Master’s Thesis

Czech Technical University in Prague

Faculty of Electrical Engineering
Department of Computer Graphics and Interaction

Multimodal interaction device for secondary tasks while driving

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Supervisor: doc. Ing. Zdeněk Míkovec, Ph.D.
Field of study: Open Informatics
Subfield: Human-Computer Interaction
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MASTER'S THESIS ASSIGNMENT

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II. Master's thesis details

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Multimodal interaction device for secondary tasks while driving

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Multimodální interakční zařízení pro sekundární úlohy při řízení vozidla

Guidelines:

Analyze scientific literature about multimodal interaction with car infotainment. Focus on the secondary tasks while driving (e.g., interaction with navigation system). Regarding the user group focus on older drivers. Design a multimodal device that will support fast drivers interaction while solving the secondary tasks. The design should focus on high reliability and speed of interaction with conversational in-car interface in stressful situations. According to User-Centered Design principles create a prototype and conduct at least 2 iterations of experiment with target user group which will check the validity of the design and help to get insights into the target group behavior.

Bibliography / sources:

Collet, C., Clarion, A., Morel, M., Chapon, A., & Petit, C. (2009). Physiological and behavioural changes associated to the management of secondary tasks while driving. Applied ergonomics, 40(6), 1041-1046.
Maciej, J., & Vollrath, M. (2009). Comparison of manual vs. speech-based interaction with in-vehicle information systems. Accident Analysis & Prevention, 41(5), 924-930.
Fofanova, J., & Vollrath, M. (2011). Distraction while driving: The case of older drivers. Transportation research part F: traffic psychology and behaviour, 14(6), 638-648.
Pfleging, B., Schneegass, S., & Schmidt, A. (2012, October). Multimodal interaction in the car: combining speech and gestures on the steering wheel. In Proceedings of the 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications (pp. 155-162). ACM.
Bjelkemyr, Anna & Dukic, Tania & Owens, Rachel & Falkmer, Torbjorn & Lee, Hoe. (2013). Support Systems Designed for Older Drivers to Achieve Safe and Comfortable Driving. Journal of Transportation Technologies. 03. 233-240. 10.4236/jtts.2013.34024.

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III. Assignment receipt

The student acknowledges that the master's thesis is an individual work. The student must produce his thesis without the assistance of others, with the exception of provided consultations. Within the master's thesis, the author must state the names of consultants and include a list of references.

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Date of assignment receipt

Student's signature

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Declaration

I hereby declare that I have written the thesis independently and I quoted all used sources of information in accord with Methodical instructions about ethical principles for writing academic theses.

Prague, January 7, 2020

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Abstract

The thesis focuses on multimodal interaction with car infotainment system, more specifically combining conversational interface with tactile/haptic controls while focusing on older drivers. The main objectives were to find out whether a touch-based controller would ease the interaction with conversational assistant in a car, especially in stressful situations, and design it.

The design was based on analysis of behaviour of older drivers while performing secondary tasks while driving such as navigation or making a phone call. Two iterations of both design and qualitative study were conducted to provide insight into needs and behaviour of older drivers and help to form a final prototype of the controller.

Keywords: older drivers, User-Centered design, multimodal interface, secondary tasks while driving

Supervisor: doc. Ing. Zdeněk Míkovec, Ph.D.

Abstrakt

Tato práce se zaměřuje na multimodální interakci s infotainment systémem v autě, konkrétně kombinací konverzačního rozhraní s taktilním/haptickým ovládáním se zaměřením na starší řidiče. Hlavními cíli bylo zjistit, jestli fyzický ovladač dokáže usnadnit interakci s konverzačním asistentem v autě, zejména ve stresových situacích, a navrhnout ho.

Návrh vznikl na základě analýzy chování starších řidičů při provádění sekundárních úkolů během řízení, jako je navigace nebo telefonování. Byly provedeny dvě iterace návrhu a kvalitativní studie k získání vhledu do potřeb a chování starších řidičů a utvoření finálního prototypu ovladače.

Klíčová slova: starší řidiči, User-Centered design, multimodální rozhraní, sekundární aktivity při řízení

Překlad názvu: Multimodální interakční zařízení pro sekundární úlohy při řízení vozidla

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Chapter 1

Introduction

In this chapter, the basic motivation behind this thesis is presented, the target group choice is justified and the main objectives are stated. Following chapters then consequently describe the analysis of the current state of the problem at hand, the design process of a solution and the progress of the experiment testing the solution with users which all lead to the final conclusions.

1.1 Motivation

Advances in automotive industry allow the car manufacturing companies to present new features to their customers every year. A lot of these features, bringing comfort and entertainment, are included in the in-vehicle infotainment systems, which are nowadays mostly controlled by a touch-screen in the vehicle. What could be wrong with such a system? As stated in [1], some tasks are less demanding with one mode of interaction than another (e.g., voice commands over touch-screen interactions to select music) and visual-manual interaction while driving should be avoided to prevent dangerous situations on the road. Therefore, if we don't want to stop the new features during the ride, we need to come up with an interface with different modalities.

But why are we focusing on older drivers in this project? According to [2], the projection for the year 2050 assume 15 % of world's population will be over 65 years up from 9 % now, moreover in more-developed countries, it will be 27 % up from 18 % now. And because of the advances also in medical fields, people will be able to actively drive a car longer. However, the one thing that can be stopping them, apparantly, is fear. In [3], it is revealed that what stops older people from driving are stressful situations. Creating an assistance system which would help the drivers in the difficult situations would consequently make driving more pleasant especially for older people and prolong the active driving time.

1.2 Main objectives

As hinted in the motivation, the main objective of this thesis is to design an interface for completing secondary tasks in a car. This interface should have different than visual modality to decrease the visual demand. Specifically, it would be a combination of voice and manual controls and the goal is to find out whether a touch-based controller would ease the interaction with the conversational assistant.

The target group for which the design is made and tested by are older drivers over 60 years of age.

Chapter 2

State of the Art

This chapter describes the analysis of State of the Art, i.e., current level of development in research related to the problem. In the first phase of this project, the focus was on analysis of existing concepts that would help to specify requirements of the follow-up design. That means studies about the behaviour of older drivers, advantages and disadvantages of voice control in the car and also comparison between voice and manual interaction.

Apart from studies from other research facilities, information gained from previous research at Department of Computer Graphics and Interaction was used, specifically modeling of conversational interface and research about the use of autonomous vehicles by older drivers.

2.1 Concept 1 - Support systems for older drivers

Described in “Support Systems Designed for Older Drivers to Achieve Safe and Comfortable Driving”.[3]

The goal of this study was to observe the behaviour of older drivers (65+ years old) and the reasons why they stop driving. The results were supposed to suggest a design for support systems to prolong the time of active driving.

2.1.1 Methodology

The study used the qualitative research method of focus groups (group discussion). 19 participants (active drivers over 65) were divided into 3 groups according to their mileage per year. The discussion consisted of two parts. In the first one, behavioural patterns of mobility participants were observed - how the drivers perceive their own driving limitations and whether they plan to stop driving in the future. In the second part, shorts clips of traffic in a city, on a main road and on a highway were viewed by the participants and they should discuss the traffic limitations and how support systems could help.

2.1.2 Results

Health problems aside, one of the main reasons why older people stop driving is stress and situations which are leading towards it. The study revealed that older drivers are avoiding driving at night, on highways, during bad weather conditions and rush hours. One of the stressful situations for them is also searching for a free parking space. They have a need to plan their journey to reduce the stress and couples often give advice to each other during difficult situations. The result of this study was that creating a support system which would help drivers in stressful situations to increase comfort and safety would prolong the active driving time of people.

2.2 Concept 2 - Distraction of older drivers

Described by the study “Distraction while driving: The case of older drivers”.[4]

The study was assessing the influence of age on driving abilities and compensation strategies of older drivers. The driving abilities were measured during the completion of secondary tasks.

2.2.1 Methodology

An experiment was conducted with 10 drivers aged between 60 and 73 years and 10 drivers aged between 31 and 44 years. The Lane Change Task method [5] was used for the evaluation of driving abilities. The method measures the decrease in driver's performance during the performance of secondary tasks in standardized manner. Participants of the experiment were instructed to change between 3 lanes in a driving simulator according to the instructions on the screen. The secondary task was "d2 attention test" [6], where characters "d" and "p" were displayed with a certain number of lines on a computer screen next to the participant. The task was to press one button when the letter "d" with two lines showed up and another button if something else showed up. The experiment was repeated one more time with a time limit for the secondary task. During the experiment, the deviation of the lateral position of the vehicle while staying in one lane and the reaction time for changing lanes were measured. Moreover, the precision of the secondary task and subjective evalution of participants were taken into account.

2.2.2 Results

The result of the study was the comparison between younger and older drivers. When staying in the same lane, bigger deviation of the lateral position of the vehicle was measured with the older drivers. The reaction time for changing the lane of both groups was comparable, which the authors attribute to older drivers focusing more on the primary task. Time pressure in the second experiment had no impact on the driving abilities but contributed to worse precision of the secondary task. However, without the time limit, the execution of the secondary task was slower.

2.3 Concept 3 - Multimodal interaction in the car

Described by "Multimodal interaction in the car: combining speech and gestures on the steering wheel".[7]

The authors of this study researched advantages and disadvantages of multimodal car interface combining voice control and gestures in comparison with solely manual control. Gestures were adding features missing in voice control (high granularity with immediate feedback and fast cancellation of actions).

2.3.1 Methodology

An experiment was conducted with 12 drivers aged from 20 to 39 years. The participants' task was to drive a vehicle in a simulation with two lanes and obstacles forcing to change the lane. During the driving, participants had also a secondary task consisting of three phases. In the first phase, two photographs of an object in an initial and final state were shown to the participants and they were supposed to name that object. If it wasn't precise, they should have rephrased their answer. In the second phase, they were instructed to suggest a gesture which would move the object from the initial to the final state. In this case, no feedback on their answer was given to them. In the third phase, the participants evaluated the difficulty of both naming the object and suggesting the gesture for it. Likert scale was used for the final evaluation.The influence of the secondary task on the driving was measured by a deviation during LCT[1] [5] and the feedback of participants was evaluated by SUS[2] and DALI[3] questionnaires.

2.3.2 Results

The results of the experiment indicated that multimodal interface is more difficult for the users and takes more time. However, it doesn't require as much visual attention. Driving capabilities are comparable in both cases.

2.4 Concept 4 - A comparative study of an in-car dialogue system

Described in the study "Speech, buttons or both? A comparative study of an in-car dialogue system".[8] In this project, 3 different interfaces for dialogue system were compared: voice control, graphic interface and multimodal interface.

[1]LCT - Lane change task
[2]SUS - System Usability Scale
[3]DALI - Driving Activity Load Index

2.4.1 Methodology

An experiment was conducted with 10 drivers from 27 to 53 years. None of them had experience with voice control in a car or a dialogue system. The participants were driving a vehicle in real traffic on a chosen route with several traffic lights and roundabouts. There were two secondary tasks for two different applications:

- Phone App
  - Call the contact “Staffan”
  - Add a contact “Elin” with number “118118” into the phone
- Logistics App
  - Ask the system to read the first instruction
  - Point out colleagues on a map

All the tasks were gradually achieved with all 3 interfaces. The participants were divided into 3 groups and each of them started with different interface to reduce bias. The head researcher who was present in the car demonstrated the first task and during the experiment he was giving advice to the participants in case they needed it. After, he evaluated the completion of tasks (OK without help, OK with minor help, OK with major help, OK with minor mistake, the task wasn’t completed) and the participants evaluated their own driving capabilities on Likert scale 1-10.

2.4.2 Results

Even though the graphic interface was the fastest and easiest to use, according to the participants, the driving capabilities were better with the use of voice and multimodal interface. The multimodal interface was overall preferred over the other two.

2.5 Concept 5 - Autonomous vehicles for older drivers

This project was done by four groups of students of the subfield Human-Computer Interaction at Faculty of electrical engineering at Czech Technical University in Prague in the winter semester 2018/2019. The students conducted qualitative research and then designed a prototype of an app for autonomous vehicle. The first part contained interviews with older respondents and provided crucial information about the problems and the needs of the specified target group.

2.5.1 Methodology

Interviews were conducted with four groups of approximately 10 people and the questions focused on life and habits related to transport and driving of the older (60+) respondents.

2.5.2 Results

The results of the interviews revealed that older drivers:

- have a problem with parking, it's difficult for them to find a parking space, especially in larger cities
- are afraid to drive at night, in winter or in bad weather
- don't want to drive fast
- prefer driving on small roads and villages
- are afraid of errors and crisis scenarios

2.6 Concept 6 - Modelling of the conversational assistant

In the winter semester of 2018/2019, a research project of Bc. Lukáš Chvátal (Model of conversational system for controlling secondary tasks while driving) was conducted at the Faculty of electrical engineering with the goal of designing a conversational car assistant and testing it with drivers over 60 years old.

2.6.1 Methodology

The primary task in the experiment testing the car assistant was an interaction with application which showed 3 cars from behind and depending on what lights were lit (for braking or turning), the participants were supposed to press a specific button. That represented driving. The secondary task was a conversation with the car assistant (controlled by the researcher using the method Wizard of Oz). Through this conversation, they were suppose to solve navigation problems and write a text message. The results of the experiment were qualitatively evaluated based on an post-interview with the participants.

2.6.2 Results

The most important information for the current thesis gained from the results was that it wasn't possible to accomplish certain tasks in a critical time, using the conversational assistant. This was one of the findings providing motivation for the design of a touch-based interface which would accompany the conversational assistant in a car.

2.7 Summary

The SOA[4] analysis revealed information about the target group - older drivers. They often stop actively driving too early because they are afraid of critical situations and are more distracted by secondary tasks in a car. That's why

[4]SOA - State of the Art

a conversational assistant, which would help in difficult situations and with managing secondary tasks, could reduce their fear of driving. Furthermore, the reasons for the use of the controller with different modality and its suggested characteristics were found. Multimodal interface combining conversational assistant and tactile/haptic controller would provide features missing in solely voice-based interface (high granularity, touch feedback and the immediate "undo" an actions) while minimising the visual attention needed for secondary tasks.

Chapter 3

Design

The chapter follows the design process of the tactile/haptic controller from setting up the design goals and use cases from the SOA analysis, through sketching and designing a low-fidelity prototype, to making a final high-fidelity prototype. Each of the prototypes were tested with users in an iteration of an experiment providing a qualitative study. Both iterations of the experiment are described in the following chapter 4.

3.1 Design goals

The SOA analysis provided motivation to create a tactile/haptic controller, which in combination with the conversational assistant would help to limit stress connected to driving, especially in critical situations. The focus was on features that voice control alone either doesn't allow or it is possible to offer more effective alternative, however, while preserving the low visual demand of the interface and easy learnability.

3.1.1 "Undo" an action

The studies focusing on habits and the behaviour of older drivers[3] [4] clearly stated that people are generally afraid of critical situations and errors which they can make as a result. While using only voice-based interaction, cancelling an action can take too long or not be intuitive. For that reason, one of the main design goals for the controller was to have a possibility to immediately cancel an action. If the driver (mainly in a critical situation) realises that the command he gave to the system was wrong, he should be immediately able to cancel it. That would reduce the impact of the error and fear and stress connected to it.

3.1.2 Confirmation/rejection

Voice control enables the user to easily confirm or reject suggested action by words(“yes”/”no”), nevertheless, in certain situations, the driver either can’t talk to the system or he simply doesn’t want to. That’s why it is suitable to offer an alternative. Also, this kind of confirmation provides more certainty than a voice-based interface, so it also contributes to reducing stress connected to solving secondary tasks.

3.1.3 Favorite action

In the previous research about modelling the conversational assistant was discovered during the experiment that solving a problem through a dialogue might not be efficient enough in time pressing situations. One of the design goals was therefore finding a way to speed up the conversation by skipping parts of the dialogue tree of the conversational assistant. The favorite action would work either that way that the driver would set his favorite suggestions for specific problems himself or the system could learn from experience.

3.1.4 High granularity

Voice-based interaction is not suitable for adjusting states on a scale (e.g. setting the volume, setting the temperature, adjusting the seat, rolling down the windows). Even though it is possible to combine simply commands like “increase volume” and “decrease volume”, the question is if a high precision can be achieved because of the delays between the user command, processing the command and the reaction from the system. The designed controller should therefore contain an element for touch/feel-based control of scalable states.

3.1.5 Touch/feel feedback

By using the voice-based conversational assistant, we are trying to limit the visual attention needed to interact with the system. The driver can then focus his eyes on the road. However, some information from the states, like the mentioned volume or temperature, can be difficult to express verbally. The controller should give feedback about these states. Second possible feedback (by vibration) is a reaction for any command given to the assistant, so that user can be sure whether the system have understood the command or not.

3.1.6 Ergonomics

The whole design should be ergonomic, which in this case means that the driver should be able to safely and comfortably drive, i.e. using the steering wheel, reaching the pedals and changing the gears, and at the same time comfortably using the controller. It was necessary to think about the physical characteristics of the controller such as size, shape and location of the controller, and number, type, size and shape of elements of specific elements and mapping the features on them. At the same time, the differences between drivers had to be taken into an account and therefore design should be universal or adjustable solution.

3.1.7 Learnability

If the controller wasn't easy to use, the previous goals would also not be achieved. That's the reason why the design should be simple while fulfilling all previous design goals. It is also important to clearly differentiate specific features, specially the opposing ones - confirmation/rejection, so they would be hard to interchange.

3.2 Use cases

Considered use cases were focused on the interaction with the navigation system in the car combined with vehicle status. They were chosen to contain the possible advantages of the tactile/haptic controller over voice-based interaction - specifically the possibility to cancel an action, go to a favorite action and dealing with information on a scale.

For better illustration of how the controller could be helpful in certain situations, there is a scenario for each use case. Tasks in the use cases are decomposed into subtasks in the Hierarchical Task Analysis (HTA) which provides better understading of single steps.

3.2.1 Use case 1

System informs the driver about the change in the vehicle status (e.g. amount of fuel). The driver can decide to give a specific verbal command to solve a possible problem (e.g. start a navigation to nearby petrol station) or use the favorite action feature to let the system suggest a solution for him.

Scenario

François is a 75-year-old widower who every weekend in the summer drives to his cottage in the mountains to escape the city rush. In the middle of his traditional route, the system informs him that the fuel may not be enough for the journey back home. François is unsure of what exactly it means but by feeling a small lever on the controller, he immediately knows how much fuel he has exactly. Then, he presses a button twice, and the system knows him so well it knows he wants to start a navigation to Benzina petrol station because he has their loyalty card. He's glad he didn't have to have a long conversation with the system about it because he just wants to listen to his favorite jazz radio station.

Hierarchical Task Analysis (HTA)

Plans defining the execution of the task in the HTA in Figure 3.1:

Plan 1: 1.1. – 2.1. – 3. – 3.1. - 4

Plan 2: 1.1. – 2.1. – 3. – 3.2.

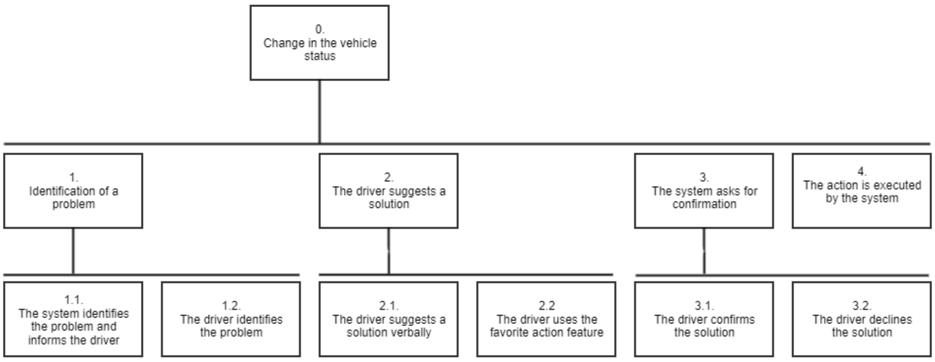

Figure 3.1: HTA of Use case 1

Plan 3: 1.1. – 2.2. – 3. – 3.1. - 4

Plan 4: 1.1. – 2.2. – 3. – 3.2.

Plan 5: 1.2 – 2.1. - 3. - 3.1. - 4

Plan 6: 1.2 – 2.1. - 3. - 3.2.

3.2.2 Use case 2

The driver gives the system a command (start a navigation to a specific place). Then, he can change his mind and cancel the command.

Scenario

Meg, 80-year-old grandmother, decided to take her three grandchildren to the zoo. The children are screaming and fighting since the moment they entered her car. However, when the car passes by a sign pointing to a nearby McDonald's, the kids turn their attention towards their grandmother and demand going there immediately. The car just arrives at a crossroad with traffic lights and Meg, trying to calm down their grandchildren, gives the system the command to navigate to a nearest McDonald's. She stops the car because of a red traffic light. Then, unfortunately, she realises that she is in the wrong lane to turn towards the restaurant. She is unsure of what to do and cars behind her start to honk, because the light already turned green.

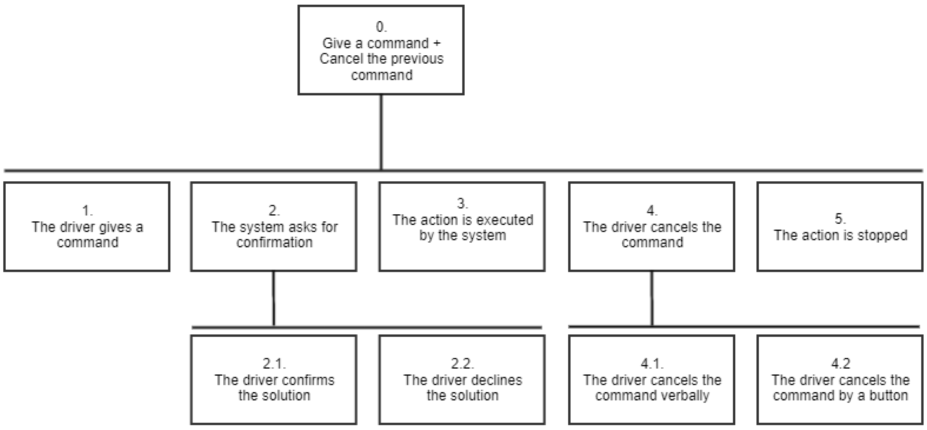

Figure 3.2: HTA of Use case 2

Then, she quickly decides to cancel the navigation to McDonald's quickly by pressing a button on the controller and continues on her way to the zoo.

Hierarchical Task Analysis (HTA)

Plans defining the execution of the task in the HTA in Figure 3.2:

Plan 1: 1. – 2. - 2.1. – 3. – 4.1. - 5.

Plan 2: 1. – 2. - 2.1. – 3. – 4.2. - 5.

Plan 3: 1. – 2.2.

Plan 4: 1. – 2. – 2.1. - 3.

3.3 Sketching

In several iterations, sketches of a prototype were created to fulfill the design goals and the use cases. Firstly, paper sketches were made and consequently also 3D physical models from clay.

Figure 3.3: Final 3 sketches

Final sketches (shown on Figure 3.3) were:

1. Spinnable wheel with buttons (placed vertically on a centre console)
2. Buttons for the steering wheel - one button in the front with a small lever, another behind
3. Design reminding a computer mouse/trackball (located in front of or on the clutch)

All 3 sketches have 2 buttons - one for rejecting and cancelling actions, another for confirmation and favorite actions (double click). They also have a lever for controlling the states on a scale and also getting feedback from them - providing high granularity. The first sketch excells with the size of buttons and specially the lever, however, the from the point of view of ergonomics, it is not suitable for frequent usage because the driver would have to reach the centre console frequently. The remaining two sketches are much better located. Both the steering wheel and the clutch are placed where the drivers often put their hands and are therefore use to it.

3.4 Low-fidelity prototype

To quote [9], the idea of a low-fidelity prototype is to use inexpensive, non-labor intensive prototyping processes to evaluate possible design flaws and to garner feedback from potential users of the system. Proponents of this kind of prototyping estimate that 80% of all interface design problems can be discovered with low-fidelity prototyping.

Control element	Action	Feature	Description
Front button (for index finger)	Button press	Confirmation	Response to the system
	Double click	Favorite action	System suggests an action based on previous experience
Side button (for thumb)	Button press	Rejection	Response to the system
	Button press	Cancellation	Cancels the previous action
Lever (next to the side button)	(no action)	Information about a state	The lever moves to a position according to the specific state
	Moving the lever up and down	Setting a state	Sets a state on a scale (volume, temperature etc.)
	Moving the lever up and down	Choosing from options	System offers different options based on lever position

Table 3.1: Elements and features of the low-fidelity prototype

Figure 3.4: Lo-fi prototype made from polystyrene

After consultations with the Department of Industrial Design at Faculty of Architecture at Czech Technical University in Prague, the third sketch was selected for making a low-fidelity prototype using inexpensive material (polystyrene). The lo-fi prototype (shown on Figures 3.4 and 3.5) contained elements and features described in Table 3.1.

The low-fidelity prototype was tested in the first iteration of the experiment which is described in the chapter 4.

3.5 High-fidelity prototype

After the first iteration of the experiment with the users, few design flaws were discovered and dealt with in a design of 3d printed hi-fi prototype (Figures 3.6, 3.7 and 3.8). The actions and features of interaction remained the same, only the size and the place of the elements changed. The small confirmation

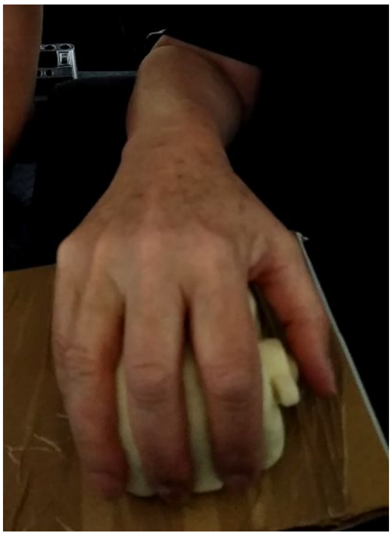

Figure 3.5: Lo-fi prototype with a hand for scale

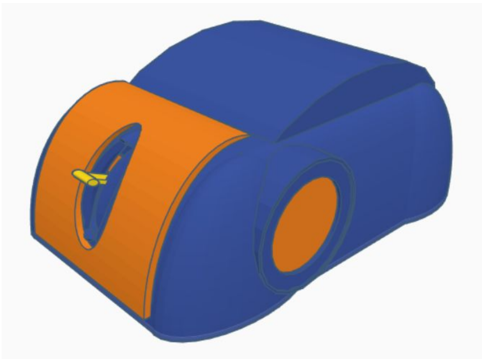

Figure 3.6: Hi-fi prototype model

button for index finger was replaced by a larger button which can be pressed by either index or middle finger to make pressing of this element easier. Also, cancellation button was enlarged, however, it remained on the side position for a thumb, which proved to be ideal position. The moving of the lever was not very comfortable so it was moved to the centre part of the front button, not unlike the wheel on a computer mouse.

The hi-fi prototype was equipped with Arduino UNO microcontroller board which allowed to get user input during the experiment.

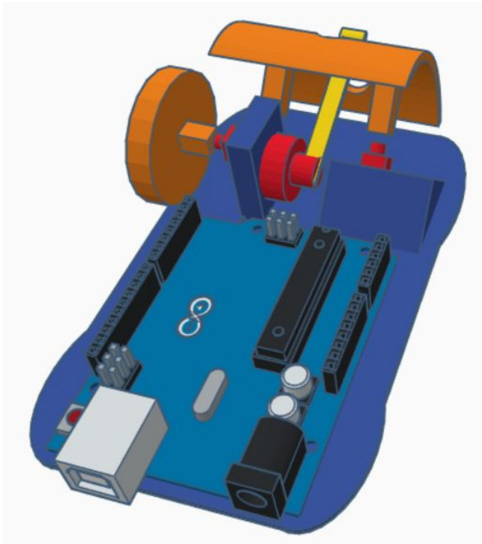

Figure 3.7: Hi-fi prototype model from the inside

Figure 3.8: Location of the controller in the car

Chapter 4

Experiment

This chapter describes the progress of the experiment which tested first low-fidelity, then high-fidelity prototype of the designed controller, with users from the target group and acquired data for qualitative research.

4.1 Participants

The target group for the experiment were people over 60 years old, who are not necessarily currently active drivers but have at least certain driving experience. Based on these two Screener questions, 11 participants were selected:

1. How old are you? (only people above the age of 60 were elligible to participate)
2. Do you have or did you ever have a driving license? (only people who ever possessed a driving license were elligible to participate)

The information about these participants is in Table 4.1. They consisted of 5 women and 6 men aged 65 to 81, most of them were active drivers, suffered from a certain kind of visual impairment and had no experience with in-vehicle infotainment system or voice control.

ID	Age	Gender	Active driver	Visual impairment	Infotainment experience	Voice control experience
1st iteration						
1	73	Woman	Yes	Yes	No	Yes
2	81	Man	Yes	No	Yes	No
3	65	Woman	Yes	Yes	No	No
4	66	Man	Yes	Yes	No	No
2nd iteration						
5	66	Woman	Yes	No	No	No
6	72	Man	Yes	Yes	No	No
7	68	Man	Yes	Yes	No	No
8	73	Man	Yes	No	Yes	Yes
9	72	Man	Yes	Yes	Yes	No
10	67	Woman	Yes	No	No	No
11	72	Woman	No	Yes	No	No

Table 4.1: Participants of the experiment

First four participated in the first iteration of the experiment with the lo-fi prototype and no primary task. Seven others were part of the follow-up experiment with the hi-fi prototype.

4.2 First iteration

The main goal of the first iteration of the experiment (with lo-fi prototyp)e was to get so to speak a proof of the concept itself and discover basic design flaws so they could be avoided while designing the hi-fi prototype. Secondary goal was to observe the participants' behaviour while interacting with the conversational assistant in general.

4.2.1 Apparatus

Environment

The experiment was conducted in a shut-down car simulator so that the participants could be seated the same way as they would in a car - the ergonomics were preserved, and participants would not be disturbed by the surroundings.

Because there was no way of monitoring the input on the lo-fi prototype, the researcher had to be seated next to the participant during the course of the experiment and observe which buttons are pressed.

Equipment

The lo-fi prototype of the controller was placed on a carboard stand in front of the clutch and during the experiment monitored by camera for audiovisual record for processing the data afterwards.

The researcher was also equipped by mobile phone which was used to measure the time of the experiment and simulate phone call which was part of the testing scenario.

4.2.2 Procedure

Training

Before the beginning of the testing scenario, the controller was introduced to each participant with all its elements and features. Then, quick scenarios were introduced to the participant so he could learn how to use all some of its features:

1. You are on your way to a cottage. The system informs you about the amount of fuel remaining (On the prototype the lever doesn't move but on the real device, its position would reflect the current state). Try the favorite action feature which in this case would be to start a navigation to the nearest petrol station.

2. You are riding with a child. He sleeps and you don't want to wake him up, so you want to lower the volume. Try to use the lever on the controller.

3. You are going to the post office to resolve some business but you know it would take a long time so you want to have lunch first. Try to use the lever for selecting from several options.

Primary and secondary task

During the experiment, the main focus was on the usability and the characteristics of the controller. For that reason, the primary task was represented by the participant only imagining he is driving a car in real traffic.

The secondary task involved solving several problems during a given scenario including controlling the navigation, the vehicle status and answering/declining a phone call.

Scenario

The participant was instructed to communicate with the conversational assistant (simulated by the researcher) during the experiment in 2 ways - with voice and also with the controller when it's appropriate. The participant was encouraged to try to solve the problems that could occur during the scenario and don't be afraid to use the assistant for that purpose.

The scenario had been constructed so the participant would have the opportunity to try the different features of the controller. In the experiment scenario, several events outside of the system could occur (weather conditions, road work, hunger etc.). Those were represented by large paper cards shown to the participant when the event was suppose to occur. See Figure 4.2.

Introduction to the scenario:

You are driving to a cottage where brother-in-law celebrates his birthday. You know this way by heart so you don't use the navigation. You promised to arrive at certain hour and moreover, it seems that terrible strom is coming so you want to arrive as soon as possible.

4.2.3 Method

The results of the experiment were qualitatively evaluated based on two parts of an interview. Pre-interview was conducted with each participant right after the training part and the post-interview after the experiment was finished.

Event	Motivation
Card: Work on the road. If you continue this way, it would take longer.	The participant should be motivated to start the navigation to find alternative route.
Card: You don't have a gift for your brother-in-law.	This should motivate the participant to start the navigation to the nearest shop or petrol station.
Card: You realised the gift is in the trunk.	This should motivate the participant to cancel the previous command.
System: The state of your gas tank is not ideal, maybe you won't have enough for the journey back.	This should motivate the participant to start the navigation to the nearest petrol station or try the favorite action feature of the controller.
Card: Hailstones are falling from the sky!	The last two events should motivate the participant to cancel the journey to the petrol station and hurry to the cottage.
Incoming phone call - brother-in-law is encouraging the driver to hurry up because a storm is coming.	

Table 4.2: Events and the motivations for the participant in the scenario

The questionnaire can be found in the Appendix B.

4.2.4 Results

The following subsection records the insights given by the behaviour of the participants during the experiment and also the responses from the interviews.

Participant 1

The participant was a 73-year-old woman who's still an active driver, suffers from visual impairment, has no experience with the in-vehicle infotainment systems, but has some experience with voice control.

During the experiment it was obvious that the participant enjoys talking to the assistant and doesn't feel the need to use the buttons. Even in the post-interview, the participant admitted that she prefers the voice control, especially in a critical situation. During a calm ride however, she sees the controller as a good alternative when it's not possible to talk.

Moreover, the participant mentioned that she liked the overall size and shape of the controller but it should be positioned closer to the clutch because this way she can't reach the pedals. Also positioning the buttons on the steering wheel would feel right for her. The small lever on the controller should definitely be more to the right.

Participant 2

The participant was a 81-year-old man who's still an active driver, doesn't suffer from any visual impairment, has an experience with the in-vehicle infotainment systems, but no experience with voice control.

Even though there was no such instruction, the participant felt the need to confirm by pressing the button every time the system talked to him (e.g. "In 100 meters turn left" or "Starting the navigation to the nearest petrol station"). He later stated that he wanted to make sure the system understood him.

All the characteristics of the controller felt comfortable to him, he would only expect two buttons in the front, like on a computer mouse. And it would make more sense to him to have the buttons directly on the steering wheel.

The participant evaluates the overall usefulness of the assistant mainly for navigation and controlling the screen. And he prefers conversation to buttons.

Participant 3

The participant was a 65-year-old woman who's still an active driver, suffers from visual impairment, has no experience with the in-vehicle infotainment systems and no experience with voice control.

The participant was a bit confused about the features and often used double click for confirmation. She also used the button when she wanted to start talking with the assistant to “wake him up”.

For her, the controller would be better positioned in the front, maybe even directly on the clutch.

She also stated that the controller makes her feel confident that the system will understand the instruction correctly and also allows her to react faster.

Participant 4

The participant was a 66-year-old man who’s still an active driver, suffers from visual impairment, has no experience with the in-vehicle infotainment systems and no experience with voice control.

This participant was also pressing the button when he wanted to give commands to the assistant. He often wasn’t motivated to solve the problems with the assistant at all and after confessed that he thinks problems should be dealt with in a more “human way“ than to rely on a system.

The participant was basically satisfied with the size and the shape of the controller but the position could be lower and the small lever was hard to control from the current place.

Even though he didn’t use the assistant so much during the experiment, he can imagine that in special situations like finding an alternative route he would use it and the controller would make him feel assured that the system understands him.

Design recommendations

The overall shape and size of the controller was rated mostly positively by the participants. Several times it was mentioned to move the lever for states on a scale more to the right, because the movement of the thumb in this position is not natural, and place the whole controller more to the front or on the steering wheel, so everyone could comfortably reach it.

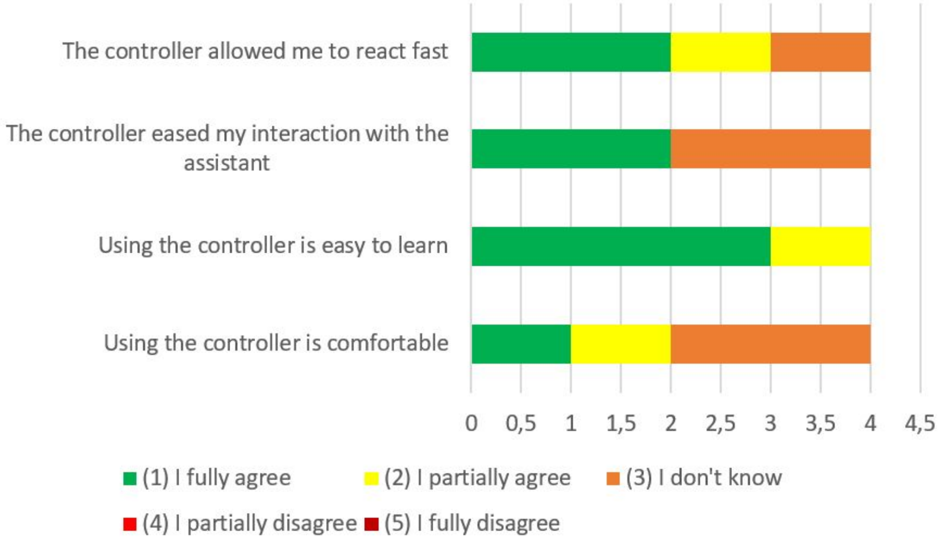

Figure 4.1: Graph of user responses in Likert scale (1st iteration)

Summary

The participants weren't too sure about the usefulness of the controller. Some of them said that they prefer the conversation with the assistant but for some situations they can see the controller as a good alternative. Others mentioned that the controller gives them the certainty because they would never fully trust the voice control otherwise.

Nevertheless, the results in this iteration were influenced by the fact that the participants could fully focus on the secondary tasks. Which of course didn't have a large impact on the physical attributes of the controller so the appropriate changes were made during the modelling of the hi-fi prototype according to the responses of the participants.

The Figure 4.1 displays responses of the participants in the post-interview for 4 statements. Likert scale was used.

4.3 Second iteration

The goal of the second iteration of the experiment (with hi-fi prototype) was to assess the overall usefulness of the controller for solving secondary tasks

Figure 4.2: View from the car simulator

while focusing on driving and furthemore explore the possibilities for specific features.

4.3.1 Apparatus

Environment

The experiment was conducted in a car simulator and a specific route was designed for fullfilling the experiment scenario needs. The view from the inside of the simulator is shown in the Figure 4.2.

The researcher was observing the simulator from outside, monitoring user input and playing response from his computer.

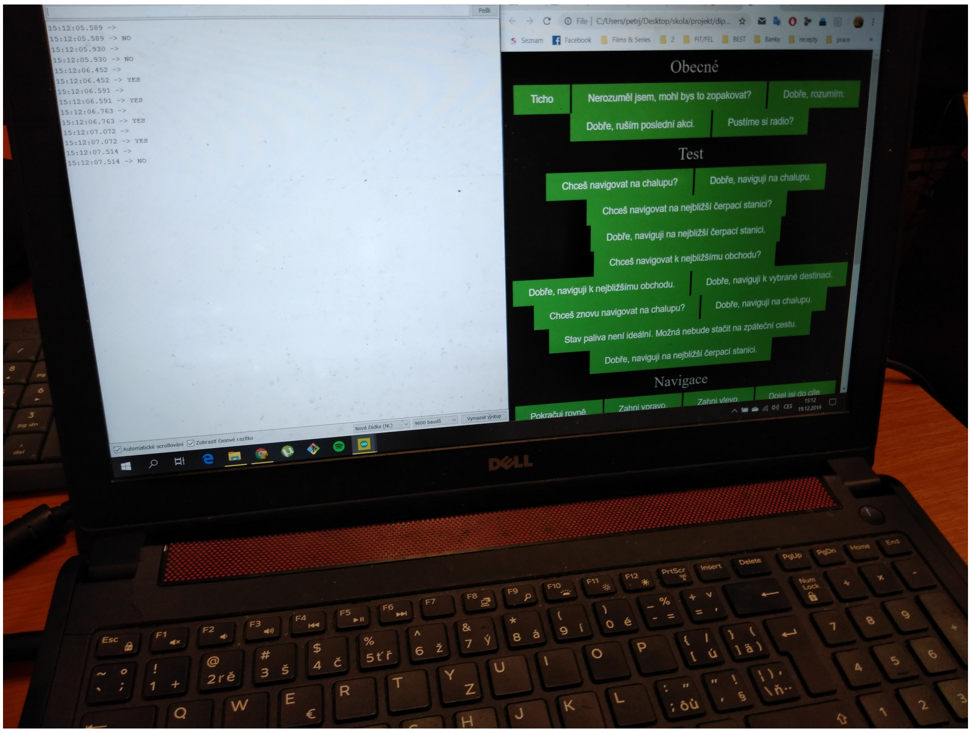

Figure 4.3: Researcher's computer screen

Equipment

The hi-fi prototype of the controller was placed on a carboard stand over the clutch (based on the suggestions from the 1st interation it was moved to the front) and during the experiment monitored by camera for audiovisual record for processing the data afterwards.

Arduino UNO was placed inside the controller to monitor user input and cable from there lead to the researcher's computer on a table outside of the simulator.

Two windows were open on the computer screen (shown in the Figure 4.3) - a simple script running on Arduino UNO for monitoring user input (it can be found in the Appendix C) and a browser with HTML page with buttons playing prepared audio tracks (simulating the assistant by the method Wizard of Oz). These tracks were made using SpeechTech TTS.

The computer was connected to a wireless speaker via bluetooth and the speaker was placed above the centre console. The speaker was not only for playing the tracks but also representing a point in space towards which the participant should talk to.

4.3.2 Procedure

Training

The training in the second iteration consisted of two parts. In the first part, the participant was introduced to the car simulator and was learning to drive on a training route. At the same time, certain general audio tracks (e.g. “Slow down, you are going too fast”, “Attention! A train is coming!” or “You don’t have a lot of fuel, should we go to the petrol station?”) from the conversational assistant were played so that the participant would get used to its presence.

For the second part of the training, the simulation was shut down and the controller was introduced to each participant with all its elements and features. Then, quick scenarios were introduced to the participant so he could learn how to use most of the features:

1. You are on your way to a cottage. The system informs you about the amount of fuel remaining (On the prototype the lever still doesn’t move but on the real device, its position would reflect the current state). Try the favorite action feature which in this case would be to start a navigation to the nearest petrol station.
2. You are in front of a crossroad and want to start the navigation towards nearest shop. However, suddenly you find out that you are in the wrong lane and want to cancel the navigation.
3. You are going to the post office to resolve some business but you know it would take a long time so you want to have lunch first. Try to use the lever for selecting from several options.

Primary and secondary task

The primary task in the second iteration is driving a car in a simulator. The route (showed in 4.4) contains also traffic, so the participant needs to be

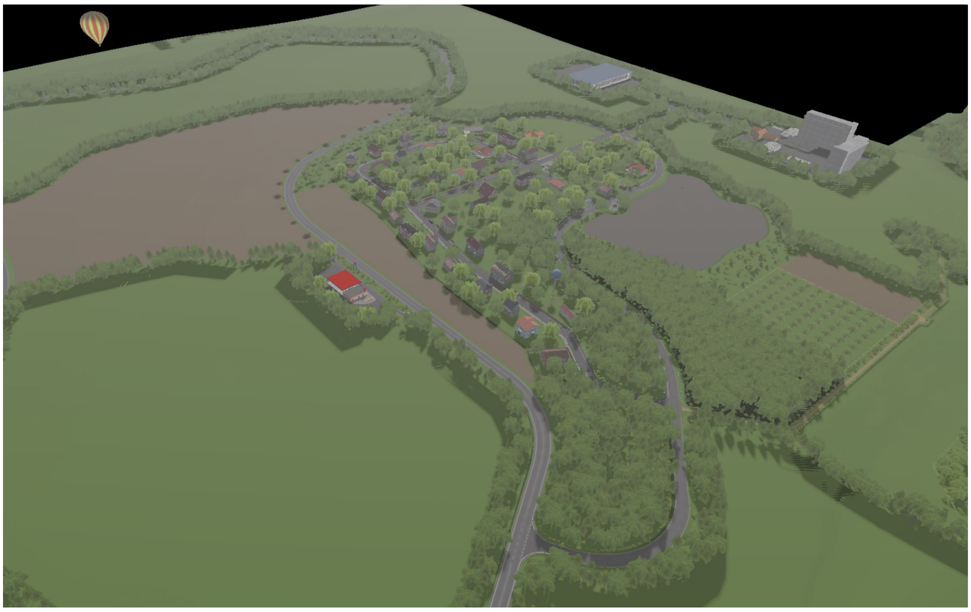

Figure 4.4: Overview of the route in the simulator

careful and really pay attention to what's happening on the road in front of him.

The secondary task was yet again solving several problems during a given scenario including controlling the navigation, the vehicle status and answering/declining a phone call.

Wizard of Oz

The basic description of the method Wizard of OZ is that it is a prototyping method that uses a human "wizard" to mimic the functions of a prospective system.[10]It saves the time for development when the focus should be on the design.

In the context of this experiment it means that there was no actual conversational system that reacted on user input but the researcher was playing prepared audio records based on what the user did.

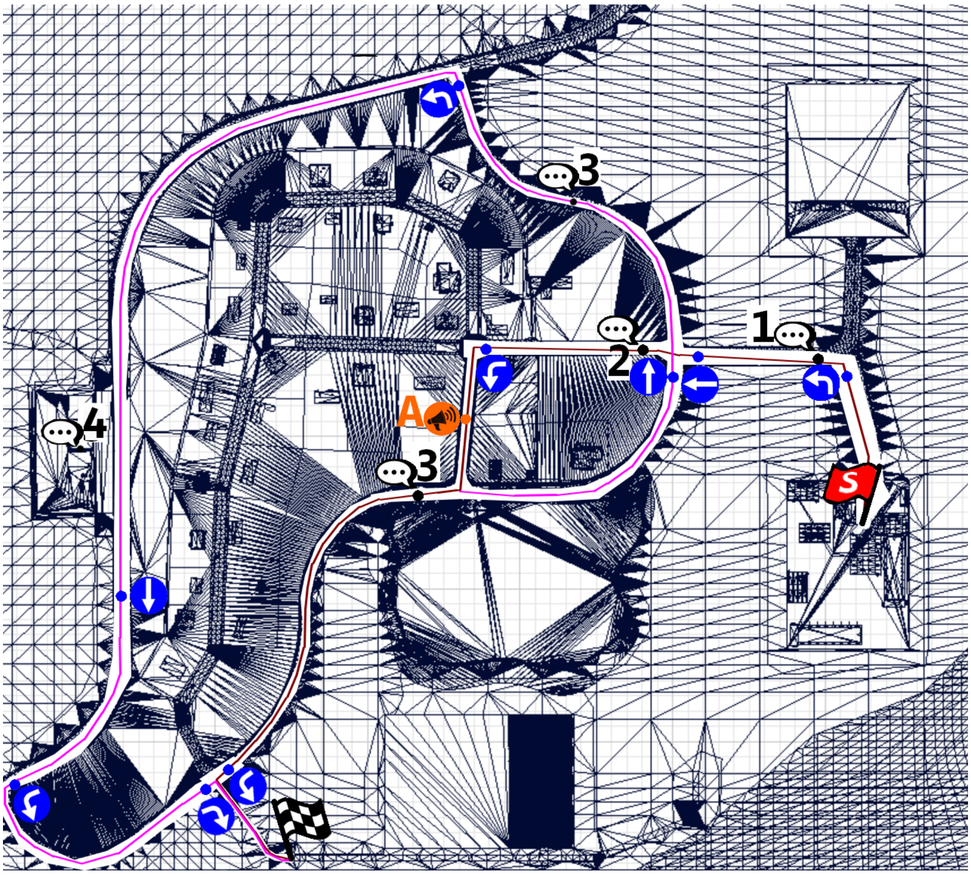

Figure 4.5: Map of the route used in the scenario

Scenario

The participant was again instructed to communicate with the conversational assistant, simulated this time by the method Wizard of Oz and prepared audio records. Introduction to the scenario:

You are driving to a cottage where your brother-in-law celebrates his birthday. You have never been there so you need to use the navigation to get there. You promised to arrive at certain hour so you want to arrive as soon as possible.

The scenario and the route is described by the map in Figure 4.5. The participant was instructed to start the experiment (at the point with the red “S” flag on the map) by expressing the command to start the navigation to the cottage (marked as a goal flag on the map). Voice navigation on the way was accompanied by large arrows in front of the car at certain points shown on the map.

At the numbered points, certain events outside the system occured (shown as a large text on the screen in front of the participant):

1. You don't have a gift for your brother-in-law.
2. You realised that the gift is already in the trunk.
3. Incoming phone call from your brother-in-law.
4. You drew full tank.

And at the point marked by letter "A", the system informed the participant that the fuel might not be enough for the way back.

4.3.3 Method

The results of the experiment were again qualitatively evaluated based on two parts of an interview. Pre-interview was conducted with each participant right after the training part and the post-interview after the experiment was finished.

The questionnaire can be found in the Appendix B.

4.3.4 Results

The following subsection records the insights given by the behaviour of the participants during the experiment and also the responses from the interviews.

Participant 5

The participant was a 66-year-old woman who's still an active driver, doesn't suffer from visual impairment, has no experience with the in-vehicle infotainment systems and no experience with voice control.

The participant was overall satisfied with the controller and felt that thanks to it, the interaction was quicker. Also, the participant stated that she doesn't have to concentrate as much on the secondary tasks when using the buttons and that not all the time a person is in the mood to talk.

In addition, the participant thought that the controller should also contain some kind of emergency button, which is present in modern cars, however she would place it directly on this controller.

Participant 6

The participant was a 72-year-old man who's still an active driver, suffers from visual impairment, has no experience with the in-vehicle infotainment systems and no experience with voice control.

The participant thought that the shape and the size of the controller are even better than with an ordinary mouse because it's easily grabbed and it is comfortable to lay the hand on it. He also liked the clearly separated "yes" and "no" functions. Generally, he would prefer to use conversation but for the cancellation of actions, he thinks the button is a better choice.

Participant 7

The participant was a 68-year-old man who's still an active driver, suffers from visual impairment, has no experience with the in-vehicle infotainment systems and no experience with voice control.

The participant stated that generally speaking, he prefers to rely on himself than on some computer system. On the other hand, he also mentioned the favorite action feature would be quite useful, if the car assistant truly knew the driver.

He had no complaints about the characteristics of the controller, but speaking seemed generally easier to him, only in the situations when there is noise or when the driver makes a mistake, the controller makes sense for him.

Participant 8

The participant was a 73-year-old man who's still an active driver, doesn't suffer from visual impairment, has some experience with the in-vehicle infotainment systems and some experience with voice control.

The participant thought that the controller was better than computer mouse, because it's harder to interchange the buttons for confirmation and rejection and is large enough to easily find it. But the only situation when the controller makes sense for him is only when the conversational assistant makes a mistake.

He also suggested that functions for monitoring the driver's attention and health could be implemented in the controller.

Participant 9

The participant was a 72-year-old man who's still an active driver, suffers from visual impairment, has some experience with the in-vehicle infotainment systems, but no experience with voice control.

At first, the participant felt he wasn't used to the layout of the buttons (compared to computer mouse) but then he appreciated the rejection button for the thumb.

Nevertheless, he believed that if the assistant understood him, he wouldn't need the physical buttons. He found the favorite action feature useful though, if the assistant knew him well.

In general, he prefers to solve problems by himself and doesn't like when technology starts to think for people.

Participant 10

The participant was a 67-year-old woman who's still an active driver, doesn't suffer from visual impairment, has no experience with the in-vehicle infotainment systems and no experience with voice control.

The participant thought the controller takes away too much of her attention but admitted that maybe because she wasn't used to it. It could be alternative way of interaction, when the driver can't or doesn't want to talk, but she personally prefers conversation.

Participant 11

The participant was a 72-year-old woman who's not an active driver anymore, suffers from visual impairment, has no experience with the in-vehicle infotainment systems and no experience with voice control.

The participant stated that she would prefer voice control over buttons, however the commands should be short, the imitation of the real conversation is not for her. But she can also imagine situations when she doesn't walk to talk at all and she would appreciate the controller as an alternative way of interaction.

Design recommendations

In the second iteration, there were practically no remarks about the wrong location of the controller or its characteristics, using it was comfortable for everyone. The participants focused more on the features and the general usefulness of the controller and the assistant itself. The future design could focus more on the features that intrigued the participants the most, especially the favorite action feature. Also, integration of the controller into the clutch itself could be considered.

Summary

The opinions of the participants again slightly differed but several repeated statements could be heard.

A part of the participants, mostly men, expressed that the assistant might be overused and people should more rely on themselves, but they also admitted

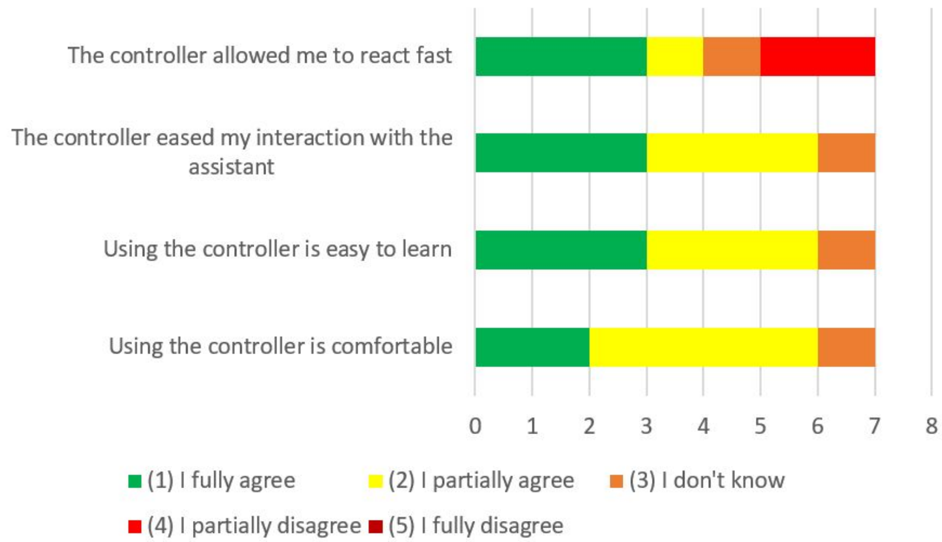

Figure 4.6: Graph of user responses in Likert scale (2nd iteration)

that maybe the feeling was stronger during the experiment because a lot of situations were compressed into short period of time.

Another fact is that most of the participants prefers conversation over the use of the buttons, but at the same time, they find the controller as a useful alternative when either the system doesn't understand the instructions or the driver can't or doesn't want to talk.

The Figure 4.6 displays responses of the participants in the post-interview for 4 statements. Likert scale was used. The Figure 4.7 then shows results of both iterations together.

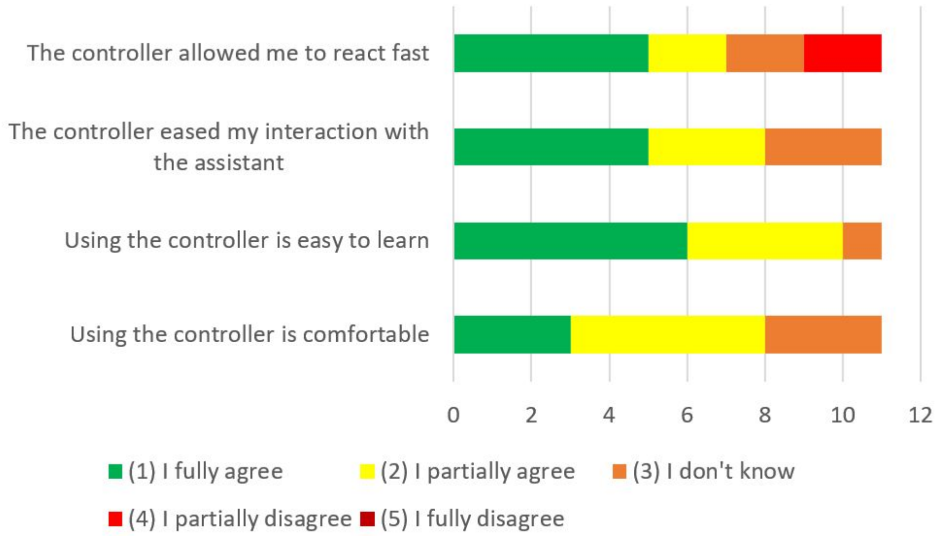

Figure 4.7: Graph of user responses in Likert scale (both iterations)

Chapter 5

Conclusions

This thesis started with the analysis of the State of the Art in the topics of designing multimodal interface and the behaviour of older drivers. From this analysis, design goals were set up ("Undo" an action, Confirmation/rejection, Favorite action feature, High granularity, Touch/feel feedback, Ergonomics and Learnability) and use cases specifying them created. Based on that, sketches and then low-fidelity prototype was created. The protype was tested in the first iteration of the experiment with 4 participants and basic design flaws were discovered and removed. That was followed by the design of a high-fidelity prototype which was tested in the second iteration of the experiment with 7 participants in the car simulator.

This qualitative study provided insights not only on the older driver's opinion on and behaviour towards the controller but the conversational system as a whole. Some of them were sceptical about it, however they admitted that it could be useful if it's not overused. Most of the participants expressed that they prefer conversation to the use of buttons but at the same time all of them could imagine situations where they would use the buttons instead. From all the designed features, the participants were mostly intrigued by the favorite action feature which could speed up the conversation if the system knew the driver very well, then by the fast cancellation of an action and last, but not least, the feeling of certainty which the tactile/haptic interface has, opposing to the voice control which can misinterpret the user instructions.

These findings are certainly worth exploring more in the future.

Appendix A

Abbreviations

- DALI - Driving Activity Load Index
- LCT - Lane Change Task
- SOA - State of the Art
- SUS - System usability scale

Appendix B

Questionnaire

B.1 Pre-interview

- What is your age?
- What is your gender?
- Are you an active driver?
- Do you have any visual impairment?
- Do you have experience with any in-vehicle infotainment system?
- Do you have experience with voice control?
- Did you find the location of the controller comfortable? Would you expect it there? Would you move it somewhere?
- How do you find the mapping of the features on elements?

B.2 Post-interview

B.2.1 Questions evaluated by the Likert scale

Rate the following statements on a Likert scale 1-5 (1=fully agree,2=partially agree,3=don't know,4=partially disagree,5=fully disagree):

- Using the controller is comfortable.
- Using the controller is easy to learn.
- The controller eased my interaction with the assistant.
- The controller allowed me to react fast.

B.2.2 Open questions

- What do you think about the size and the shape of the controller? How was holding it in your hand?
- Describe the interaction with specific elements. What do you think about their size, shape and location? Did you miss any element?
- Do you find the specific features of the controller useful? What other features could be added?
- Does it make sense to use the controller with the conversational assistant? Why? Why not?
- Describe the advantages and disadvantages of the controller during the situations in the scenarios.
- Do you have any other thoughts?

Appendix C

Arduino UNO Script

```
const int buttonPin1 = 13;
const int buttonPin2 = 9;
const int potPin = 2;
int oldValue = 0;
int oldValue2 = 0;
int potoldValue = 0;

void setup() {
 Serial.begin(9600);
 pinMode(buttonPin1, INPUT);
 pinMode(buttonPin2, INPUT_PULLUP);
}

void loop() {
   int buttonValue = digitalRead(buttonPin1);
   int buttonValue2 = digitalRead(buttonPin2);
   int potValue = analogRead(potPin)/32;
   if ((buttonValue != oldValue)||(buttonValue2 != oldValue2)){
     if (buttonValue == LOW){
        Serial.print("\nNO\n");
     }
     if (buttonValue2 == LOW){
        Serial.print("\nYES\n");
     }
   }
   if (potValue != potoldValue){
      Serial.print("\n");
```

```
        Serial.print(potValue);
        Serial.print("\n");
    }
    oldValue = buttonValue;
    oldValue2 = buttonValue2;
    potoldValue = potValue;
}
```

Appendix D

Bibliography

[1] David Strayer, Joel Cooper, Rachel Goethe, Madeleine McCarty, Douglas Getty, and Francesco Biondi. Assessing the visual and cognitive demands of in-vehicle information systems. *Cognitive Research: Principles and Implications*, 4, 12 2019.

[2] 2018 world population data sheet with focus on changing age structures. https://www.prb.org/2018-world-population-data-sheet-with-focus-on-changing-age-structures. Accessed: 05.01.2020.

[3] Anna Bjelkemyr, Tania Dukic, Rachel Owens, Torbjorn Falkmer, and Hoe Lee. Support systems designed for older drivers to achieve safe and comfortable driving. *Journal of Transportation Technologies*, 03:233–240, 01 2013.

[4] Julia Schuettenhelm and Mark Vollrath. Distraction while driving: The case of older drivers. *Transportation Research Part F-traffic Psychology and Behaviour - TRANSP RES PT F-TRAFFIC PSYCH*, 14:638–648, 11 2011.

[5] Stefan Mattes. The lane-change-task as a tool for driver distraction evaluation. pages 57–60, 01 2003.

[6] Wolf Oswald, Bernd Hagen, and R. Brickenkamp. Test d2 - aufmerksamkeits-belastungs-test. *Zeitschrift fuer Differentielle und Diagnostische Psychologie*, 18:87–89, 01 1997.

[7] Bastian Pfleging, Stefan Schneegaß, and Albrecht Schmidt. Multimodal interaction in the car: combining speech and gestures on the steering wheel. pages 155–162, 10 2012.

[8] Jessica Villing. Speech, buttons or both? a comparative study of an in-car dialogue system. 01 2011.

[9] Leah Schultz. Using low-fidelity prototyping to teach the basics of interface design. *Proceedings of the Information Systems Education Conference, ISECON*, 25, 01 2008.

[10] Stephan Schlögl, Gavin Doherty, and Saturnino Luz. Managing consistency in wizard of oz studies: A challenge of prototyping natural language interactions. 06 2013.