Enhancing Off-Road Driving Experience with Haptic Navigation

This paper explores the challenges faced by drivers when navigating off-road terrain using visual navigation systems, which can distract them from their surroundings and the road. During this study it will be investigated whether a visual navigation system can be replaced by a haptic navigation system, integrated within the steering wheel. A user test will be conducted to evaluate the user experience of visual-only, haptic-only, and a combined visual-haptic navigation system. The outcome of this study will generate valuable insights for the future development of off-road vehicle HCI. To obtain more accurate results and ensure a more realistic and practical evaluation, it is recommended to conduct further research in a field or more of a realistic lab test setting. This ensures that the test setup aligns more with the real-world conditions, creating a more comprehensive understanding of the subject.

CCS Human-centered computing; Human computer interaction (HCI); Interaction devices; Haptic devices;

Additional Keywords and Phrases: HCI, haptic navigation system, off-road, virtual reality

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1 INTRODUCTION

When traveling through off-road terrain by car, the driver aims to focus on their surroundings to the greatest extent possible, making it difficult to navigate using a visual navigation system. This is due to the fact that the human ability to process multiple stimuli at once is limited. This becomes particularly noticeable when driving a car and attempting to perform other tasks simultaneously [1], such as utilizing the navigation system while driving. Visual input plays a crucial role in driving. Presenting driving advice through visual means can heighten subjective workload and distract the user from the road ahead [2]. Furthermore, an overload of visual information has been demonstrated to negatively impact both reaction times [3] and lateral control [4]. Besides that, two visual tasks can not be performed simultaneously due to the competition for perceptual resources within the visual channel [5].

The sense of touch is an effective, but underutilized, human communication channel [6]. Haptic feedback to support the user in navigating from point A to point B, has frequently been proposed [1,7-9]. Research has shown that employing the tactile modality appears to be a valuable solution to the demands on the automotive industry to improve the man-machine interfaces [8]. Next to that, in 2019, a study was conducted on the effectiveness of using cutaneous push feedback to direct drivers towards their intended route, it was found to be a highly effective form of tactile feedback for navigation, with accuracy scores ranging from 98% to 100% [9]. Furthermore, tactile displays have significantly improved decision making with faster cognitive processing/response speeds and reduced cognitive workload [10]. These benefits could prove to be particularly useful in off-road scenarios.

However, there is a lack of research on the implementation of haptic feedforward integrated within the steering wheel to enhance user assistance focused on navigation along mapped, off-road routes. The shift from combustion engines to electric motors in off-road vehicles enables users to maintain their hands on the steering wheel continuously, as the absence of gears eliminates the need for shifting. This provides new ways of looking at certain possibilities of integrating systems in the steering wheel. Therefore, this study will be researching whether an haptic feedforward force navigation system, integrated in the steering wheel, can, in relation to the visual (traditional) navigation system, better assistance the user and provide a greater user experience while driving through mapped unpaved roads with an (electric) 4x4 car.

The study will start with a short pilot test aimed at designing the appropriate haptic effect and gaining a better understanding of the potential impact of the steering wheel's shape on the user experience. Subsequently, the final user test will comprise three different scenarios. One scenario will involve exclusively a visual modality as a navigation system, another scenario will only have a haptic modality as a navigation system, and last scenario will incorporate both visual and haptic modalities as a navigation system.

2 METHODS

2.1 Participants

To participate, all individuals were required to meet two conditions: to have a valid driver's license and be at least 18 years of age. A group of 21 students (15 male, 6 female), which met these two conditions, took part in the study. The age of the participants ranged from 19 to 26 years old of age (M = 21,9 years, SD = 2,1 years). Out of 21 participants 29% had 0-2 years of driving experience, 52% had 2-5 years of driving experience and 19% had 5-10 years of driving experience. Furthermore, 24% of the participants used their navigation system weekly, 62% used their navigation system monthly and 14% never used it. Out of all the participants 29% drives off-road on yearly base and 71% never drives off-road.

2.2 Pilot test

To gain a better understanding of the appropriate haptic effect and steering wheel shape, which would be used during the final user test, two small pilot tests were carried out. The first pilot test aimed to explore the impact of the steering wheel's shape on the user's behavior while driving. Participants were shown a 2-minute off-road virtual reality (VR) video and instructed to put themselves in the role of the driver, as if they were driving the car. Their steering behaviour and grip on the steering wheel were observed, followed by a semi-structured interview to gather additional insights.

In the second pilot test, the design and timing of the haptic effects were explored. Various effects were developed specifically for different actions (making turns and going straight ahead) upon reaching an intersection. Participants experienced the same situation through the VR goggles multiple times while different haptic effects were played on the steering wheel. Four dissimilar effects were tested for straight driving, while five effects were tested for making turns. Afterwards, participants engaged in a semi-structured interview, expressing their preferences regarding the effects they experienced. These pilot tests provided valuable insights into the influence of the steering wheel shape and the determination of the design and timing of haptic effects for the final user test.

2.3 Data collection and analysis

Before participating in the study, all participants were required to provide their consent. Following this, they were asked to complete a digital demographic questionnaire using Microsoft Forms. This questionnaire aimed to gather general information about their age, driving experience and experience with off-road driving. During the user test, the participants needed to fill in a UX questionnaire each time after they watched one of the VR off-road driving environment video [11]. The participants were given two minutes to fill in each UEQ. Afterwards a semi structured interview was conducted.

The quantitative UEQ data was processed through an Excel format [11]. After the data was processed it was analyzed with a one-way ANOVA and a post-hoc test (Bonferroni Correction). The qualitative data was analyzed using thematic analysis [12]. These phases included getting familiar with data, conducting thematic searches, defining the themes, and categorizing the data accordingly.

3 USER STUDY

3.1 Driving environment design

The VR driving environment was recorded in a forest near Eindhoven. A 1976 Range Rover Classic and GoPro Max were used to create this driving environment. The VR files were edited in Premiere Pro and played through the VR box with an Apple iPhone 12 mini with the VRPlayer app. Three different environments (videos) were created and watched by the user, one haptic environment, one visual environment and one haptic+visual environment. For the visual environments, blue arrows on the road / dashboard were projected, like most common AR head up displays [13]. This so the participants knew which direction the car would take. For the haptic only environment, no visual guidance was displayed, and the participants were guided by the haptic effect. For the haptic+visual environment a combination of both visual and haptic guidance was given. In each driving environment video, participants encountered a varying number of intersections, ranging from 4 to 5. The order in which actions directions were taken at each intersection were completely randomized to eliminate any potential bias. Each video had an approximate duration of 2 minutes. Among the 21 participants, the order in which they experienced the different modality modes was carefully assigned. Out of the total 21 participants, seven participants were given the *haptic* - *haptic+visual* - *visual* order, seven participants were given the *visual* - *haptic* - *haptic+visual* and the remaining seven participants were given the *haptic+visua*l - *visual* - *haptic* - order. Prior to the testing phase, participants were told to imagine being on holiday in a remote country and having the task of driving a relatively long distance between two locations.

Figure 1: Fragments from the visual and haptic+visual modality driving environment.

3.2 Interface design

Following the literature research and pilot test, the final interface design was developed. A combination of custom 3D printed parts, stock plastic parts and electronics. A steel table clamp was used to hold the interface design in place during the user tests. On the left and right side of the steering wheel a high torque brushless motor named Feelix [14] was integrated. The Feelix motors provided the haptic feedforward during the user tests. Before each intersection two pulses were created, indicating the direction the car would take. Before each left turn, the left motor initiated outward rotation, before each right turn, the right motor initiated a outward rotation. When maintaining driving straight at an intersection, both controllers turned inward. This happened 10 and 2 seconds before each intersection. This timing was based on both the pilot test and Di Campli San Vito's study [8]. The adjustments for a precise motor control for the speed and the angle of rotation were created by adjusting the "target_velocity" and duration of the haptic effect in milliseconds (ms). This resulted in a target velocity of 1.5 and a duration of 1000ms for each haptic effect which was given. Both Feelix motors were enclosed by a 3D printed casings with a diameter of 50mm and a height of 90mm, information was taken from the DINED anthropometric database source [15]. The width of the steering wheel (outside-outside) was based on the average width of most steering wheels 400mm [16]. Participants were able to sit in a height and angle adjustable seat from Ahrend [17]. The user tests were consistently conducted at the same location.

Figure 2: User test setup.

4 RESULTS

4.1 UX questionnaire

The User Experience Questionnaire evaluates the user experience on 6 different scales. The attractiveness, the pragmatic perspicuity, the pragmatic efficiency, the pragmatic dependability, the hedonic stimulation and the hedonic novelty. The different navigation systems have a significant effect on difference in user experience, within all scales as can be seen in figure 3. The focus within this study is on the attractive and pragmatic quality side. When looking at the attractiveness scale, there is a significant difference in the mean scores of the modalities ($F(2,60) = 4.54$, $p<.05$.). Post-Hoc analysis revealed that there is a significant difference between the haptic+visual (M0.70, SD1.25) and visual (M-0.18, SD0.6, p<.01.) *(Bonferroni correction)* modalities within the attractiveness scale. Besides that, there is a significant difference in the mean scores of the efficiency ((F(2,60) = 3.372, p<.05.) and perspicuity (F(2,60) = 12.243, p<.01.). The efficiency unveils a significant difference between the visual (M = 0.24, SD = 0.48) and haptic (M = 0.81, SD = 0.95, p<.01.) *(Bonferroni correction)* modalities. On the perspicuity scale, the haptic+visual modality achieves the overall highest score (M = 1.70, SD = 1.05). To finish, the visual modality attains the overall lowest score (M = -0.77, SD = 0.56), this on the stimulation scale.

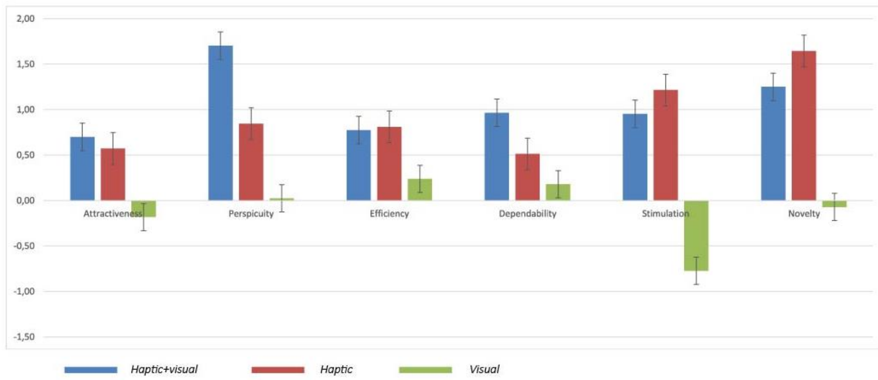

Figure 3: UEQ results.

4.2 Interview

After each participant completed the three UEQ's, a semi structured interview was conducted, focused on the user experience of the different modalities. This to get a better understanding of the overall experience of participants. One of the noteworthy findings was that some participants appreciated having the option to rely on the visual aspect when they missed the haptic effect, as it provided a sense of certainty. This is probably the reason why haptic+visual scores higher on dependability. However, some participants experienced haptic+visual as an incentive experience. In addition, one participant expressed discomfort due to the loss of grip on the steering wheel when both motors were in motion. Nevertheless, the overall experience of the haptic effect, whether this was haptic only or a combination of haptic+visual was experienced as valuable and exiting.

5 DISCUSSION

The results indicate significant difference in user experience across different scales when comparing the visual, haptic+visual, and haptic modalities. However, the way the visual navigation system is imitated differs from what people are used to. This can be attributed to the fact that most individuals are used to relying on a well-established visual navigation system, such as Google Maps, which was not utilized during the user test. Instead, blue arrows placed on the dashboard were used as a substitute. Therefore, the difference in the way the visual system is presented could have influenced the outcome. For example, one participant found the blue arrows annoying in some situations. Nonetheless if the blue arrows would have influenced the score in a not intended way it could be argued that it also would have influenced the haptic+visual score.

Another factor that could have influenced the scores on the scales was the utilization of VR goggles. When conducting this laboratory-based user test with an off-road driving experiment, there were several haptic inputs that were not present. For example, the vibration when sitting in the car seat could influence the dependability score of the haptic modality since it could potentially influence the way the users feel in control of the car in combination with the haptic integration. Incorporating such an effect would require substantial additional development efforts.

While it has proved that it enhances the user experience, it is crucial to understand in what manner it provides added value that users would be willing to pay for. This due to the fact that the user scenario where the haptic controllers would be used is relatively limited in scope. A small proportion of individuals engage in off-road driving, as 91% of the SUV and crossover buyers drive on dirt or gravel one time a year or not at all [18]. Similarly, only 60% of American drivers use a GPS service at least once a week [19]. This makes it arguable for a company to not implement this haptic navigation system in a car. Especially since it is not interesting to use it on road since autonomous cars do not need navigation and if people drive themselves, they often drive with only one hand placed on the steering wheel. Nevertheless, with the rise of electrical off-road cars, there is potential to attract a new audience, as the entire experience of off-road driving undergoes a transformation.

When avoiding any bias and having three different modalities which need to be tested, the participant sample should be divided by six. This so each order of modalities will be experienced. However, due to time constraints, only three distinct orders of modalities were created and tested. Still, each modality has been started and ended with ones.

To finish, the UEQ handbook suggests allowing participants to familiarize themselves with the system before condutcting the user test. This protocol was not followed in the present study, which could have potentially impacted the results. In addition, haptic and haptic+visual scored, compared to visual relatively high but relatively low on most scales when comparing it to the UEQ benchmark, which contains the data of 452 product evaluations with the UEQ (with a total of 20190 participants in all evaluations) [11]. To further enhance the overall user experience, additional development of the haptic controllers is required.

6 CONCLUSION AND FUTURE WORK/LIMITATIONS

In this paper we presented a study that explored the effect of a haptic navigation system to enhance off-road driving experience. Based on the findings, it can be concluded that the addition and so use of a haptic navigation system can enhance the user experience when driving through off-road terrain by car. This solution could potentially support the driver in being able to pay more attention to their surroundings and the road while driving off-road. Besides that, when driving in remote areas there is a chance your GPS system will lack signal and so won’t work properly. A visual display will freeze and will distract you from your primary task, as experienced when creating the VR videos. With this haptic navigation system your route will be downloaded before the start of your journey. By utilizing data from your tires to track the distance traveled, the system can potentially determine the appropriate timing for making turns along the route.

Additional research should be conducted to explore the optimal way of integrating the haptic controllers into the steering wheel interface. This should be argued by the use of a more realistic user test setting. One thing that should be paid attention to is the effect of vibrations on the rotating motors when driving along unpaved roads. An essential aspect to consider is the grip that the user has on the steering wheel, which is a factor that this study has not investigated. Particularly when discussing the force output applied by the motors when rotating, this is due to the variability in grip force exerted by each user on the steering wheel.

Furthermore, attention should be given to the implications of using this system for several hours a day, as it involves repeated twisting of the wrist. How does this prolonged usage impact the long-term user experience? Upon that since the scope is releatvily limited as discussed in the discussion, further research should be done about the possible applications. Nevertheless, the current findings of this study serve as a solid foundation for future research, aiming to enhance the user experience in off-roading activities.

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7 HISTORY DATES

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