Innovative and Contact-free Natural User Interaction with Cars

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Abstract: Within the last two decades, the vehicle industry has majorly changed the way humans interact with cars and their embedded systems that provide aid and convenience for the passengers. Today, instead of using the ordinary physical button for each function, cars have multifunctional control devices with hierarchical menus, which demands the visual attention of the driver and also, they are getting progressively complex.

In our approach, we introduce a contact-free, multimodal interaction system for automobiles to make interactions more natural, attractive, and intuitive. We designed an interactive car driving simulation in which various car functions such as radio, windows, mirror, and cabin lights were integrated. They are controlled by a combination of speech, natural gestures, and exploiting the visibility of objects in the car. This yields a heavily decrease in visual demand and improves robustness and user experience.

Keywords: Natural user interaction; automotive user interfaces; gesture based interaction; speech based interaction.

1 Introduction

In the past 20 years, the car industry has majorly changed the way humans interact with vehicles and their embedded systems that provide aid and convenience for the passengers. Cars are more than the individual means of transport; Many people value their cars as personal spaces and they spend significant time in their cars while commuting to work. Besides the functionalities offered to operate and drive the car, vehicles have become a place for information access, communications, media consumption, and personal entertainment. Many users have become accustomed to these technologies and they do not want to miss them while driving. As most of the technology in the car is digital, cars have become interactive spaces and human factors play a central role in their design and the resulting user experience [SDKS10].

Overall, we see that these developments are an exciting trend: on one hand complex and difficult tasks are taken over by technologies and ease the primary driving task for the user. On the other hand, we see that new interaction needs arise from the use of mobile and embedded technologies in the automotive context [SDKS10]. For drivers, this means a trend towards more complicated devices that leads them away from the driving, i.e., primary task. These distractions significantly slower reaction times, made more eye movements away from the roadway and may cause car accident [LCH13]. This was one of the important motivations for this work to design a novel method to make the interaction with certain main functions of the car naturally and more intuitively to cause a less cognitive load for the driver's brain. We felt this change would make the drivers concentrate on the road better, hence it could reduce the fatal accidents. Furthermore, the driver and the task of driving should not be the only focusing for car design, but it needs to create positive experiences for drivers and passengers as well. Thus, the driver assistance systems should be designed to empower human capabilities and maintain "the joy of driving", rather than as a means to provide assistance or help [KHL+12]. This fact motivates us to design new contact-free interactions and user experiences with the functions of the car, more attractive and interesting without touching of the components.

In this paper, we implemented a simulation software which user can naturally interact with. Trying to make it as natural as possible, we aim to use devices that user doesn't need to touch or wear. We designed a 3D car model in a way that user can interact with different parts of it such as mirrors, windows, radio, etc. Through our research, we performed user studies in order to evaluate system performance alongside its user experience by doing quantitative analysis on data.

Figure 1: Operating the simulator. **On the left** user is driving in the simulator in debug mode. **On the right** user is interacting with the system while wearing the Oculus Rift.

2 Related Work

Cars are no longer mainly mechanical objects, rather they are complex computer systems with very particular input and output devices, and mobile functionality [TBK06]. So far, using physical buttons is the most common way to use these functions, however, the number of these control buttons must be limited.

As one solution, the car industry has tried to map the direct interaction devices down to a single multifunctional controller and a hierarchical menu structure. For instance, BMW iDrive [NDEK09], Audi MMI and Mercedes COMMAND APS are controllers that provide access to most of the functions in a unified way. This approach has been adopted from the computer domain [TBK06].

Several prototypes of the in-car systems have been proposed by researchers. In the Bullseye system [WKL12], input gestures can be made by the driver without regard to the widgets' location and he can interact with the in-car touchscreen without gazing into it to find out the exact location of the items which causes less distraction in comparison to the currently existing systems.

To reduce the driver's distraction, several solutions are pointed out by Pfleging et al. [PSS12]. They deployed an eye-tracker, which supports highlighting of the last gaze position and detects the driver's attention between the real world and the interaction with a screen in the car. That way, they could reduce the time for the attention switch. Also, they reduced the required visual attention by mounting a multitouch screen on the steering wheel [PSS12].

Asif et al. [AHB10] described a tactile information presentation in the car. They mounted vibration actuators into a belt (or probably later integrated into a seat belt) to transmit vibration patterns to driver to declare directional instructions from the navigation system. They use vibration patterns and reports differences in user preference and the measured performance of the information transmission.

With the recent advances in technology, car drivers, nowadays, are offered with a wide variety of in-vehicle systems, i.e., route guidance systems, climate controls, music players. Based on the several research studies, interacting with such in-vehicle systems, while driving highly challenges drivers' attention on the primary task of driving [JST+08, Gre04, LBCK04] and the majority of available application programs requires extensive learning periods and adaptation by the user to a high degree [AMS+01].

Based on Jæger et al. [JST+08], the aim of designing Natural User Interaction metaphors, is to plan a novel interaction structure based on gestures in which no button is touched. Besides gestures, the use of speech input provides a more robust interaction detection and also an interesting alternative for people with certain disabilities [MALR04]. We used speech synthesis, e.g., text to speech [MAR+01] and some colour indicators to show the user the state of interaction and provide system feedback.

Miller's law [Mil56] reveals that the working memory allows remembering only five to nine numbers. Thus, LaViola et al. [LK11] presume that the number of created gestures that one can remember could be around seven [JPF13]. Despite the constraints mentioned above, the operation concept should, as far as possible, be generic, easy to learn as well as interactively explorable, and, above all, intuitive [MAR+01].

Freehand gestures have not yet incorporated in the car industry for the sake of few issues. One of the problems is the ambiguity; in order to trigger a function, an activation gesture is required to prevent non-intended input. Furthermore, in most use cases, gestures induce an abstract function matching so the user needs to learn how to perform a specific action to trigger a function [BR12].

2.1 Our Interaction Design

Since humans have a tendency to talk to machines [Gra03] as a natural communication way, we proposed a combination of visual and auditory input and output ways for a more robust and natural communication between the car and the driver. As input channel, freehand gestures [MEMS11] with single hand, was used so that the driver has no physical tactility to the controls while driving with the other hand. Also speech recognition was used as supplementary input with no ordinary push-to-talk button in the way that it always listens to what the driver says and is waiting for the driver's command keyword.

Using hand gestures was the key feature in our metaphors, giving the driver a new form to interact. Based on Pavlovic et al. [PSH97] the use of hand gestures provides an attractive alternative to cumbersome interface devices for human-computer interaction (HCI). Given the advancements towards self-driving, it is more than likely that self-driven cars would be the new way of travelling. When the user is free of the driving task, he could find using our defined gestures more attractive and more natural.

At the point of output, we claim that a natural visual presentation requires a seamless integration of displays into their environment [BR12]. Therefore, head-up display was used to render virtual contents, and the vehicle's state directly on the windshield. Considering that, if displayed virtual information occludes imminent information from the real world, or if the driver's perception is reduced due to too much virtual information, the driver's recognition of danger is reduced [TBK06].

3 System Design and Architecture

First of all, we decided to use Unity game engine because it covers most our needs such as supporting different I/O devices (Oculus Rift, Kinect, Leap Motion), multiple programming languages, network connectivity, being cross platform, etc.

We combine various input devices to get a superior motion capture accuracy which is crucial for using interaction metaphors. We used a Kinect for skeleton tracking, Leap Motions for hand posture and gesture detection and microphone with Google speech recognition API. Our overall system has a modular design. By using a middleware software, all components are able to send and receive messages to each other over the network.

Steering-wheel buttons were used to provide an alternative and middleware-independent way of performing the specified interactions for testing purposes to provide an approximated comparison between natural and conventional interactions (see Fig. 2). The middleware

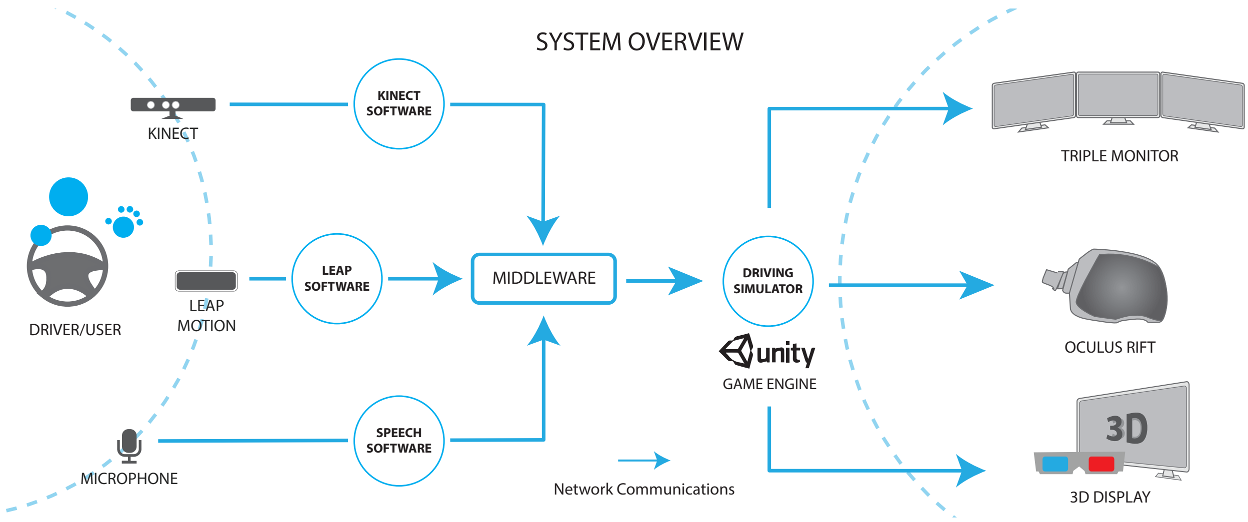

Figure 2: Overview of our virtual environment system components. The driver interacts with the input devices on the left. The middleware is an intermediatory component between input devices and the game engine. The game engine renders the simulator environment to the output devices on the right.

application is developed as the centerpiece of the distributed system. It acts as an abstract middle layer that hides detail about input/output device and their applications from the game engine. It derives the interaction metaphors from received data and forwards the proper response. It is modular and configurable, i.e., in order to change the metaphors, we can alter the rules of the configuration file without recompiling the application.

We used off-the-shelf Kinect device in order to fulfill hand tracking, swipe gesture recognition, and hands pointing. We also used Leap Motion controller to perform a precise grab detection by tracking hand finger. A microphone was used to retrieve user's voice in order to recognize the voice commands.

We simulated the environment using Unity v4.2 engine as a racing game, containing the streets of University of Bremen's campus as the racetrack. to mimic the real world traffic, we added several AI cars into the scene and the collision handling between all the cars.

As the system output, three types of devices were used in different contexts. By putting the Oculus Rift - Virtual Reality 3D headset on, users can get fully immersed in the simulation environment. Apart from that, system can support a triple monitor display to provide a super wide field of view for the user in the car. Additionally, our system can be displayed on a 3D TV.

4 Interaction Metaphors

Generally, there are two significant groups of devices inside a car: primary and secondary. The primary devices are the ones that influence directly the heading and speed of the car including usually steering wheel and brake pedals. Interacting with these devices constitutes an adequately complex primary task that requires considerable amount of mental load. Therefore, they must be directly mapped from the real world into our driving simulator environment by using the regular gaming steering wheel device with pedals. Additionally, such primary devices must generate immediate feedback whenever they are used in a way that user feels driving in a real car with rather exact measures, e.g., rotation of the steering wheel transforms directly and uniformly into car rotation and virtual steering wheel.

The secondary tasks are not associated directly to the driving and are mandatory to keep the safety of the car. Therefore, direct access should be granted, but not as direct as for primary controls. In that case, there are more possibilities to design natural interactions to perform them. Due to the safety issues, designing secondary in-car interaction systems have to be extremely user-centred [TBK06].

These input devices cannot request drivers to use both hands at the same time in order to interact with them, since at least, one hand must be on the steering wheel while driving. So, all input devices that require both hands, such as two handed joysticks and tablet computers, are not acceptable. Furthermore, additional input equipment such as data gloves or ring mice are not suitable to do the interaction while driving.

In addition, they should require as little visual attention as possible and should not require an explicit learning phase. As a result, only limited cognitive and motor capabilities are available for the interaction task and should cause minimal distraction from the driving task.

In order to display the interaction feedback and information to the driver, we decided to show information on the windshield using head-up display (HUD) technology. Yet, it also brings new questions concerning the safety problems such as cognitive capture, cognitive tunneling [Tuf97] and its element design demands specific principles [HCTH13]. The importance of HUDs in cars will grow significantly, as soon as it is technically feasible to project large amounts of information in high resolution onto the windshield.

Speech input could be a proper interaction type in the car since it does not need visual distraction. However, it has its own drawbacks. Even though it only uses non-visual channel, users need a feedback to know whether the system understands their voice command or not [Eck13]. In addition, speech recognition systems are not completely accurate, also, they are sensitive to background noise and people accents. We decided to integrate voice commands into our interactions as well as hand gestures, to create a multimodal approach and gain more accuracy and less false positives while they are being used together.

Since using natural interaction has become a new concept in the vehicle industry, we proposed and developed novel natural user interaction metaphor that can be used in the future in cars. To do so, we avoided using the buttons, any artificial or unnatural element for interaction. Besides, the interactions should be easily understandable and useable, minimize the cognitive load of the driver, enhance the driving experience and be intuitive.

The interactions are derived from how we commonly interact within our environment in daily life. For example, we point at an object to show our interest, then we grab it and interact with it. Considering that, no learning phase is needed for the users they can interact with car components in a freehand way.

All the interactions are backed by the visual and audio feedback to notify the driver, the current state of the system. A timeout function with configurable time length is applied in order to overcome staying in an interaction and end it.

While gestures are prone to various problems like the "Gorilla Arm Syndrome", our metaphors avoids such problems. They are short, do not require continuous interaction and shun long interaction time.

4.1 Proposed Metaphors

We chose four common secondary interactions in the car by taking limitation of time and present technology into account:

(a). Radio/music player: Interaction begins by pointing at the car radio/music player for two seconds. Doing the grasp gesture with one hand and moving it up or down will increases or decreases the volume. Likewise, moving the hand to left or right will go to previous or next track. Opening the hand indicates the end of the interaction (see Fig. 3). User has to use the speech commands to pause or play the music.

(b). Three mirrors in car: Interaction begins by pointing at the target mirror (rear, left or right mirror) and using mirror's name as voice command to select it. In order to make the mirror follow user's hand movements (s)he should grasp and move the hand up or down and left or right. The mirror will rotate to the corresponding directions. The interaction ends by opening the hand.

(c). Two windows: Likewise, interaction triggers by pointing at left or right windows, saying their name, doing the grasp gesture and pulling the hand up or down. It will pull the windows up or down. The interaction ends by opening the fist.

(d). cabin light: The voice command "cabin light on" will turn the light on, and for turning it off user has to say "cabin light off".

Due to the limitations of the first generation Kinect, we used Leap Motion to achieve a sufficient finger tracking accuracy which is crucial for grasp and fist opening detection.

4.2 Interface For Natural User Feedback

The human machine interaction occurs in the "medium" user interface. It should be fluid, iterative [Nie93] and its learning curve should be as less as possible to make it natural to the

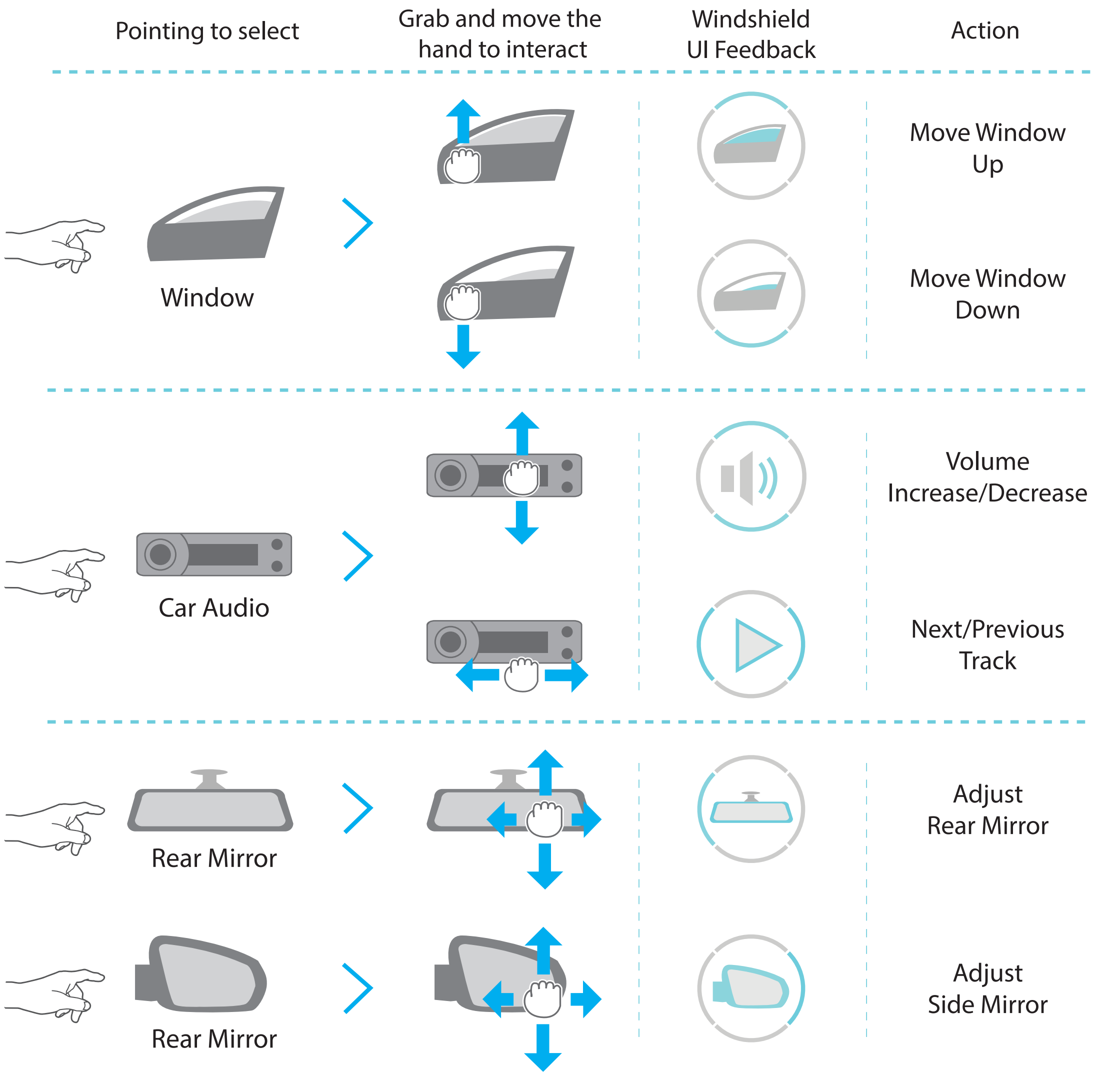

Figure 3: Our interaction metaphors with the corresponding UI feedback

user. Therefore, user interface design is a matter of compromise and trade off [May99] and making every user satisfy with the design is far fetched.

The user interface should be simple, adaptable and provide an overview of all ongoing interactions. Additionally, it is important to group and arrange the interface elements according to their function such that the cognitive load is minimized while retaining all necessary information in front of the user [HN07].

The aim of the UI is to provide a visual feedback of the ongoing interactions to the driver. We found out that the optimum position of the GUI elements is the centre of the windshield above the steering wheel. The design must be minimalistic in a way that it does not obstruct the driver's main line of sight.

The proposed UI involves a circular layout. The currently selected object located in the center and the interactions mapped around it in four quadrants of the circle's border representing the four possible interaction directions. When we point to the object, both the object icon and the circle are first made semi-transparent in gray becoming selected, it turns to a futuristic blue with increased opacity.

We chose only the required parts of the information system to be displayed such as speedometer which is always there, and various warning signs and current shift notifications that appear for a certain amount of time. We also integrated navigation, which is displayed right above the speedometer and a text base direction guidance system to the UI.

5 User Studies

For our user studies we used a PC with an Intel Core i7 4770 CPU, Nvidia GeForce 780 GTX, and Windows 7 64-bit. In order to have a comparison between natural and unnatural interactions, we used a steering wheel with control buttons. Two Leap Motions on each sides of the steering wheel, one Kinect on top and a microphone in front of the user act as input devices for our system. We used three displays to have wide view and enough freedom for users to interact with different virtual in-car components such as mirrors, windows, music player, and cabin light (see Fig. 4). We also used in game sounds such as car feedback and music tracks. We planned to use Oculus Rift too, but as some users felt dizzy during tests, we skipped it. We like to conduct a user study with Oculus Rift V2, as most of the problems are resolved, claimed by its developer. To evaluating the system, volunteer students with

Figure 4: Experimental hardware setup that was used for prototyping.

driving experience were asked to try it. Sex, age and their experience in working with devices such as Leap Motion and Kinect were considered, as it may result in different feedback from users. Everyone had previous experience with computer games. The testing group consists of 14 users, 11 males and 3 females. Each user performed 3 different interactions with the system, both by using natural interaction (NUI) and conventional, unnatural interactions (UNUI). For UNUI's, each action is performed by pressing a button. At the end there were totally 42 tasks for NUI and UNUI methods.

Each person had to follow a few steps in order to complete the evaluating tasks. At first, a tutorial video was shown. In the video, user got used to the devices, technology and how to interact with them. Following this, the user tried the system in order to get familiar with the environment and clarify any misunderstanding of how the system functions. Once training is done, the user is asked to perform the actual test. The whole process of the user interacting with the system, as well as in-game action was recorded for further analysis. The user was asked to perform 4 different scenarios; each of them consisted of three acts triggered by voice command from user for both NUI and UNUI methods.

After system testing is finished, participants will be asked to fill out a questionnaire to get user's feedback on usability, cognitive load and distraction. At the end, video footages of in-game driving and interactions were reviewed.

There were totally 6 collisions done by users; two of them happened while user tried to interact with the car in the natural way (NUI). This number is 4 when users used steering wheel buttons for interacting (UNUI). By collision we mean hitting the other cars or the road edges. Sometimes it happened that system recognized interaction as false positive. Interestingly, the amount of false positives for NUI method is 3 times compared to UNUI which was 7 times. Also, it showed that the user needed to take her eyes off the road for about 1.0 seconds using NUI compared to 0.4 seconds for UNUI which.

	Collisions	Distraction time	False Positives
NUI	2	1.0 sec	3
UNUI	4	0.4 sec	7

Table 1. The results for collisions, distraction time and falsely recognized interactions for NUI and UNUI interactions.

Based on the User Experience Questionnaire (UEQ) [LSH06] we divided questions into six dimensions that are called *perspicuity*, *efficiency*, *dependability*, *stimulation*, *novelty*, and *attractiveness*. The questionnaire consists of twenty-five 7-point items with scores between -3 to +3 that measure the above-mentioned dimensions [LHS08]. By averaging all values from questions for respective dimension, we can do statistical analyses on the data.

As expected, the NUI method achieved good results in attractiveness and efficiency. It shows that users are eager to use natural interaction instead of the conventional ways, especially when they found how easy it makes the interacting. Based on the perspicuity, it's not clear enough for users how interactions work. In particular the Leap Motion needs some experience in order to get the best results. Users didn't find the system novel enough, something that was expected to be high. It may be due to the users' background because all of them were familiar with the technologies that we used and it wasn't novel enough to them. Stimulation is close to what we expected, as most of the users found the idea exciting. Figure 5 shows the final results of the questionnaire. Overall we achieved fairly well ratings for attractiveness and efficiency. In our opinion, the hardware limitation of input devices is the main reason for perspicuity, dependability and novelty being too low.

6 Conclusion and Future Work

This paper aimed to introduce contact-free multimodal interaction possibilities which could be equipped in automobiles for enhancing the interactions making it more natural, attractive and intuitive.

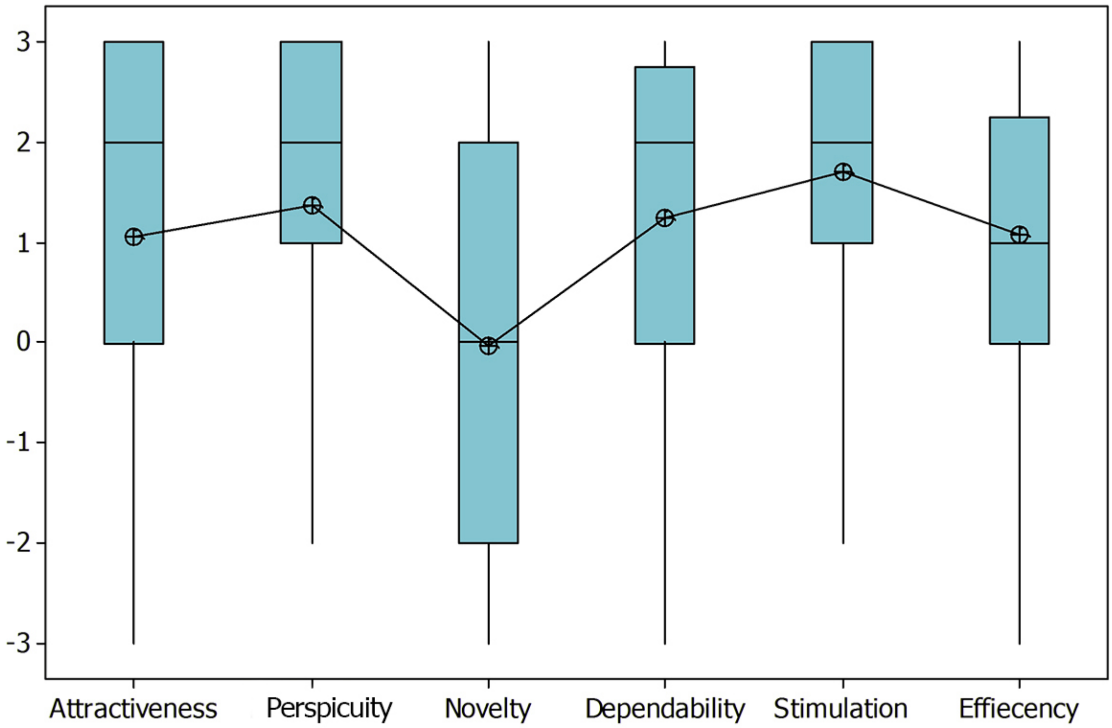

Figure 5: We observe a wide range in questionnaire answers about NUI; however, their aggregation is close to what we expect. Most of the users found our system attractive and easy to learn. Security and efficiency are lower, mostly due to hardware limitations. Though, we assume users familiarity with technologies such as Kinect, Leap Motion and similar systems, caused novelty to score less than other dimensions. In the graph the box shows Divergence, box inline shows Median and dots represent Mean values.

In this work an interactive car simulation game was designed using Unity game engine in which various car applications like radio, windows, mirror, and the cabin lights were designed to be controlled using gestures and voice interactions. We used a modular software architecture that allows us to combine a variant modules of different input and output devices. This also made our system very flexible for future interactions.

The proposed project was implemented using Microsoft Kinect for detecting pointing posture, Leap Motion for grab and swipes, Oculus Rift for enhancing the real gaming experience, and an Android application with Google API for detecting voice commands. We used certain distinct voice commands and gestures specific to certain interaction so that the system is more robust, and reduce the user confusions while using the gestures. The proposed prototype, turned out to be pretty satisfactory with respect to the goals set during the research sessions before the implementation. Though, we had certain setbacks due to working efficiency of certain devices used.

Refining current interactions to getting close to the goals and continued development of integrating more in-car features to the prototype, e.g., navigation system, handling and making phone calls and etc. Furthermore, we are interested to use integrating gaze detection technology to detect the driver's focus and adjust the intensity and the transparency of the visual contents displayed on the HUD. Another feature that we plan to implement in this project is the tracking user's head. Finally, we like to broaden our testing group, inviting people with different background to get our user study closer to an universal one.

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