘splayed out’, is used in sign language [13]. This gesture expresses “light” while the splayed out fingers are indicatinglight rays. Although sign language requires expertise, bothgestures seem to be very common. Due to their standardization in sign language, these gestures are probably known to the subjects from other contexts and are kept in mind (consciously or subconsciously) because of being very pictorial. Another standardized gesture is the pinch-to-zoom gesture, which is known from touch-based interaction. A three-dimensional interpretation of the pinch-to-zoom gesture might be the gesture observed for *'navigation: zoom in'*, where the hand pose 'fox' changes to 'splayed out'. Although this gesture derives from cultural knowledge in tools (e.g. smartphones with touchscreen) and is likely to favor intuitive interaction, it has to be considered that this gesture has to be unambiguously assigned to its function by the gesture recognition system. Especially when applied together with the above described gesture for *'truck cabin: light on'*, this will provoke errors in gesture recognition due to the gestures being too similar to each other.

The dominant characteristic of the gestures observed for *'infotainment: more/less'* and *'audio: volume up/down'* is the verticalmovement of the hand. This movement probably stems from the mental model of the user, in which an increase is represented by an upward movement,while a decrease is represented by a downward movement. However, regarding the intuitiveness of gesture interaction, it is not only the mental model of the user which is decisive, but also how the mental model is supported by the design of the interface. This is shown by the gestures performed for the function *'audio: next title'*. According to the mental model – which is dependent on culture – the next title is located on the right side of the current title, as often indicated by the arrow symbol on buttons of CD players or audio devices. Consequently, some subjects performed a movement of their hand to the rightand/or pointed with the finger to the right. In contrast, other subjects wiped their hand to the left, probably having a Cover Flow interface in mind, which they might know from touch-based interaction on mobile devices. Although these subjects all have the same mental model, they performed completely opposing gestures.

In summary, it can be stated that the gestures observed within the experiment derive from different sources of prior knowledge. However,it seems thatthe decisive factor for intuitive gesture interaction is not the level of prior knowledge per se. It is more likely that in this context user expectations in gestures are affected by the awareness of a particular operating principle or interface design, or by the existence of standardized or predefined gestures. Anyway, regardinggestures whichtruck drivers performed, an application of occupational knowledge or expertise could not be observed.As a next step, functions outside the truck will be taken into consideration.

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