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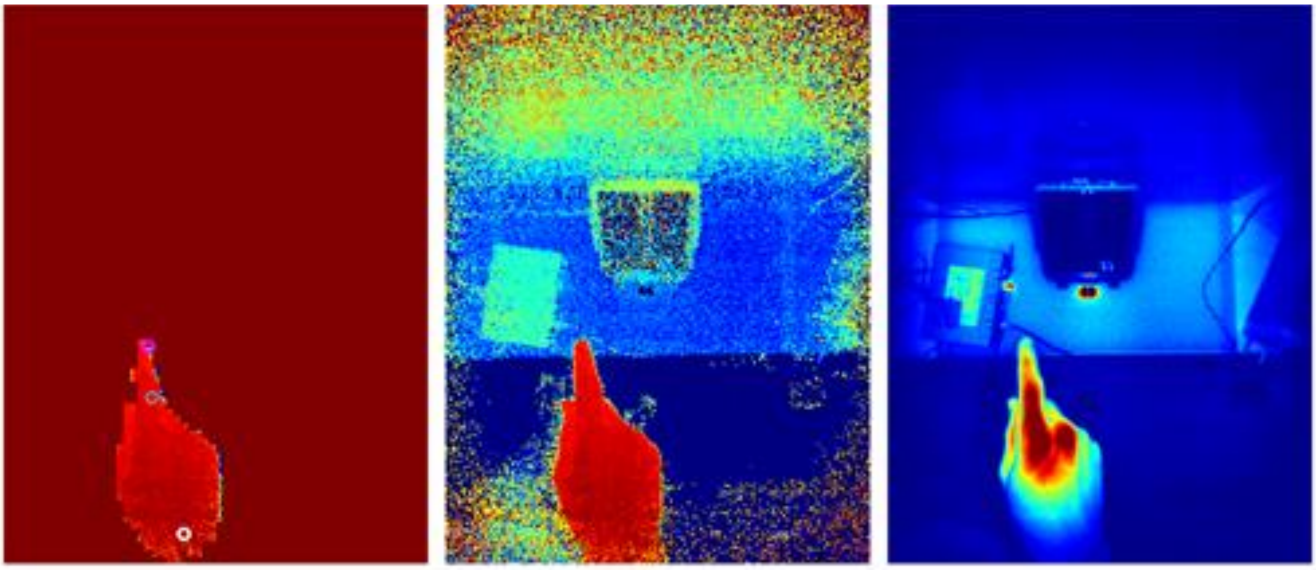

A Design Science Study on Methods of Feedback for In-car Gesture-controlled Infotainment Systems

Bachelor of Science Thesis in Software Engineering and Management

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[A picture detailing the view from a gesture recognition camera of which, the camera is used for this study. Please referred to Fig. 8 in the study in the section IV. Result a) Artefact.]

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Abstract— **Navigating an in-car infotainment system by using gesture-control can be distracting, drivers usually seek for confirmation from the infotainment system by rapidly glancing at the screen and therefore reduce the eyes-on-the-road time, this can be dangerous. This study aims to evaluate whether if by applying both visual and auditory feedback from the infotainment system can reduce the distraction. One iteration of design science is performed with results showing that by applying the combination of audio (different clicking sounds) and colour (different colour changes) feedback, the distraction is reduced according to the qualitative interview results, participants claimed that they can use the system without looking at the screen. Suggestions are also made to improve the system by adding feedback methods such as voice assistant, or different audio cues, can be applied and have the potential to reduce the distraction even further. Although the study could not distinguish between whether if the result is led by the user interests to the gesture control technology or the feedback system itself.**

Keywords—feedback; usability; distraction; auditory; visual; infotainment system; gesture recognition; gesture controlled; comparison; car; driving; safety.

I. Introduction

A. Background

With the development of modern cars, more and more features have been introduced into the vehicle to provide and ensure a safe and comfortable driving experience. Studies indicate that the introduction of advanced technologies, such as navigation systems, climate controls, and infotainment systems, has a detrimental effect on the driver's performance while driving [11,12]. Operating these systems are usually highly visually demanding when driving. The driver is generally required to look at the system to be able to navigate throughout the menus or confirm that an action was executed correctly. Studies have shown that drivers have less focus (eyes on the road) while interacting with infotainment systems [13,14].

However, with technological advancements, gesture recognition systems have been made possible. Several studies conducted have investigated whether if gesture recognition systems are feasible for the in-vehicle environment [8,9], with results showing that gesture-controlled infotainment system can be an alternative to decrease the distraction when interacting with the infotainment system. However, Bach et al. also pointed out that the in-vehicle gesture recognition system still has a relatively high demand for visual attention from the driver. They also suggest that more studies should focus on how a gesture recognition system should give feedback to the user.

As related studies have shown, even though car manufacturers are already implementing this technology in newer models, there is a gap in research on the effects of feedback when using gesture-based input. Of traditional methods of interacting with an infotainment system there is always at least some form of tactile or haptic response, but with gestures there are no buttons nor vibrations to feel. What the user instead has to rely on is either their vision or their hearing, yet

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these are two key senses used by the driver already. To retain high usability and a low interference with the driver, new and clever ways of giving the user feedback needs to both be invented and tested.

Looking at current infotainment systems in the automotive industry, we decided to evaluate and find potential improvements on systems that are currently in development. We contacted a company in our geographical region, Aptiv (A company that provides in-vehicle solutions for automotive manufacturers, located in Sweden, Gothenburg), that is working on an infotainment system using gesture control. The system uses a circular graphical user interface (GUI) for navigation in menus (see Fig. 2 and Fig. 3). Their setup requires the user to still look at the screen to manoeuvre the graphical interface, and as the system is intended for a vehicle infotainment system, this can be a distraction for the driver and compromise both their and others' safety while in traffic.

This paper is done in cooperation with Aptiv, looking for a more reliable and non-distracting feedback system for gesture-controlled, in-vehicle infotainment systems by comparing the visual workload of the driver while interacting with the gesture-controlled infotainment system with two different feedback setups. Since this specific project (gesture controlled in-vehicle infotainment system) is still under development, it means that the legacy gesture recognition system has not been fully integrated into their new infotainment system. Therefore, this project has not been published or released to the market. Moreover, since the project is under development, the company have not investigated any similar topics.

B. Research Questions

We have defined two research questions that we are planning to investigate:

RQ1: In the context of gesture-based feedback for in-car infotainment systems, how well can colour feedback, in the form of colour changes seen through peripheral vision combined with auditory feedback, replace the need to look at a screen comparing to only auditory feedback?

We are aiming for a system that allows for use with minimum to no use of the screen. To accomplish this, we use colour information within the user's peripheral vision. It is then important to understand how this impacts the use of the system; how well the user can perform, and how willing they are to try to work with only peripheral feedback.

RQ2: What further improvement can be brought to the feedback system in order to reduce distraction and increase usability while using the gesture-controlled infotainment system while driving?

We want to suggest ideas for further development of such a system that allows better usage with minimum distraction. To be able to do this we need to gather information about what may be suitable development paths to take.

C. Objective

For this study, design science methodology is applied. Firstly, the gesture recognition system was integrated with the existing infotainment system. It was then developed into two versions; one with auditory feedback, and another with both auditory and colour feedback. Both versions of the system were then evaluated based on if the feedback system reduces the visual demands of the driver (participants) while interacting with the system. We then propose suggestions on how to improve the feedback system, based on the response from the participants.

As the study is intended to improve the design and quality of feedback for gesture-controlled infotainment systems, this study is primarily looking at usability and user experience, and how to design it best. In accordance to the guidelines of SWEBOK Guide V3.0 chapter 2-6, section 4.4, "*Use colour change to show the change of software status.*", the goal is to understand and improve the presentation of information. The product of this study is a software artefact and data collected from interviews can affect the requirements while designing such software.

The paper first discusses related work on feasibility of the in-vehicle gesture-controlled system, as well as related work on methods that reduce the distraction of such systems. Further, the method of feedback developed while conducting this study is illustrated. Then the evaluation set up, the method used to gather participants, and how it was evaluated is outlined. Finally, the results are discussed.

II. Related Work

Gesture-controlled in-car infotainment systems on the market usually have the most basic commands, e.g. answer/hang up the phone, or lower/raise the volume. For these features, there are accepted solutions using sounds or a virtual assistant to relay feedback to the user. When navigating through menus on the infotainment system glancing at the screen is usually necessary, forcing the user to look away from the road.

Ohn-Bar et al. did a study in 2012, focused on the feasibility of a gesture-controlled user interface for infotainment systems. [6] It indicates that most of the drivers or passengers in the study are using the hand gesture-controlled infotainment system. Of that 97.9% of user gesture can be correctly classified (recognised).

Ohn-Bar et al. conducted yet another study in 2014 [8] with focus on the feasibility of hand based in-car gesture-controlled system, it showed similar results where the gesture recognition system could apply to the in-car environment and suggested that more studies should be conducted. Neither of the two Ohn-Bar et al. studies provided any concrete solution to what is considered appropriate feedback.

Ulrich et al. [7] conducted a study focusing on the possibility of the steering wheel mounted thumb-based gestural interface. The result shows that the user can remember all the gestures, and the participants have also reported high satisfaction and high usability of the system. However, in their study, how the system provided feedback was not examined.

Pickering et al. [9] discussed in their study that gesture recognition system can be a potential alternative to solve the issue of distraction brought on by the infotainment system, but it has not addressed the problem of the gesture recognition system is distracting itself. More specifically, the need for the driver to look at the screen of the infotainment system to verify if a gesture performed has been recognised or not.

The result from a study done by Bach et al. at 2008 [10] indicates that in-car gesture recognition system does indeed require the driver to glance at the infotainment system rapidly to navigate the GUI. The system in the study, on the other hand, lacks when it comes to feedback, according to them. They suggest that new studies should investigate on how to couple the input from user gesture and the output from the system, i.e. relaying feedback from the gesture recognition system.

Shakeri et al. [1] discusses the issue of distractions due to the in-car infotainment system and aim to understand how gesture control can affect the driver in comparison to a legacy system such as one using buttons and a display. They conclude that using gesture-controlled infotainment system does, in fact, minimise the distraction of the driver. They also evaluate specific ways of relaying feedback to the user but does not propose any further solutions to reduce the distraction caused by interacting with the in-car gesture-recognition system, e.g. time spent looking at the display.

Ideally, we would like to develop a method of relaying feedback to a user without requiring the user to glance at the display. This is comparable to the problem domain of enabling the use of smartphones among blind people, where developers have tried different ways of improving interaction without the use of the display, for as long as the smartphones have been a common commodity. The non-visual methods that are deployed today include haptic feedback (vibration), various sounds corresponding to action and text-to-speech. Same technologies have been implemented on cars, yet studies have shown that the solutions have shortcomings [1,2]. Users may find the feedback unclear, or that it is responding in unexpected ways. The users may then lose trust in the system, not wanting to rely on it. [2]

What differs between blind users and preoccupied drives are that a driver can take in information using their peripheral vision from a display or dedicated LEDs lighting up in different colours.

Zhao et al. have done a study on a non-visual menu selecting method using earPod (an eyes-free menu technique using touch input and reactive auditory feedback) [3] in 2007. The result suggests that an earPod-like system is comparable in both speed and accuracy with a modern menu selection method, a method which requires the user to use non-colour feedback to navigate through the system. The result also shows that a user of the non-visual menu navigation method can outperform users of the visual technique within a relatively short amount of time (30 mins).

Brewster et al. have conducted a study on Multimodal ‘Eyes-Free’ Interaction Techniques [4], the result shows that the user's gestures are made more efficiently and accurately with a dynamically guided audio-feedback system, and it demonstrated that the audio-feedback system could be a useful alternative for devices with visually emphasised interaction. This result also confirms that audio-feedback can be used to redirect the driver's eyes from the screen while using the in-car infotainment system. It can also potentially improve the efficiency and accuracy while navigating through the infotainment system without the visual attention of the driver.

III. Research Methodology

For the evaluation, two existing artefacts were combined into one system. One, a gesture recognition camera and the other an infotainment system developed in android studio and used for in-house testing at Aptiv. The infotainment system consisted of a circular interface, built to run on a touch device. The gesture recognition module uses a range of sensors to measure the depth and position vectors of up to two hands, which are then used to calculate gesture commands. Data representing the recognised commands are then published on the camera's TCP/IP socket, for the use by external programs.

For the purposes of this study, these two systems had to be interfaced to be able to use gestures as input for the infotainment system. Further, a method of feedback for the baseline as well as an alternate method used for the treatment group had to be developed. The alternate method of feedback developed uses colours seen through peripheral vision, as mentioned earlier, and will be discussed in more detail later in the paper. The latter method of feedback was conceived in discussions with a manager at Aptiv.

The study uses design science methodology, as an artefact was developed and evaluated, yet only one iteration was completed as this study was made under time constraint. The iteration includes the development and evaluation of both artefact versions. In the *Conclusion* section, suggestions on further implementations are instead made that can be tested using the same methodology as this study.

To answer the research questions, both quantitative and qualitative data was collected through measurements during a controlled test, with 10 test participants divided into two groups. One, the control group and the other, the treatment group. RQ1 is answered using data on how well each of the control- and treatment groups performed during the experiment, together with a comparison of the sentiment of all the test participants, collected through the means of an interview (Appx. 1). We are aiming to understand how the two test setups were separately perceived. RQ2 is answered with a selection of improvement suggestions gathered from the interviews, meant to improve the method of providing feedback when using a gesture-controlled infotainment system.

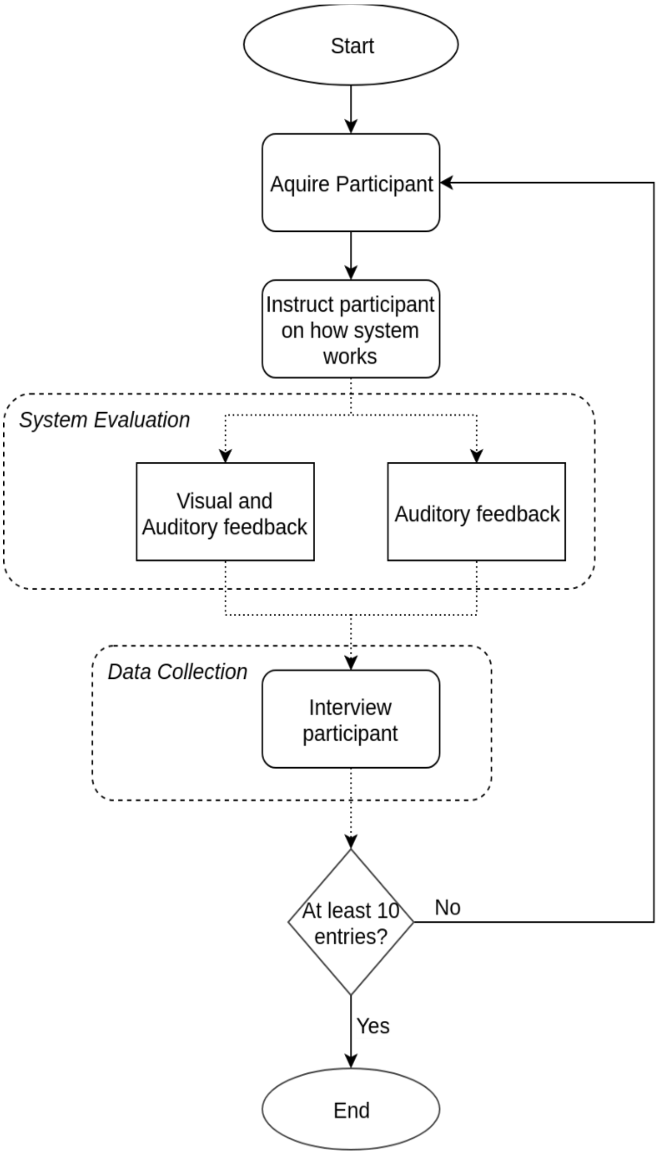

Figure 1. Flowchart of the procedure of the evaluation

A. *Sampling Method*

The sampling method used is convenience sampling. The participants are developers of the company we are collaborating with. Invitations were sent out to the office staff/developers, and a time table for participants to sign up on.

The participants were allocated to each group in the order of "treatment group, control group, treatment group…" in order of arrival.

B. *Ethical Considerations*

All participants are kept anonymous. They were debriefed that they are not judged by their performance in any way, i.e. their performance in the evaluation does not affect their employment. The manager is not able to get specific evaluation details, especially not any participant's name.

All participants were also debriefed before the evaluation about the procedure, as well as that the study would do no physical nor psychological harm to them. The participants were also informed that they can withdraw at any time of the study.

C. *Evaluation Setup*

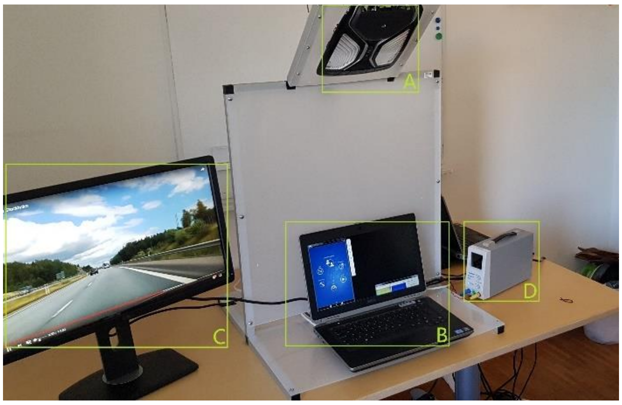

Figure 2. Evaluation Setup

Fig. 2 shows the evaluation setup. There are four different components in the setup, all of them are marked with a box and letter. A is the head unit, it contains the sensors and cameras used for gesture recognition. B is a computer that runs the Android based infotainment application, due to some technical limitations, we could not run the application on the dedicated hardware. C shows a screen that is playing the YouTube clip of the video recording, it is used to simulate the driving scenario. D is the power supply for the sensor and cameras (in A).

For the evaluation, different system versions were used for the control group (without colour feedback) and treatment group (with colour feedback). Participants were asked to sit in front of the screen C during the evaluation and try to think that they are driving.

D. *Procedure*

During the evaluation, introduction, instructions of tasks and the interview is all done in English. The same script is used for each session, read by the same person (See Appx. 1).

1) *Introductions to the System*

The participants were first assigned an ID, and their name was noted down together with the ID in a record. This record will not be published and not seen by anyone else than the researchers. The purpose of the study was not disclosed to the participants, in order to reduce the response bias. Instead, a general goal was given, i.e., *"The goal of this study is to evaluate the usability of the gesture-controlled infotainment system."*.

The participants were introduced to the system by the same person each time, e.g. how the system works and what gestures they can use. The participants were informed about the testing process and the tasks they would be asked to do. Each participant was then given 2 minutes to try the system out before the evaluation started, where they were freely got to try out the same system version they would use for the evaluation. The instructor would show where and how the participant should perform their gestures. The 2 minutes of trial were held strict to minimize the effects of a learning bias between participants. The reason for the 2 minutes of time given to the participant to become acquainted with the system will be talked about in the section *5) Preliminary Test.*

2) *Testing Process*

The test environment consists of the gesture recognition module, a screen hosting the graphical user interface and a second screen showing a video recording from the point of view of the driver[1]. The participants were asked to evaluate the system, with the control group only using the auditory feedback and the test group using the system including both auditory feedback and colour feedback. The participants were Both groups were asked to perform the same instructions, at the same time-stamps, while evaluating the system. They were told that their task is to keep in mind how many lane switches (4) have occurred in the video.

After the simulation, the participant was asked to recall how many lane switches occurred, in addition, they were asked questions regarding metrics that were not disclosed to them beforehand. The questions were not disclosed because the metrics were designed to measure how much they actually paid attention to the video (the general awareness of the participants to the video), the metrics are the following:

- The number of bridges passed under (1).
- The speed limit of the road (110KM/h).
- The number of cars that passed (overtook) going the same direction (2).

During the evaluation, all participants were asked to perform the following three tasks (Marked with time stamp of the YouTube video):

Start test at 4:50

*a) Task 1 **start at 5:00***

- **Switch** to "Apps" category and **enter** this category **start at 5:05**.
- Switch to the **fifth** application, "**Clock**", in this category.
- **Exit** this category **start at 5:30**

*b) Task 2 **start at 5:45***

- **Switch** to "**Navigation**" category and **enter** this category. **start at 5:50**
- **Exit** this category **start at 6:00**

*c) Task 3 **start at 6:25***

- **Switch** to "**Communication**" category and **enter** this category. **start at 6:30**
- **State** how many applications there are in this category.
- **Exit** this category **start at 6:50**

End test at 7:00

If the participant failed to do the task before the time marked for next step, the unfinished step was considered as failed and skipped. Failed tasks were marked down.

3) *Interview*

The subjects were informed that if they wanted to participate in the evaluation, the audio of the interview would have to be recorded and would later be transcribed into text for coding. The transcripts and the audio recordings will not be published.

The interview started with 10 background questions (for interview questions, see Appx. 2) including questions on how much they paid attention to the video. This was followed by 11 closed-ended questions and ended with 8 open-ended questions. These are aimed to gather general feedback from the participants on how they felt about the system, if the feedback system was sufficiently functional as well as responses on how they would improve the feedback system.

The closed-ended questions are taken from USE(Q.15-Q.21) and NASA-TLX (Q.11-Q.14). Questions are modified to be more related to the study and fit the style of an interview. A 6-point Likert scale is applied, in order to remove the central tendency bias.

NASA-TLX (Task Load Index) is an assessment tool developed by NASA, and it is widely used to evaluate the perceived workload of a task, system or similar aspect. It is in the form of a questionnaire that focus on the mental demand, physical demand, temporal demand, performance, effort and frustration.

USE questionnaire is a free and standardised questionnaire that is an assessment tool developed by Arnold M. Lund and his colleagues. It is used to measure the usability of a system from the aspect of Usefulness, Satisfaction and Ease of use.

Q.22 – Q.28 are open-ended questions, that aims to collect more subjective and quantitative data.

Table I shows the goal of each open-ended questions, e.g. what kind of information each question is asked to obtain. In Q.15 – Q.17, since different groups are only using one of the systems, in order to draw useful result, the question needs to compare the system they used with another system, this is done by comparing the system under evaluation to a legacy system.

[1] Link to the video (4:50-7:00): https://youtu.be/Yy-UWWMt-W8

TABLE I. DATA COLLECTED FROM INTERVIEW

Q.ID	Goal
Q.22 Could you use the system without looking directly at the screen?	Gather information about whether if the participant can use the system without looking at the screen. (RQ1)
Q.22.A What would enable you to better accomplish this?	Gather information about how the participant think, that can be considered as ideas of improvements. (RQ2)
Q.23 Did the system feel distracting in any way, compared to a legacy infotainment system?	Aim to find out whether if the system used in the evaluation is considered distracting or not, by the participant (RQ1)
Q.24 Would you prefer navigating by looking at the screen or with the use of feedback?	Find out the participant's preference, and if the evaluated system is believed to be better than a legacy system in the sense of reducing distraction (RQ1/RQ2)
Q.25 How do you feel about the system in general?	Gather general remarks about the system. (RQ2)
Q.26 Do you have suggestions for improvements?	Requesting direct suggestions to improve the system (RQ2)
Q.27 Do you see yourself using this kind of system in the future?	Gathering preference, on whether if the participant would use a gesture-controlled system in the future (RQ1/RQ2)
Q.28 What do you feel is crucial for you to want to use this system?	Requesting participant to give insight on what's important for them to want to use a gesture-controlled system, collecting user requirements. (RQ2)

The open-ended questions were recorded with two different phones, a Samsung Galaxy S8 and a Samsung Galaxy Note8, to create redundancy. The recordings were then transcribed and coded into different categories.

4) *Data Coding*

The data collected from the interviews was processed collaboratively by the researchers. Statements made by the participants were categorised with the use of keywords that best describe their sentiment. By using these keywords, similar opinions of the participants could be better correlated. This is to then be able to present the results in a more cohesive and comprehensive manner.

Remarks related to both setups as well as the gesture-controlled infotainment system were given a description, but only the entries related to the feedback system was analysed and discussed in detail.

5) *Preliminary Test*

The way the system communication was built, was using an external development tool for the gesture recognition system. The camera sent information to a camera suite (the development tool) on the computer, which then sent the gesture commands via a socket connection, passed into an android virtual machine hosting the infotainment software, where it was then used to control the system. Somewhere in this chain, an instability existed, resulting in limited uptime of the system.

A preliminary test was conducted using the researchers as subjects, to evaluate the setup functionality. We found during these tests that the hardware setup was limited in the amount of time it could be kept running, and it needed to be shut down for a time before it could run again. The maximum reliable time we could achieve was 5 minutes, with 20 or more minutes of downtime, limiting the duration a test could be performed reliably.

The original interview questions taken from NASA-TLS and USE used 21-point and 7-point Likert scale questions, it was found that while doing the interview, asking the participant to rate from 1 to 21 was considered to be a too large of a scale when asked in an interview, and odd numbered Likert scale might result in participants more willing to select the middle/neutral selection, therefore, the questions taken from both standard questionnaires were then reformatted to a 6-point Likert scale.

During the preliminary test, we found that the colour purple initially used for the Colour Feedback System appeared to be too similar to the colour of blue while identifying colours using peripheral vision, therefore, fuchsia was selected to be a replacement of purple.

IV. RESULTS

A. *Artefact*

The artefact developed for this study implements only the most basic functionality, to serve the purposes of the evaluation. It was developed to conform to the design of the existing infotainment system GUI, as to limit the amount of novel functionality and instead focus on the method of feedback. The gestures used in the study were taken from the selection of gestures already implemented on the gesture recognition module. Since the programs involved and developed in this study are considered trade secrets, the development of the programs can only be explained briefly.

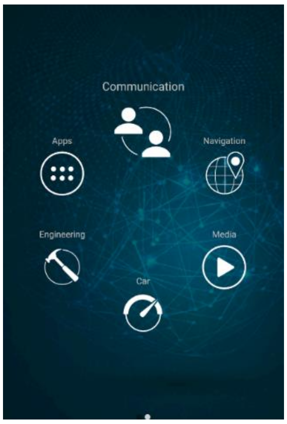

Figure 3. Original Infotainment system

Figure 4. Original Infotainment System in Category “Apps”

As mentioned in the introduction, the infotainment system uses a circular GUI for navigating menus, as shown on Fig. 3 and Fig. 4. The user can rotate their finger in a circular motion to select different categories and click on the category icon to view applications that belong to that specific category. This software was developed for Android, in Android Studio.

Figure 5. Infotainment System with Colour feedback System Implemented

Figure 6. Infotainment System with Colour feedback System Implemented

Figure 7. Original Infotainment System in One Category with Colour feedback System Implemented

The new Colour Feedback System that has been developed and added to the system, it changes the background colour of the Infotainment system depending on what category is selected. It will continue to change colour whenever a different category is selected (Fig. 5,6,7).

There are, in total, 6 different colours implemented into the new Colour Feedback System, they are: red (#ff0000), green (#00ff00), blue (#0000ff), fuchsia (#ff0080), orange (#ff6000), yellow (#ffff00). All colours have an alpha of 50 I.e. the hex code for the colour will be #50ff0000 for red. Colours that are similar are kept apart from each other, e.g. the colours red and orange are not next to each other, in order to improve the contrast of the colour changes when switching category. The colours used in the Colour Feedback System are not according to any colour scheme, instead, colours with stark contrast were selected (red vs blue or green etc.).

It was found in the preliminary test that a person with normal vision should be able to use their peripheral vision to distinguish the colour, therefore distinguishing between categories and different applications that are stored in each category.

The original system did not provide any feedback to the user other than looking at the screen, therefore, a new Auditory Feedback System have also been developed and added to the system for the usability aspect, it was used as the baseline for the evaluation. The Auditory Feedback System have 3 different sounds, it will play the same clicking sound when a gesture is successfully recognised and completed, “swapping” to the next category or the previous category, a different sound is heard when the user “Enters” a category, and finally, another different sound (lower frequency) is played when the “Back” gesture has been recognised by the system and there is a category to exit from (Fig. 7) to the main category selection menu (Fig. 5, 6).

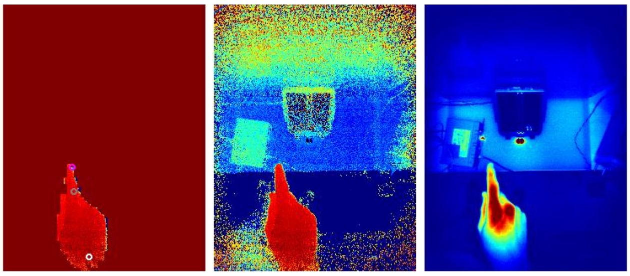

Figure 8. Gesture Recognition System Simulation

The system provided by Aptiv uses different techniques to identify the gestures of the user. Fig. 8 shows the view of the interpreter provided by Aptiv, interpreting the gesture into different commands, that are then sent through TCP/IP, e.g. "Right *Hand Rotate Anti-clockwise*".

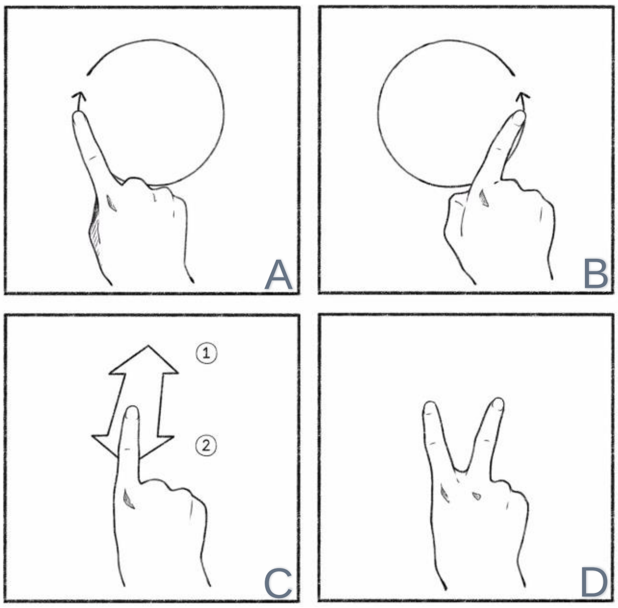

Figure 9. Implemented Gestures

Four different gestures were used in the evaluation, as shown in Fig. 9, A is to rotate the category clockwise with one figure pointing forwards, B is to rotate the category anticlockwise, C contains 2 motions with 1 pointing the finger in and 2 pulling the finger out and D is to exit an entered category.

B. Data Collection

1) *Quantitative Data*

Table II shows the data collected from the interview, where C$\bar{x}$ shows the average value of the result from the control group, T$\bar{x}$ shows the average value of the result from the treatment group. A column labelled with "*d*" is also added with the difference between C$\bar{x}$ and T$\bar{x}$.

The first five questions (Q.1 - Q.5) are evaluations of how much the participants payed attention to the video. It is shown as "R" meaning "right", "W" meaning "wrong", for the evaluation of the participant's answer to those questions. Within the 10 participants, 8 participants managed to get more than half of the question correct, with 60% or more correct answers, of which one answered all question correctly. Two participants did not manage to remember the scenario details from the video. Questions from 11 to 21 are the Likert scaled questions, the answers are indicated as number from 1 – 6. Average are added to the column at the end of the table.

As shown in Table II, none of the participants have any form of colour vision deficiency, only participant C3 suffers from some kind of hearing loss, but during the evaluation, the condition was not obvious. Most of the participants have a driver's license, although participant T1 was at the time of the evaluation taking driving lectures, hence T1 had been practicing driving in the past three years, however, C1 had a driver's license but had not driven in the past three years. Although all of the participants are from Aptiv, only three participants (C1, C2, T4) have had previous experience with the original infotainment system.

During the evaluation, T3 could not manage to exit the category, hence failed task 2, T4 selected the 6th application instead of the 5th, therefore failed the task 2.

TABLE II. DATA COLLECTED FROM INTERVIEW

Q.ID \ P.ID	C1	C2	C3	C4	C5	T1	T2	T3	T4	T5	C x̄	T x̄	d
Q.1 How many apps were in the "App" category?	R	R	R	R	R	R	R	R	R	R	1	1	0
Q.2 How many lane switches were there?	R	W	R	R	R	R	R	W	R	R	4/5	4/5	0
Q.3 How many bridges did you pass under?	W	R	R	W	R	R	R	W	W	W	3/5	2/5	- 1/5
Q.4 What was the speed limit?	R	R	W	W	W	R	R	W	W	W	2/5	2/5	0
Q.5 How many cars passed you, going the same direction?	W	W	W	R	W	W	R	W	R	W	1/5	2/5	1/5
NUMBER OF CORRECT ANSWERS IN PERCENTAGE:	60%	60%	60%	60%	60%	80%	100%	20%	60%	40%	60%	60%	0%
Q.6 Do you have any form of colour blindness or vision deficiency?	No	No	No	No	No	No	No	No	No	No	0	0	0
Q.7 Do you suffer from any form of hearing loss?	No	No	Yes	No	No	No	No	No	No	No	1/5	0	1
Q.8 Do you have a driver's license?	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	1	1	0
Q.9 Have you been practicing driving in the past 3 years?	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	4/5	1	-1
Q.10 Do you have any previous experience with this infotainment system from before?	Yes	Yes	No	No	No	No	No	No	Yes	No	2/5	1/5	1
Q.11 How mentally demanding was the tasks?	2	4	2	3	4	2	3	5	1	4	3	3	0
Q.12 How successful were you in accomplishing what you were asked to do?	5	3	4	4	5	5	4	5	5	4	4.2	4.6	0.4
Q.13 How hard did you have to work to accomplish your level of performance?	3	5	4	4	3	4	3	3	3	4	3.8	3.4	-0.4
Q.14 How insecure, stressed or annoyed were you?	3	5	5	2	2	4	4	4	1	3	3.4	3.2	-0.2
Q.15 The system can help me be more effective, compared to a touchscreen.	2	4	6	4	3	3	5	6	5	4	3.8	4.6	0.8
Q.16 Controlling with gestures makes controlling the system easier, compared to a touchscreen.	1	6	4	3	3	2	6	6	4	5	3.4	4.6	1.2
Q.17 It requires less attention to accomplish what I want to do with it, compared to a touchscreen.	1	4	3	3	3	3	4	5	4	4	2.8	4	1.2
Q.18 I believe I can use it successfully every time.	2	3	1	2	6	3	5	5	3	5	2.8	4.2	1.4
Q.19 I could easily remember how to use it.	6	5	5	5	6	5	6	6	5	5	5.4	5.4	0
Q.20 I quickly felt that I became skilful with it.	5	5	5	4	5	5	5	5	4	4	4.8	4.6	-0.2
Q.21 It works the way I want it to work.	2	4	3	4	5	3	4	5	4	6	3.6	4.4	0.8

2) *Qualitative Data*

The qualitative data was collected from the open-ended question in the interview, the transcripts are cross examined by researchers and any similar findings, throughout different participants, were then marked with different categories (codes). This section is divided into control group and treatment group for each category.

The following are some categories used in the coding process:

a) Limitation

The *limitation* category are responses from the participants in the interview that related to the general limitation of the feedback system, for example, if the participant cannot use the infotainment system without looking at the screen, if the auditory feedback is not sufficient and that the system does not provide enough feedback for the participant to use the system etc.

CONTROL GROUP

Most of the participants in the control group have commented on whether they can use the system without looking at the screen (*"No, I couldn't. I don't think I could, even if I got more practice. I mean, you'll have to look what's next…", "Not really, ... I still needed to see the symbols when I do it. ..."*); or a way to confirm that they are in the correct position (*"I don't know where I am, and I know that something moved but I don't know where I am in the system", "Because I needed to see where I was going"*). One participant has expressed that only auditory feedback is insufficient, but better methods of giving feedback were required (*"I don't see how I could use the system without looking at the screen without any form of additional feedback from the system."*).

TREATMENT GROUP

Different from the control group, most of the participants in the treatment group expressed that they can use the system without looking at the screen directly, although one participant mentioned that he/she could not (*"I think umm, not totally, so I needed to see if I'm in the right application,"*); other participants either expressed that they could use the system without looking at the screen or they still needed to glance, but it was due to the fact that he/she was not familiar with the colour sequence (*"Yes, except for when, well I don't remember the colour coding, so I had to look for the name of the application and roughly where it was before I rotated.", "no I could not. Because, I guess getting familiar to the colours. ... if I had more time to kind of study ... then I guess it be good to have, ... easy to identify through peripheral vision what exact category I'm on."*).

b) Suggestion

Suggestions are labelled by comments that the participants gave during the interview that contain ideas for the feedback system. It can be improvements to the current solutions (auditory feedback or the combination of auditory and colour feedback), or other ways of giving feedback as an addition to the system, e.g. voice assistant.

CONTROL GROUP

All of the participants in the control group managed to give suggestions on how to improve the system. Some suggested that a Virtual assistant that reads out the category title or the application name would be preferred (*"if there is some sound. like um when I rotate it, "navigation", "Communication", so I know I am in the right...", "why not have audio feedback; if you choose, say, "car" (the menu category) ... but that would also be quite irritating I think. But could be nice."*); other participants wanted either a secondary screen closer to the dashboard, or a windshield projector that projects the necessary information (*"if I had some feedback in the cluster ..., closer to the steering wheel - and get feedback from the cluster. Then I would be more comfortable.", "... having this screen here *pointing to behind steering wheel* instead. I think that would be an improvement…", "It's one of those that projects under the windshield. ... then I don't have to look like this"*).

TREATMENT GROUP

The participants in the treatment group have gave different suggestions as well. Similar suggestion to a voice assistant have been brought up during the interview (*"...some sound for example. Like "navigation selected" or "car selected" - or the name of the app that's currently highlighted."*). Other suggestions such as customisability (*"if I was allowed to rearrange, or put a colour to my own categories, like phone: I want it green…"*); voice control (*"maybe a gesture that could enable a mic that could listen to you where you want to, what you want to do, so you could just speak to the system", "maybe you need to incorporate other senses, other inputs, like voice"*); the position or size of the screen (*"Maybe a bigger display could also make a difference", "...maybe something closer to the driving wheel..."*); and different auditory feedback (*"If you can hear something like a different sound notification.", "maybe different clicks even, to which category you are on ... different sounds depending on where you are."*).

c) Requirements

The following section summarises comments that were considered as requirements to a gesture-controlled infotainment system, examples such as good usability, accuracy or reliability etc., therefore labelled "requirement" in the data coding process. However, this study is focused on the feedback rather than the system itself, the result will be still listed but will not be analysed further.

The crucial factor that would make the participants want to use the system, are similar for both groups. Most of the participants required good usability, such as user experience, accuracy, responsiveness, and allow the user to recover from fault (*"I think that's very critical that you can use it without having any prior experience, or, having to practice anything.", "That it works well with the gestures.", "Maybe have a smoother experience", "need to be more user-friendly...", "Performance need to be quick.", "It's ok if it fails sometimes as long as I can verify where I am by sound or by colour for example.", "Usability. How easy it is for me to learn the gestures, and how easily the system can detect my gestures."*). Some of them require the system to be more reliable and responsive (*"I also feel like sometimes... accuracy ... I don't know here I should click", "I guess not failing", "first of all it needs to be much more responsive in order to be useful in a real car - real driving situation. ... the responsiveness is the main thing ...", "I would say performance, as in it being responsive."*).

d) Praise

The following section includes all remarks made by the participants, expressing their approval or appreciation to the feedback system, comments such as positive remarks on the auditory feedback, the colour and that the auditory feedback method requires less attention compared to legacy systems etc.

CONTROL GROUP

During the interview, participants of the control group have shown their appreciation towards the system. Although most of the praise are commenting on the gesture recognition/control technology (*"Yeah, the technology is cool in the sense that you don't need to touch anything.", "So like a summary...I think it's very promising technology."*). One participant in the control group have expressed positive remarks towards the auditory feedback system (*"I think the clicking noise is good."*). One participant thinks it is easier to use compared to a system using touch screen (*"... comparing it to a touch screen, where you need to find where is the button - it's easier to use without looking."*).

TREATMENT GROUP

Participants in the treatment group provided more positive remark on the system, which includes the usability (*"Generally I would say, from a usability view it's good. I like that I was able to learn the system like really quickly", "I think that is already very user friendly.", "I think it's more productive", "because I don't even need to look directly to the to the display there, when there is a colour and I know this is red and I'm in the navigation point for instance."*); the user experience (*"Gives the user a very exciting experience, and - to have gesture control. It's much easier for users. ... Good user experience. Good innovation for safety.", "Other than that I think it's good, and especially the sound cues when you rotate."*); and that the system requires less attention (*"It's less distracting, I would say."*).

V. THREATS TO VALIDITY

1) *Internal Validity*

Due to the time constraint of this being a 10-week study, compromises to the typical multi-iterative process of Design Science had to be made. Instead of following the first iteration of the software, built based on researched current technology, with a second iteration of development based on feedback of the first artefact, this paper aims to provide data and support for other studies to continue on, suggesting ideas of improvements for gesture-controlled infotainment systems. However, this also means that for the study we could not conduct long term evaluation of the developed feedback system, which is meant for expert use, where it ideally should have been tested for days if not weeks. This problem was also understood by many of the test participants, saying they believe they could use it "eyes-off" given time to practice.

The constructed test setup used hardware, as mentioned earlier in this paper, where the connection between the gesture recognition module and the infotainment system limited our test durations due to an uptime of only about 5 minutes at a time. If the camera module were turned on after a recent drop in connection, it would only run for about 1 minute before dropping the connection again. Tests of the modules were conducted trying to analyse what caused it to lose connection, no clear reason was discovered, but turning off the camera module for around 20 minutes would allow for another 5 minutes of use. This had to be taken into account when designing the evaluation test, thus we could not achieve more than 4 minutes of hands-on to leave some margin, introduction included. Luckily there were no issues of the server crashing during any of the sessions.

Since the researchers themselves conducted the interviews, transcripts and coding of the transcripts, there might be forms of researcher bias. All researchers followed their respective scripts during the interviews in order to manage the risk of influencing the data, as well as them retaining their roles. The categories used for coding the transcripts were also discussed between researchers, in order to try to make them as objective as possible.

Although questionnaires are not used in the evaluation, questionnaire styled questions are still used in the interview. There participants were asked to rank/rate the answer with a number (Likert scale), thus different forms of response bias were needed to be taken into consideration.

The Likert scaled questions are taken from two different standardised questionnaires, and then modified to fit the purpose of this study. By using a 6 points rating, it was meant to force the participants to "pick a side", as in making their results positive or negative. This was a conscious decision to decrease the effect of social desirability bias, the opposite of extreme response bias.

2) *External Validity*

The participants of this study were all sourced from Aptiv, they have signed up via an online sheet that was passed around the office at Aptiv, this means that the sample was not randomly selected since all participants signed up freely. This opens up for bias in the form of participants already having interest in gesture-controlled infotainment systems. As mentioned earlier, three participants of the sample group had previous knowledge about the infotainment system. In regard to the sample size of 10 participants, having three of them know about it from before is significant. However, only one participant stated he/she had actually used the system in development, the other two had briefly seen it. As the layout of the infotainment system menu is of a generic style it is believed to not pose any major threat to the validity of the study in that regard.

As for data collected during the interviews, since the participants work in a department that develop solutions for infotainment systems in cars, it can be assumed that the interest expressed during the interviews may affect the result, as it is within their profession.

The setup was designed to resemble a car environment in terms of the use and positioning of the screen showing a video from a driver's perspective, the position of the infotainment system and the gesture camera. However, with the lack of a steering wheel, pedals and other key components, the setup does not fully reflect a test done in an actual car and on an actual road. In addition, the position of the screens in relation to each other are not exactly the same as in an actual car, but instead a rough estimate. This may cause the results to be skewed, as it may be easier or harder to see the infotainment screen in the peripheral vision.

The tests are done in a controlled environment where the mental demands of the given tasks are different to those in a traffic environment. This means that the results are less accurate compared to what they would be in a test on drivers in normal traffic, or at least a good simulation of it.

3) *Generalisability*

During the evaluation, as mentioned before, only 10 participants participated in the evaluation, therefore the data might not be significant enough to be generalised in the bigger scale. Studies using more data points should be conducted to better consolidate an answer.

The evaluation is done in Gothenburg, Sweden, the langue used is English. The driving/traffic situation may differ from other countries, e.g. left-hand traffic or right-hand traffic, different regulations etc., studies have also been conducted suggesting that different cultures may affect driving habit and driving safety [18], therefore, further localisation studies should be conducted to revaluate the results.

As the study is mainly focusing on the use of shifting colours to inform the driver the with state of the infotainment system. This affects the generalisability since part of the population has some form of colour vision deficiency and may have difficulties using the system as intended. Therefore, while designing such systems in the future, colour vision deficiency should be taken into consideration while selecting colours used in such colour feedback system. Alternatively, develop modes for different types of colour-blindness.

VI. Discussion

For RQ1 to come to any meaningful result there needs to be a discrepancy between the control and treatment group, as it is in regard to how peripheral and auditory feedback holds up against the use of only auditory, using gesture-controlled infotainment system. RQ2 is focused on further development of feedback methods for the infotainment system and requires suggestions, from different participants, that complement each other.

In the control group, participants were asked to evaluate a gesture-controlled infotainment system with only auditory feedback. All of the participants managed to score 60% of the answer correct, where the questions are designed to find out whether if they have been paying attention to the driving scenario. This could mean that the participants of both the control group and the treatment group experienced the same level of distraction. It is arguable that one participants claimed that he/she is suffering from some kind of hearing loss, as mentioned previously, thus the auditory feedback might not be helpful to that participant. Additionally, this participant said that it is easier to use the system comparing to the legacy infotainment system (with buttons etc.).

As for the treatment group, participants evaluated the same system as the control group but with the addition of the changing colours when cycling the menu options. On average all participants performed equally to the control group, 60%, yet some participants in the treatment group performed either worse or better compared to the control group, showing a wider distribution. One participant (T3) only got 20% of the questions 1-5 right, whilst one (T2) scored a full 100%. This is likely due to normal variance among the participants as participant T3 experienced the tasks to be more mentally demanding (5/6) compared to T2 (3/6) as seen in Q.11.

All of the participants in the control group managed to finish all of the tasks with no great difficulties, as shown from the result from Q.11, Q.12 and Q.14, although around 60% of the participants answered with 4 or greater in the question, the participants reported that they need to work harder to achieve what they were asked to do (Q.13). T3 and T4 both failed at task 2, with the reason that, T3 could not remember the gesture to exit the category, the gesture of showing the index figure and the middle finger in a V-shape, when the participant tried to exit; T4 selected the 6th application in the category instead of the 5th, it is because that the participant was not looking at the screen but instead relying on the feedback system implemented, participant heard 5 sounds and saw 5 different colour changes and thought that the system was at the 5th icon instead of 6th. This was stated during the evaluation.

The difference comes between the question Q.15-18. Where most of the participants from the treatment group expressed that they believe that they can control the system with ease, use the system with more effective results and that the system requires less attention, when comparing to legacy touch screen infotainment systems. In contrast, participants in the control group shows a reported lower average according to the results. This suggests that with the same level of performance and attention paid to the road while driving, the system with both colour feedback and auditory feedback show a positive impact on reducing the distraction in terms of usability.

All of the participants in the control group claimed that they cannot use the system without looking directly at the screen if there are no feedback, in the interview. This might be due to the fact that participants are used to have some kind of sound feedback while using any kind of technology, whether if it is a phone or an infotainment system and are therefore expecting the system to have haptic or tactile feedback by default for example, and therefore weakens the effect of the auditory feedback. Where comparing to the treatment group, 3 participants claimed that they do not need to look directly in to or glance at the screen while using the system, after getting familiar with it. Hence, the colour feedback can be considered as a reinforcement feedback that helps the driver to navigate the infotainment system, therefore reducing distraction.

During the interview, participants are asked to give suggestions on how to improve the system in a way that they believe is less distracting and enables better usability. Participants from both groups have mentioned voice assistant as suggestions i.e. the system will “read out” the category names of the menu, gestures recognised or the application names, with the reason that they are seeking a way to confirm where they are in the infotainment system. Some participants mentioned that the auditory feedback can be modified for different categories, i.e. different sounds or different tones will be played for different actions and when different categories are selected. Some participants mentioned that a voice assistant could be a distraction while driving and can create annoyance or frustration, e.g. if the voice assistant kept on saying the wrong action when the system does not recognise the gestures or mistakenly recognise a gesture. Further studies need to be conducted to determine whether if a voice assistant is increasing the amount of distraction, or if it can be an improvement for existing solutions. It is worth mentioning that the participants from the control group did touch upon using peripheral vision similarly to the solution we had as test setup for the treatment group.

Setup suggestions such as dashboard display, windshield projector or dashboard LED light that also changes colour are also mentioned in the interview and can be applicable to the system, since some of the participants mentioned that it is of their preference to look at the screen to gather the correct information while interacting with the infotainment system. Moreover, some participants also commented on the gesture-controlled infotainment itself, they stated that they wanted additional, and more intuitive, gestures and that the system should have high accuracy when recognising gestures. Customisability of the order the categories or the colour of each category's representation is in, as well as customisation of gestures, are also mentioned during the interview. It is suggested that further studies should be conducted to evaluate how different feedback or the effects of different combinations of feedback can improve usability and minimise distraction.

VII. Conclusion

The goal was to look for a way to deliver useful information to the user while driving. It is challenging, as the infotainment system by its nature can be considered a distraction [17]. With the use of different feedback such as auditory (the clicking sounds, the voice assistant etc.), visual (colour coding of the category perceived through peripheral vision, windshield projector etc.) or even vibrio-tactile feedback [16], the infotainment system is becoming less distracting.

With the combination of colour and auditory feedback (the treatment group), some participants were seemingly able to navigate through the system without any issues, and most of the participants believed that if they were more familiar with the system, they could easily use the system without looking at the screen. Thus, the driver may be able to keep their eyes on the road the whole time when using the infotainment system. There are small differences in the results between the treatment group and the control group, i.e. participants from the treatment groups gave more positive feedback in general during the interview but based on the quantitative and qualitative data collected, and due to the sample size (10), it is hard to distinguish whether if the participants are more interested in the gesture-controlled system or the way the gesture-controlled system is giving feedback. Additional studies on what combination of feedback could provide better results when using visual, auditory or even tactile feedback should be conducted. Research to better distinguish between whether if the participants are more excited about the gesture recognition technology in general (warping the data) or of how the different ways of giving feedback is affecting the participant's preference, should also be conducted.

For future studies on using peripheral colour feedback, looking into how colour relations affect user performance is important. This could allow for different colour setups for different users, or even customisation. This is especially important for users with different colour deficiencies or preferences.

It is acknowledged that due to the limitation of time, number of participants and the laboratory evaluation setup, the result may not be applicable to a bigger scale, therefore research should be done to replicate or improve on the findings of this study but with a more realistic setup, ideally in an actual in-car environment.

The results from this study can hopefully provide support for both future studies on methods of feedback, and apply to more than specifically infotainment systems, as well as a methodology for additional cycles of our design science study.

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APPENDICIES

Appendix 1 – Script used in the evalation

Script

We would like to thank you for participating in this evaluation for our project.

Before we start introducing you to the system we would like to inform you that participating in this evaluation will not cause you any mental or physical damage. Your performance will not be judged in anyway, the result and any data collected in the evaluation will not affect your job evaluation, the manager will not be able to get specific evaluation details, this means your identity will be kept anonymous. You have the right to withdraw at any time of the study, by contacting us. The evaluation will have 3 different stages. We will first introduce you to the system, then we would like to ask you to evaluate the system by performing a few tasks we designed for you. Finally, we would conduct an interview related to how you feel about the system. Please be noted that we will need to make an audio record of the interview, so that we can transcript it into text for our study to use. The recording and the text transcript will only be used for the study and will not be published publicly.

Do you have any questions?

If you agree to the recording and have no further questions, we will now introduce you to the system.

First, we would like to inform you about our purpose of the evaluation which is to evaluate the usability of the infotainment system.

So, please allow us to introduce you to the system. The system is an infotainment system. *(show the system)*

The system can be controlled by gesture, so far, we have 4 set of gestures implemented,

- One is switching to the left
- One is switching to the right
- Enter the category (like the clicking or tapping action)
- Exit the category
-

***The following will be only explained to treatment group.* **

- *One colour for each category,*
  - *Blue*
  - *Red*
  - *Green*
  - *Yellow*
  - *Fuchsia*
  - *Orange*

There are applications stored in some of the categories, for example the Apps category which is indicated as red, Communication category which is blue, and navigation category which is orange.

End

Feel free to try it out by yourself and get familiar with it.

2 mins

Now that you have tried the system out by yourself, we would like to start the evaluation.

Please sit here. Notice that we have two screens here, the one in front of you will be showing you a clip of video recording which is recorded while driving, we would like you to think that you are driving, keep your eyes focused on the road, and the environment.

During the evaluation, we would like you to count how many times you have switched lanes.

And please pay attention to the surroundings as if you are driving.

During the evaluation we would also read you some instructions which is related to the interaction with the infotainment system, we would like you to follow the instruction, execute them when you are instructed to do so, otherwise we will remain silent.

Please note that you CAN NOT do wrong in this evaluation, and we will only be giving the instruction and that's all.

Now, if you don't have any questions, keep your eyes on the road, and let's begin the evaluation.

evaluation start with category Car, Video starts with time stamp 4:50

a) *Task 1 **start at 5:00***
- Please switch to "**Apps**" category and **enter** this category ***start at 5:05**.*
- Please switch to the **fifth** application, "**Clock**", in this category.
- Please **Exit** this category ***start at 5:30***

b) *Task 2 **start at 5:45***
- Please Switch to "**Navigation**" category and **enter** this category. ***start at 5:50***
- Please **Exit** this category ***start at 6:00***

c) *Task 3 **start at 6:25***
- Please Switch to "**Communication**" category and **enter** this category. ***start at 6:30***
- Please **State** how many applications there are in this category.
- Please **Exit** this category ***start at 6:50***

End at 7:00

Thank you for participating in the evaluation, we would like to ask you some questions.

As a reminder, we will be doing an audio recording during the interview, your audio record will not be published, the recording will only be used for our study. You have the right to withdraw at any time as you wish, if you want to find out your result or the result of the study, you can contact us.

***Start recording. Read the questions from the questionnaire and take down answers" ***

We would like to thank you again for participating in our evaluation, your result will be a great help to our study and we would like to ensure you again that you will be kept anonymous in our study. If you don't have any questions right now, the evaluation is completed.

Please contact us if you have any questions related to the evaluation or the study in the future.

Please do not tell your colleagues about the study and what you did before Friday (2018-5-18).

Have a nice day!

B. Appendix 2 – Interview Questions and Form

Interview

Participant ID ________________

1. How many apps were in the "App" category? ______________

2. How many lane switches were there? ______________
3. How many bridges did you pass under? ______________
4. What was the speed limit? ______________
5. How many cars passed you, going the same direction? ______________
6. Do you have any form of colour blindness or vision deficiency?

   □Yes □No

7. Do you suffer from any form of hearing loss?

   ☐Yes ☐No

8. Do you have a driver's license?

   ☐Yes ☐No

9. Have you been practicing driving in the past 3 years?

   ☐Yes ☐No

10. Do you have any previous experience with this infotainment system from before?

    ☐Yes ☐No

11. How mentally demanding was the tasks?

    Very low ☐ ☐ ☐ ☐ ☐ ☐ Very high

12. How successful were you in accomplishing what you were asked to do?

    Very low ☐ ☐ ☐ ☐ ☐ ☐ Very high

13. How hard did you have to work to accomplish your level of performance?

    Very low ☐ ☐ ☐ ☐ ☐ ☐ Very high

14. How insecure, stressed or annoyed were you?

    Very low ☐ ☐ ☐ ☐ ☐ ☐ Very high

15. The system can help me be more effective, compared to a touchscreen.

    Strongly disagree ☐ ☐ ☐ ☐ ☐ ☐ Strongly Agree ☐ N/A

16. Controlling with gestures makes controlling the system easier, compared to a touchscreen.

Strongly disagree ☐ ☐ ☐ ☐ ☐ ☐ Strongly Agree ☐ N/A

17. It requires less attention to accomplish what I want to do with it, compared to a touchscreen.

Strongly disagree ☐ ☐ ☐ ☐ ☐ ☐ Strongly Agree ☐ N/A

18. I believe I can use it successfully every time.

Strongly disagree ☐ ☐ ☐ ☐ ☐ ☐ Strongly Agree ☐ N/A

19. I could easily remember how to use it.

Strongly disagree ☐ ☐ ☐ ☐ ☐ ☐ Strongly Agree ☐ N/A

20. I quickly felt that I became skilful with it.

Strongly disagree ☐ ☐ ☐ ☐ ☐ ☐ Strongly Agree ☐ N/A

21. It works the way I want it to work.

Strongly disagree ☐ ☐ ☐ ☐ ☐ ☐ Strongly Agree ☐ N/A

22. Could you use the system without looking directly at the screen?
    a) What would enable you to better accomplish this?
23. Did the system feel distracting in any way, compared to a legacy infotainment system?
24. Would you prefer navigating by looking at the screen or with the use of feedback?
25. How do you feel about the system in general?
26. Do you have suggestions for improvements?
27. Do you see yourself using this kind of system in the future?
28. What do you feel is crucial for you to want to use this system?

C. *Appendix 3 – Full table of interview data coding*

ID	Description	Reference	Code
C1	Higher level of distraction	So - I wouldn't say it's very distracting but it's more distracting than a legacy system is.	Distraction Remark
C1	More feedback needed to use without a screen.	Test Subject : I mean, I could use it but then i wouldn't get any feedback right since then we don't have any audio feedback or haptic feedback, so, I don't see how i could use the system without looking at the screen without any form of additional feedback from the system.	Limitation
C1	Audio feedback is insufficient.	Test Subject : Oh yeah, yeah actually that's a good point. But I don't know where I am and i know that something moved but I don't know where I am in the system. But that's - yeah, it did have audio actually. It was kind of subtle, the sound.	Limitation
C1	Positive feedback on gesture recognition	So like a summary...I think it's very promising technology.	Praise
C1	Positive feedback on current solution	I like the gestures and the whole thing - one finger and then two - that's kind of convenient and easy to understand. I think it's - you did a great job of making it simple. It's very intuitive.	Praise
C1	User habit	So in general I prefer having physical buttons. I don't - I'm not fond of touch screens either	Preference
C1	Safety concern	I feel like it's more dangerous when - I don't get enough feedback from the system compared to turning a knob or something.	Reflection
C1	Safety concern	But I feel like looking to the side, or like looking down there *pointing down to his right side* is more distracting and more dangerous. Especially if you're driving in high speeds.	Reflection
C1	Voice feedback may be more distracting	Yeah I'm not sure what kind of feedback would be appropriate, because I think it would be more distracting if I would, let's say, have a voice telling me "this is; camera, calendar" as I swipe - or something.	Reflection
C1	Usefulness remark	But then of course I don't know how it would be navigating apps themselves, that's the next question right?	Reflection
C1	Interest remark	But yeah, I could see myself using some kind of gesture recognition in a car.	Interest
C1	HMI is to complex	Then also, this user interface with this round scrolling thing - I feel like, maybe it's not the best. it's to complex,	Requirement
C1	Reiterate responsiveness	I would say performance, as in it being responsive.	Requirement
C1	Reiterate responsiveness	But I think, first of all it needs to be much more responsive in order to be useful in a real car - real driving situation. ... the responsiveness is the main thing ...	Requirement
C1	Ergonomics concern	if I'm driving, then it's also not very ergonomic. It's not nice for the shoulders. I feel like some older people might not be able to do it, so I think that is a potential problem as well.	Requirement
C1	Unpredictable gesture performance	Test Subject : I think the main problem with this system, as it is right now, is the responsiveness - it's slow and it's like, you don't really feel like it's corresponding. You know, If you move your finger faster, then you swipe faster. Like, if you swipe between home screen on your smartphone or your tablet or what ever.	Setup Limitation
C1	Visual feedback from the dashboard	What could work is like .... if I had some feedback in the cluster ...smaller movements or gestures, closer to the steering wheel - and get feedback from the cluster. Then i would be more comfortable. ... as a driver you're kind of used to looking at the speedometer now and then.	Suggestion
C2	Required glancing at the screen	Sometime ... I had to look into the screen,	Limitation

C2	Prefer using both screen and feedback	I think both, uh... So normally, I just want the feedback, ... when I mistaken how sure I am, so if you say "navigation system" , then ... i'm quite sure, but if you just "deng, deng" so I know its change so it sense my rotating ... but I don't know if I'm in the right target... if i'm quite sure, then I don't have to look into the screen	Preference
C2	Participant felt system was distracting	Yea.. I think there is... some disturbances.	Reflection
C2	Remarks responsiveness	I think they have potential, um... because, I think if somebody call me, then I switch then that's that's could be quite handy. But because the response is rather slow so, oh.. yea.. I think there is potential with this system	Reflection
C2	Interest only if system is reliable	(Do you see yourself using this kind of system in the future?) Yea? if I can relax and not so very stressful, I think that's that's ok.	Interest
C2	Voice feedback	If, if there is some sound. like um when I rotate it, "navigation", "Communication", so I know I am in the right... the system shouldn't say too much then you feel annoying...	Suggestion
C3	Not able to use system without looking at the screen	No, I couldn't. I don't think I could, even if I got more practice. I mean, you'll have to look whats next on the clock (menu system interface)	Limitation
C3	Positive feedback	I think the clicking noise is good	Praise
C3	Easy to learn	I think I understood how it worked quite quick. It was very easy gestures, and I think that is very critical	Praise
C3	Would like to have the option of chosing mode of interaction	I would prefer to have - to be able to chose the option, but probably looking at it.	Preference
C3	Felt that the GRS could be more distracting	The least distracting thing is proper good old fashioned buttons because you know you did hit ... I felt that I need to check that it actually do what I want it to do.	Preference
C3	Finds GRS easier to use, if not looking at the screen, compared to touchscreen	... comparing it to a touch screen, where you need to find where is the button - it's easier to use without looking.	Reflection
C3	Participant wants good usability	I think that's very critical that you can use it without having any prior experience, or, having to practice anything.	Requirement
C3	Problems with the experiment setup	it's gonna be a problem if you gonna need your hand here *gesturing to his right where the console is* I think so - maybe - a wider angle camera would be preferable.	Setup Limitation
C3	Visual feedback from the dashboard	... having this screen here *pointing to behind steering wheel* instead. I think that would be an improvement because then you don't need to take your eyes of the road. ... instead of looking down to the right, taking your eyes completely off the road	Suggestion
C3	Voice feedback	And, yeah why not have audio feedback; if you choose, say, "car" (the menu category) ... but that would also be quite irritating I think. But could be nice.	Suggestion
C4	Found the system distracting	Yeah, a little bit. Maybe because I'm not used to it. And I felt like I missed a couple of times, like I didn't manage to leave a menu or something.	Distraction Remark
C4	Unpredictable gesture performance	Practice, I guess? Or - maybe scrolling a bit faster. it's a lot of spinning (with hand) and if miss one number, I'm lost. Then again I don't know if - how I'm supposed to know where I am without looking.	Setup Limitation
C4	Interest in the system	Because it's kinda fun, and I think if you get a hang of it - it can be very convenient.	Praise
C4	Require looking at the screen	Because I needed to see where I was going.	Limitation
C4	General feedback on the system	It worked a lot better than I thought ... and the best one was the two-finger (gesture) to move back.	Praise

C4	Usability preference	there were a lot of spinning, *inaudible*, so maybe move two steps per 360 degrees.	Preference
C4	User prefers using screen	I would say: screen.	Preference
C4	User wants 2 menu steps per rotation	(be sure about where you were in the system, ... Is that what you mean?) I guess so, maybe.	Requirement
C4	System reliability	I guess not failing	Requirement
C4	Unpredictable gesture performance	I wanted to scroll and it clicked instead, and that's - I don't think that would happen if I had buttons.	Setup Limitation
C4		I think the spinning was hard, or not so intuitive. It didn't respond exactly as I imagined it would. ... I felt if all the commands would have been as easy as the two-finger command, then it would have been really great.	Setup Limitation
C4	Windshield projector	It's one of those that projects under the windshield. ... then I don't have to look like this *shifting his head down to his right*	Suggestion
C5	Interest in technology	Yes definitely. ... Probably because it is going to be in every car	Interest
C5	Required to look at the screen	Not really, ... I still needed to see the symbols when I do it. ... I think that training over time probably solves a lot of it. Since you are not really 100% sure how much you should turn your finger to move three symbols.	Limitation
C5	Interest in technology	Yeah, the technology is cool in the sense that you don't need to touch anything.	Interest
C5	Prefers using feedback	... it would be much better for driving if you actually get feedback for where you are.	Preference
C5	Remark about performance and reliability about the gesture recognition system	That it works well with the gestures. ... it did not really pick up my finger all the time, but I thought that might be because of the adjustments here but in a car... I would probably get annoyed if it doesn't understand one finger.	Setup Limitation
C5	Suggestion of Virtual Assistant	... a voice telling you in what menu you are. ... because that would actually give you the ability not to turn your eyes towards the panel and check where you are.	Suggestion
T1	Good usability	Generally, I would say, from a usability view it's good. I like that I was able to learn the system like really quickly, like how to navigate around it.	Praise
T1	General feedback on the system	I would say feedback would be better. Though my preference out of now currently is the other term that you used. And the reason behind that is because gesture control systems aren't really effective at this point, so in an ideal world I would obviously want feedback system.	Preference
T1	Postive view on GRS	... if implemented correctly, in the best way, could replace system that exist right now.	Interest
T1	Usability requirement	Maybe have a smoother experience	Requirement
T1	Opinion on what is crucial	(What do you feel is crucial) Reliability and usability.	Requirement
T1	Could not use without looking	no I could not. Because, I guess getting familiar to the colours. ... if I had more time to kind of study ... then I guess it be good to have, ... easy to identify through peripheral vision what exact category I'm on.	Setup Limitation
T1	Responsiveness issue	That would be mainly due to it being kind of unresponsive at times, or maybe not doing the things that I exactly wanted to do.	Setup Limitation
T1	User experience defect	because animations seemed kind of, I'm forgetting the word but, this kind of blocky	Setup Limitation
T1	Customizability	if I was allowed to rearrange, or put a colour to my own categories, like phone: I want it green, so when I'm turning around the screen,	Suggestion
T1	Placement of screen	If it is more closer to the dashboard of the car. That would have made it easier for me to know and see.	Suggestion
T1	Screen size	Maybe a bigger display could also make a difference	Suggestion

T1	More guesture required.	maybe more gestures could also be another thing, into the usability. Maybe you could customise gestures could be another thing.	Suggestion
T1	Voice control	maybe a gesture that could enable a mic that could listen to you where you want to, what you want to do, so you could just speak to the system	Suggestion
T2	Colour helps to identify the category	because I don't even need to look directly to the to the display there, when there is a colour and I know this is red and im in the navigation point for instance.	Praise
T2	Safety concern	... having keyboards and buttons is not very useful, having display, touch, is not that safe maybe.	Distraction Remark
T2	Music control	control the music play	Feature Request
T2	GPS navigation request	navigation is very important	Feature Request
T2	Personal interests on the technology	I totally would like to see this,	Interest
T2	interests in the technology	i personally like to see this technology in the car.	Interest
T2	User can adapt to the colour by training	i think getting used to the colours maybe?	Learning/Training
T2	System limitation	I think umm, not totally, so I needed to see if i'm in the right application,	Limitation
T2	Pro feedback	Yes of course feedback, with feedback is more easy.	Preference
T2	Same level of distraction	(Comparing it if you have the same level of knowledge about this system to compare with one you used before)... I think it might be the same	Reflection
T2	Gesture concern	in terms of actions ... you need to add on... come up with those intuitive gestures ... so that's one thing you really need to consider.	Requirement
T2	Feature request	maybe you need to incorporate other senses, other inputs, like voice, i don't know, maybe one gesture is not enough.	Suggestion
T3	Infotainment system with more functions.	more and more functionality will be integrated to the infotainment system.	Feature Request
T3	Personal interests	(Do you see yourself using this kind of system in the future?) Sure, of course.	Interest
T3	General remark on the system	Gives the user a very exciting experience, and - to have gesture control. It's much easier for users. ... Good user experience. Good innovation for safety.	Praise
T3	General remark on the usability of the system	I think that is already very user friendly.	Praise
T3	Preference on looking at the screen	Personally I prefer to look at (the screen)	Preference
T3	Can use without looking	(Could you use the system without looking directly at the screen?) when you drive or do something, yes	Reflection
T3	Thinks GRS is more distracting	(Did the system feel distracting in any way, compared to a legacy infotainment system?)Yeah absolutely.	Reflection
T3	Usability concern	We need to be more user-friendly...	Requirement
T3	Usability concern	I also feel like sometimes... accuracy ... I don't know here I should click.	Requirement
T3	Usability concern	Performance need to be quick.	Requirement
T3	Different Auditory Feedback	If you can hear something like a different sound notification. ... Tone, notification	Suggestion
T3	Alternative Visual feedback - Colour highlight	You can use the same appropriate colour,but it can be highlighted.	Suggestion
T4	Possitive remark on auditory feedback	Other than that I think it's good, and especially the sound cues when you rotate	Praise
T4	Personal interests	(How do you feel about the system in general?) I feel that I would use it myself	Interest
T4	Pro gesture controlled system	(Do you see yourself using this kind of system in the future?)... Yeah, because it gives me more possibilities to focus on the road	Interest
T4	Using the system for a while can leads to better performance	I actually think that using this for a few more minutes, you know, using it for real would be enough to remember the colours, and then I would be fine.	Learning/Training

T4	User can remember the category	what I mean after a few minutes you'll learn that the next category is two	Learning/Training
T4	Needs to glance at screen before learning colours	Yes, except for when, well I don't remember the colour coding, so I had to look for the name of the application and roughly where it was before I rotated.	Limitation
T4	User habit	I think it didn't really connect for me which direction I was going when I rotated for some reason,	Limitation
T4	Hardware limitation, reliability issue	...as long as the hardware I guess became more capable, and the area you can do the gestures in became a bit bigger; small tweaks to the placement of it, or the accuracy.	Limitation
T4	Prefer to use feedback	With the use of feedback, while driving. ... It just enables me to have more attention to the driving.	Preference
T4	Reliability issue, Usability issue, Recover from fault	Only when it misses my gestures, of course, but... or when missed to do it in the right spot, but that's hardware related I would say, so no.	Reflection
T4	Reliability requirement	getting the accuracy more precise system,	Requirement
T4	Responsiveness requirement	That it is very responsive, or that and a combination of knowing without looking where I am.	Requirement
T4	Recover from fault	It's ok if it fails sometimes as long as I can verify where I am by sound or by colour for example. So the accuracy and the cues.	Requirement
T4	Auditory feedback suggestions	to indicate which category you're at ... maybe not using colours but instead... maybe different clicks even, to which category you are on ... different sounds depending on where you are.	Suggestion
T5	Easy to remember the system	I can easily remember – in two moves for example, there is "navigation"(system category) there or something.	Praise
T5	Interest in using GRS	Whenever I have this kind of opportunity - I'm really into using them.	Interest
T5	Familiar with the system might lead to a better performance	(Could you use the system without looking directly at the screen?)I think so, it required to be a bit more - familiar with the gestures.	Learning/Training
T5	System feels stable after learning/training with it	I mean it - the learning curve in the beginning - but it gave me the idea that it feels a bit stable. So maybe I don't get the gesture correct the first time, but it means it's from my side and I have to find the correct range.	Learning/Training
T5	General remark on the system	(Do you see yourself using this kind of system in the future?) Yes, of course. ... I think it's more productive	Praise
T5	Prefer to use feedback	(Would you prefer navigating by look at the screen or with the use of feedback?) I think feedback - is better.	Preference
T5	Limitation on the legacy system	...it takes full attention for some period of time...	Reflection
T5	Gesture controlled infotainment system is less distracting	(Did the system feel distracting in any way, compared to a legacy infotainment system?) It's less distracting, I would say.	Reflection
T5	Reliability requirement	Importance to be able to what I want it to do, without having to look.	Requirement
T5	Requirement on usability	Usability. How easy it is for me to learn the gestures, and how easily the system can detect my gestures.	Requirement
T5	Voice assistance	Something like a feedback should be - as we have here, some sound for example. Like "navigation selected" or "car selected" - or the name of the app that's currently highlighted.	Suggestion
T5	Screen location	...maybe something closer to the driving wheel...	Suggestion
T5	Touch sensation	...like the sound, that touch sensation.	Suggestion