Get in touch with mid-air haptic feedback. Human centered design of feedback patterns.

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Abstract: Gestures are one of the most natural forms of mid-air human-machine-interaction and come with many benefits. For example, at public kiosks, an interaction design using gestures come up with a more intuitive interaction in comparison to regular systems. However, compared to manual interaction, no haptic feedback is provided for the user. As a consequence, system usability tends to suffer and acceptance of mid-air gestures is rather low. Here, systems providing mid-air haptic feedback have the potential to overcome this drawback. One approach is the use of ultrasonic actuators which send ultrasonic waves to the hand. However, research regarding human factor aspects is still limited and no guidlines on the design of feedback patterns are available. With this article, the authors report on the user experience during the use of mid-air haptic feedback. In a within-design, four interaction designs and one baseline were presented. Feedback patterns differed in the position when interaction with the object is triggered and the position the feedback has been given. During the interaction, participants were encouraged to formulate their thoughts about the respective type of interaction. Results show that interactions were preferred in which the feedback was presented immediately after the first contact with the virtual object. We conclude that mid-air haptic feedback patterns influence the user experience of gesture interaction and needs to be considered during the design phase.

Keywords: Usability, Human-Machine Interaction, Mixed-Methods Research, Mid-Air Interaction

1. Introduction & Related Literature

Gestures are part of many applications, e. g. virtual environments, infotainment systems or the navigation of cut images of magnetic resonance imaging (MRI). Compared to physical keyboards, buttons, touch or voice interfaces they promise to be advantageous in terms of hygiene, privacy and hedonic quality. Especially because of the tracking with six degrees of freedom (6 DOF), gestural mid-air input is recommended for the use of spatial interaction (interacting with MRI-images, grasping virtual objects or VR interaction). State of the art mid-air interaction is characterized by a touch-free approach, hence lacking haptic feedback. As a result, perceived usability is lower (Hasegawa et al. 2018). Systems providing haptic feedback for mid-air interaction are not established within today's products. One promising approach are ultrasonic actuators, which send ultrasonic waves to the hand. The waves are concentrated on a focus point, oscillate the skin and therefore are perceivable by the user (Rakkolainen et al. 2020). Because of the rapid movement of the focus point, the system can create simple haptic shapes. Also, vortex-generators are a valid alterantiv for mid-air feedback. However, they can't produce simple shapes (Bernhagen et al. 2019).

Given the novelty of the technology, only few research has been done to study human factors aspects of mid-air haptic feedback. A basic technique for the interaction with a user interface is a short vibration when touching a virtual button. In an early study with a head-mounted display and a simple user interface, participants rated that they had slightly less mental, physical and temporal demand then receiving tactile feedback (Sand et al. 2015). Ito et al. (2019) proposed a haptic rendering for a quasi-click sensation. The first state (weak feedback) indicates the first touch of the button and the second (strong feedback) the activation. Participants were able to distinguish between both feedbacks and relate it to a button. Also, virtual piano keys were designed with haptic feedback (Hwang et al. 2017). Here, the authors compared no feedback, continuous and adaptive (increasing in strength) feedback. Results indicate that adaptive feedback was rated better in terms of clarity, reality and enjoyment. Comfort and satisfaction showed no significant difference. Despite comfort no feedback was rated significantly worse for the other categories.

Another design parameter is the position the user receives the feedback and triggers the action. Shakeri et al. (2018) discussed the length of the feedback and studied which other modalities should be presented in parallel. However, they did not systematically vary position or moment of the feedback which was at the heart of the study to be presented subsequently.

2. Method

In the study, a special laboratory set up was used, a 'HapTisch' ('Tisch' is German for table). The HapTisch consists of a 65-inch screen, a Microsoft kinect camera for human motion detection and the ultraleap stratos inspire device. Embedded in an individually manufactured wooden desk and frame, this setup represents a kiosk system (figure 1, right). The software was programmed in Unity3D with ultraleap SDK. It shows a simplified user menu with spherical virtual buttons. On the lower part of the screen the software displays the ultraleap device as a visual reference for the user (figure 1, left). The interaction area was limited to a distance between 10 and 40 cm above the device and an area of 25 cm x 50 cm in depth.

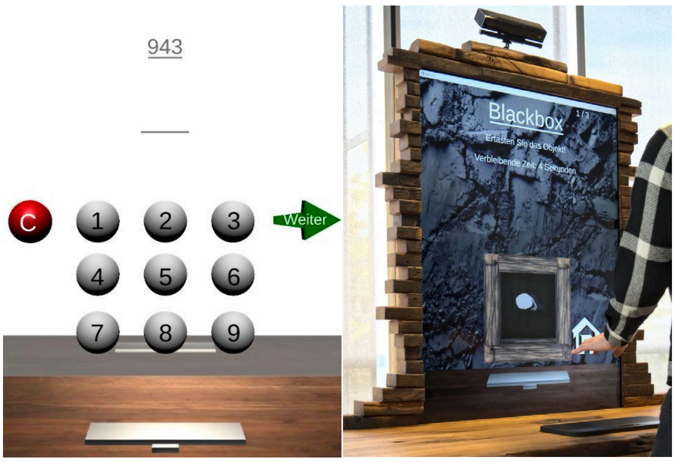
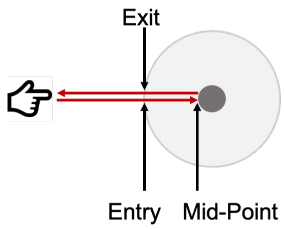


***Figure 1**: Illustration of the user interface (le.) and HapTisch table (re.)*

To asses participant's opinion about different feedback patterns, the button interactions were varied. Three virtual positions for actions and feedback were brought up (figure 2, left). Also, a baseline without feedback was used when the hand reached the outer surface of the sphere (entry). The other conditions varied action and feedback positions as derived in a workshop with human factor experts. In this context, ‘action’ stands for the immediate execution of a function (e.g., press the number or go to the following scene). The following figure depicts an illustration of the conditions.



	Interaction 1	Interaction 2	Interaction 3	Interaction 4	Interaction 5
Entry	Action	Action & Feedback	Feedback	Feedback	
Middle			Action		
Exit				Action	Action & Feedback

Figure 2: *Interaction designs (virtual sphere with a visible boundary and a non-visible mid-point, representing possible trigger points for the button interactions)*

The study started with an introduction to the topic and a questionnaire for demographic data. As the mid-air feedback technology is unknown to most people, participants received a demonstration of the technology by touching virtual bubbles with feedback. Afterwards people had to do two simple tasks. One was to tap three numbered spheres in the right order and second to tap numbers on a virtual 3x3 keypad in the order, displayed above the keypad. The study pursued an explorative research approach. Therefore, the method Thinking Aloud was used to derive qualitative data. Here, the participants should express their thoughts about the interactions, especially on the efficiency and expected feedback. This happened parallel to the system usage. After the study the instructor asked further specific questions regarding the perception of the tactile feedback. Participants should also rate which condition they liked most to less (rank 1 to 5).

3. Results

This study consisted of N = 15 participants, two of whom were female. All statements were checked on contextual relevance, i.e. all information about the experiences of the haptic feedback and the linked action. In the following sections, the different mid-air interactions will be reported separately.

3.1. Interaction 1 – no feedback, triggered action by entering the sphere

Eight subjects reported that the interaction representation is hard to understand. The most named reason was missing feedback. Because of that, users couldn’t confirm their inputs were recognized by the system. Also, it was noted that the interaction is less satisfying or resulted in a bad user experience. Five persons had a “neutral” respectively “unemotional” attitude towards the interaction and two called it “calm, not confusing and efficient”. They maintained that they didn’t fail most of the time and interacted more precisely with the objects. The moment of the systems’ answer was described as appropriate or it wasn’t commented on.

3.2. Interaction 2 – feedback and triggered action by entering the sphere

12 subjects reported the interaction as positive. They emphasized that this treatment was “very efficient, pleasant, overall good and satisfactory”. One person perceived the interaction as less helpful describing it as ‘slight tingling’. Two subjects found the variant "rather uncomfortable and not supportive" perceiving the moment of the haptic feedback as “abrupt”. On the contrary, most of the people classified it as “appropriate” or ideal”. Only one person indicated the moment as “too fast” and because of that as “confusing”. The duration of the feedback was termed as “ok”. Four persons wished ongoing feedback instead of a short one. Three other subjects liked the interaction, but proposed that the duration could hold on “for a few more milliseconds”.

3.3. Interaction 3 – feedback by entering the sphere, triggered action by entering the middle

Only two persons were completely satisfied and noticed, that the interaction was “intuitive and natural”. The rest of the sample perceived the variation as “unnatural, irritating, uncomfortable and inefficient". The most frequently cited reason for this estimation was that the haptic feedback was starting too early. Besides, sometimes the system didn’t react after an input, although sensing the ultrasonic. Every participant who described the last situation also reported a negative experience. It is "frustrating and annoying when the input is not triggered despite noticeable feedback". Aside from that, the feedback was felt too early and was evaluated as “not satisfactory”. For the reasons mentioned, the time of the response action was classified as too late and, if action was not taken, as “counterproductive”. Only two subjects noted that they were classified as “precise” and “clear”. One subject felt the feedback was "too long".

3.4. Interaction 4 – feedback by entering the sphere, triggered action by leaving the sphere

Most of the people enjoyed this interaction. 13 subjects reported that this variation is “supportive, easy to handle or pleasant”. Two participants commented that the haptic feedback was adjusted too strongly so that they got “irritated” by the interaction. The trigger point and the corresponding reaction were evaluated as “well-chosen and precisely adjusted”. The participants explained, that they had “a better perception by selecting the object” and “clear knowledge about the moment of pushing the button”. That concluded in an “easier and more satisfactory” interaction. It could also be observed, that the subjects acted more efficiently over the whole pass. The duration of the feedback was perceived as "pleasant and supportive". This variant gave the test subjects a "better feeling" and "better usability".

3.5. Interaction 5 – feedback and triggered action by leaving the sphere

This variant was experienced mostly negatively. The majority of the participants narrated, that they “don’t like” this interaction and it is “bad, confusing and not supportive”. The time of the feedback together with the response action was “clearly too late”. Therefore, the tactile feedback was sometimes “barely noticeable”. The short duration of the feedback at the end of the collision was perceived hardly and described as “less efficient and unsatisfactory”. One subject reported a loss of the reference of the feedback and because of that a handicap in interaction. The “unnatural and less intuitive” operability were reflected in many incorrect entries and the long duration of solving the task. An "estimate of the moment" when the action will occur was often missing. The operation was rated "difficult" and "unsupportive" for this variant.

3.6. Ranking of the interaction variations

At the end of the study, the participants were asked to rank the experienced interaction from the best place one to the last place five. Figure 3 shows how the participants assessed the respective interaction.

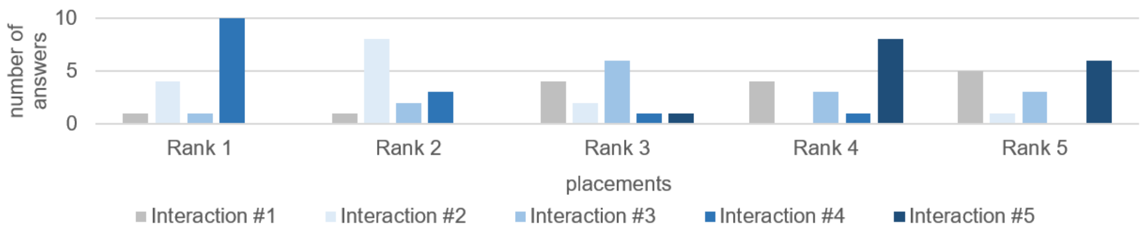


***Figure 3**: Placement of the ranked interactions*

Interaction 2 and 4 received a lot of approval. Variant 4 is the best-evaluated one. The last five votes are distributed, that rank two took three ones and rank three and four respectively one. On the other hand, interaction 2 got for rank one just four votes, but rank two, which is most strongly represented, got eight votes. The same applies to interaction 3 at rank 3. While interaction 4 is relatively evenly distributed, variant 5 is represented only in ranks four and five.

4. Discussion

It can be concluded that mid-air interactions with tactile feedback received more positive approval than interactions without tactile feedback. Also, the ranking reflects the comments of the participants: The interaction patterns where the haptic feedback was projected together with the action were preferred. On the contrary, the variations providing haptic feedback after the action trigger were rated negatively. These results suggest that the virtual position of action and feedback influence the user experience.

Thus, the best rating for interaction 4 can be explained by the fact that the users want immediate confirmation of the visible virtual representation. Like the haptic feedback, they receive when pushing a button in the real world. Due to this observation, we conclude that people recognize this interaction as they learned it in everyday life from similar real-world interactions. As a result, they describe interaction 4 as more intuitive. Furthermore, the feedback gives information about the positioning of the hand in the virtual room, so that fewer visual resources are used and the cognitive workload can be reduced.

Interaction 2 was also evaluated positively. Similar to interaction 4, the subjects triggered the action but immediately received haptic feedback. The direct input seemed “very efficient”, but didn’t work out, because the operation ended abruptly and the feedback was enforced slightly. A longer duration of the haptic feedback could help to increase the user experience.

The worst-rated condition was interaction 5. The visual information did not link to the haptic perception because participants did not sense the virtual object when they reached it. Only after the hand left the virtual object, short haptic feedback could be perceived. Also, users had problems with the orientation of their hand, because of the missing position information by touching the object. This mismatch between system reaction and haptic feedback led to confusion, which can be explained by the lack of contiguity (Schnotz et al. 2002).

5. Summary

By an increasing complexity of technology in everyday life, human factors in system design become ever more important. Because of its intuitive handling and its attractivity, haptic feedback will become fundamental in the research and application of mid-air gesture interaction. There are still missing design recommendations. However, this study shall tie on this point and pursued the question about the influence of haptic feedback on the user experience by mid-air gesture interaction.

The results show, that haptic feedback has a positive effect on the user experience. Due to the bad design of feedback patterns, the workload could increase and impact user experience negatively. The user statements reveal that haptic feedback should take place at the beginning of a visual collision with an object. Likewise, for an efficient workflow, the system action should begin at the same time as the tactile feedback by entering the object.

This work gives first insights into the development of mid-air gesture systems with haptic feedback. Taking up the results of this work and the continuous further processing of mid-air systems will improve the user experience, making human-machine interaction increasingly natural and intuitive so that the boundaries between the idea and actually implementable application are becoming smaller.

6. Literature

Bernhagen M, Dettmann A, Dittrich F, Trezl J, Bullinger AC (2019) Nutzerzentrierte Entwicklung eines Demonstrators zur Generierung taktiler Rückmeldungen für die berührungslose Gesteninteraktion (Conference Session). In: GfA e.V. (Ed), Kongress der Gesellschaft fuer Arbeitswissenschaft e.V. (GfA), GfA-Press.

Hasegawa K, Shinoda H (2013) “Aerial Display of Vibrotactile Sensation with High Spatial-Temporal Resolution using Large-Aperture Airborne Ultrasound Phased Array,” in Proc. of World Haptics, 31–36.

Hwang I, Son H, Kim JR (2017) AirPiano: Enhancing music playing experience in virtual reality with mid-air haptic feedback. IEEE Worlds Haptic Conference.

Ito M, Kokumai Y, Shinoda H (2019) “Midair Click of Dual-Layer Haptic Button,” Proc. 8th Jt. Eurohaptics Conf. IEEE Haptics Symp. - World Haptics Conf. ’19, 349–352.

Rakkolainen I, Freeman E, Sand A, Raisamo R, Brewster S (2020) A Survey of Mid-Air Ultrasound Haptics and Its Applications. IEEE Transactions on Haptics, 1412(c), 1–1.

Sand A, Rakkolainen I, Isokoski P, Kangas J, Raisamo R, Palovuori K (2015) Head-mounted display with mid-air tactile feedback. Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST, 13-15-Nove, 51–58.

Schnotz W, Bannnert M, Seufert T (2002). Towards an integrative view of text andpicture comprehension: Visualization effects on the construction of mental models. In: Otero J, Graesser A, Leon JA (Hrgs): The Psychology of Science Text Comprehension. Erlbaum, Mahwah, 385-416.

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