HapTech: Intelligent controls in public spaces through mid-air haptic interaction

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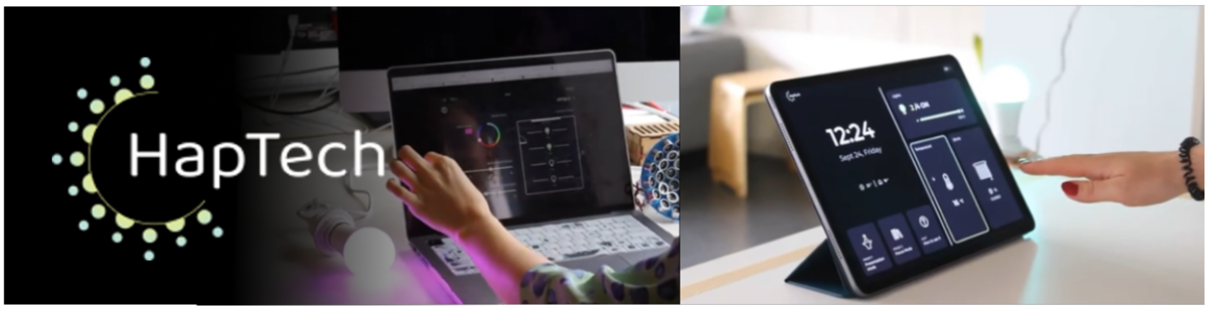

Fig. 1. HapTech logo and mid-air haptic smart home control panel

Recently, public spaces have seen a shift towards touch-free interaction to address hygiene concerns. HapTech, a prototype of a gesture-controlled interface with mid-air haptic feedback, offers a solution. It allows users to control essential functions like lights and HVAC without physical contact. To understand the impact of visual user interfaces, a Wizard-of-Oz study was conducted. The findings suggest that while including a visual UI improves self-explainability, it also leads to longer task completion time and errors. Striking a balance is crucial, emphasizing simplistic UIs for intuitive gesture language and optional visual feedback. This optimization enhances touch-free interaction and overall user experience in public environments. We conclude that the inclusion of a visual user interface influences gesture choice and task completion, but it plays a pivotal role in improving user experience and self-explainability.

Additional Key Words and Phrases: Mid-Air Haptics, Human.Computer Interaction, Natural User Interfaces, Gesture-Based Interaction

1 INTRODUCTION/MOTIVATION

Due to the Covid-19 pandemic, there has been a surge of concern for hygiene in public spaces. This issue was substantiated by our preliminary study involving 12 participants for qualitative data gathering in form of interviews and 53 survey participants (quantitative data gathering), revealing that more than 70 % of respondents expressed their genuine worry regarding cleanliness in these environments. This is exactly where HapTech, a mid-air haptic control panel for smart home functionalities such as lights, blinds and HVAC, comes into play. HapTech strives to eliminate the need for physical contact by transferring user interaction into mid-air, thus promoting a touch-free experience. The system aspires to provide users with a seamless and natural interaction

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design, aligning perfectly with the growing demand for enhanced hygiene measures. As such, this paper shall explore natural user interaction in the mid-air context and empirically deduce, whether the inclusion of a visual UI in the system design impacts performance, user experience and gesture choice. This inquiry into the critical interplay between touch-free interaction and the incorporation of a visual UI aims to lay the groundwork for future advancements in user interface design for public spaces.

2 RELATED WORK

Haptic feedback has a long tradition in computer science to support the overloaded visual channel. With the evolution of mid-air haptics technology [1, 7] focused ultrasound can now be utilized to directly provide haptic feedback "on to user's unadorned hands" [1], reintroducing the tactile information which is lost by the touchscreen modality, while simultaneously enhancing the user experience [5]. In Young et al.'s (2020) study on mid-air haptic gesture-controlled user interfaces for cars, it was found that using haptic feedback in mid-air enhanced user performance and reduced driver distraction compared to traditional touch-based interfaces, showcasing potential to make graphical interfaces obsolete [8]. However, the limited range of distinguishable tactile output from ultrasound transducers [6] and the recommendation for using mid-air haptic feedback to indicate system state changes [3] led to the design choice of using the Ultrabits device as a trigger for user input. Furthermore, mid-air gestures that should benefit from tactile feedback need a precise positioning of the hand in open space [2]. Based on related work, we defined a three dimensional interaction area in mid-air to help guide correct hand positioning and focused this work on analyzing, whether mid-air haptic technology can overcome the need for a visual interface.

3 METHOD

Following Golden Krishna's sentiment, "the best interface is no interface" [4], the HapTech project focuses on how system design affects users' interaction strategies, specifically gesture selection. Thus, a Wizard-of-Oz experiment was conducted, which – diverging from previous research (e. g., [2]; more details in section 2) on gesture recognition and triggering in mid-air haptic technology – shifts the attention away from technical practicability in favor of user experience and allows for the selection of custom gestures by the participants with the goal of deducing, whether the inclusion of a visual UI in the system design impacts performance, user experience and gesture choice.

3.1 Empirical Study

The WoZ user study follows a 2*3 factorial design with two independent variables (IVs): the inclusion of a visual UI (yes/no) and type of control (lights, blinds, HVAC). The dependent variables include performance metrics such as task completion time and error occurrence, while the gesture choice is assessed by examining the overall gesture selection and changes made after switching between the UI and no UI condition. User experience is qualitatively analyzed in a post study interview, focusing on user satisfaction and effort. The study hypotheses are as follows:

- H1: The integration of a visual user interface into a mid-air haptic smart home control system will significantly increase the user experience compared to the baseline (no UI).
- H2: The integration of a visual user interface into a mid-air haptic smart home control system will influence the gesture choice of the participants compared to the baseline (no UI).

To facilitate comparison between the two variants a within-group approach was employed, where half of the participants start with no UI, while the other half begins with the UI variant, followed by the opposite condition. Participants were asked to perform three tasks, each representing one of the three control types, per condition (figure 2). The order of the control tasks is randomized using a 3x3 Latin Square design in order to minimize the learning effect. Since HapTech aims to improve hygiene in public spaces, the study was conducted in a university classroom. Twelve individuals, representing a real life lecture scenario, with different backgrounds participated in the study, three of whom were university staff, while the others were students.

Fig. 2. HapTech: Wizard-of-Oz study setting and study task excerpts

Figure 2 depicts the experimental arrangement of both conditions. After a short introduction and gathering of demographic data, participants were instructed to complete the aforementioned tasks through interaction with the mid-air haptic control panel placed on the table in front of them, while thinking aloud and notifying the moderator when they felt the task in question was completed successfully. Moreover, participants were encouraged to come up with their own intuitive gesture language, with the only two constraints being that a) the gestures had to be performed in a predefined three-dimensional area on the table marked by red tape, ensuring that their hands can be captured by the camera and thus remain visible for the wizards responsible for controlling the HapTech system b) before new control tasks could be initiated users were required to place a hand above the Ultrabits device, serving as a trigger area, informing users that the system is ready to receive input via ultrasonic, haptic feedback.

4 RESULTS

The gathered data in form of video recordings of the experiment was employed to analyze participants' gesture preferences and gesture range depending on the control type and in- or exclusion of the visual UI to determine which gestures were perceived as natural. A summary of the most commonly used gesture categories, which were formed by analyzing reoccurring patterns in the spatial positioning of the hand, gesture duration and velocity, can be found in table 1. The depicted gesture choice highlights that when no UI was present, gestures were

	Lights	Blinds	HVAC
UI & No UI	Turning hand (knob)	Moving hand down	Turning hand (knob)
No UI	Swipe right to left	Horizontal & vertical swipe	Hand up/down
UI	Circular motion hand/finger	Moving down/up in steps	Hand/fingers half circle

Table 1. Preferred gesture categories depending on control type (in columns) and IV "visual UI" (2 levels: with, without).

chosen in accordance with the user's existing mental model of a certain control type, such as turning the whole hand in a circular motion, which is reminiscent of physical knobs, while the selected gestures in the UI condition reflect the graphical control elements such as circular sliders shown on screen. Furthermore, only 2/18 gestures were repeated by the first half of the participants after the switch to the UI variant. In comparison, 11/18 gestures were reused by the second group during the change from UI to no UI.

4.1 Performance metrics

Firstly, the normality of the data was assessed using the Shapiro-Wilk test, which revealed that the data followed a normal distribution ($W = 0.9610$, $p > 0.05$), thus allowing for parametric analysis such as a t-test to be performed.

The results of the conducted paired, one-tailed t-test indicate that there is no statistical difference between the two conditions (UI M=43.39, SD=25.49 and no UI M=36.56, SD=22.06; t(35)=−1.54, p = 0.07, α= 0.05). However, the comparison of the mean task completion time (TCT) suggests, that the inclusion of a visual interface instead leads to an increase in TCT. Moreover, the error occurrence in form of missed system activations drastically surged from 2 (no UI) to 14 (UI) between the two variants.

4.2 User experience

The analysis of the post study interview revealed that a significant portion of 66% participants emphasized the importance of a user interface in comprehending the current state of the smart home system, which especially holds true for HVAC controls without a visual interface for feedback and guidance. 83% of participants found the mid-air haptics device and its visual user interface to be user-friendly and intuitive. Additionally, 50% of participants provided valuable feedback on potential enhancements for the device, such as providing auditive feedback for successful gesture. These insights can help guide future iterations of the HapTech system.

5 LIMITATIONS

The study was restricted by the unavailability of advanced mid-air haptic devices, resulting in less precise and customizable feedback sensations during the testing phase. The limited capabilities of the Ultrabits device might have affected the accuracy and variability of mid-air feedback experienced by users during interactions with HapTech.

6 DISCUSSION

During usability testing, participants' gesture choices were influenced by the presence or absence of a visual UI. Those who started off without a visual UI demonstrated a wider range of natural gestures, while participants who did with a visual UI exhibited more limited gestures resembling the graphical elements on the screen. The absence of a visual UI increased the effort required to perform gestures and lacked in the area of self-explain ability. Ongoing research and development in the field of mid-air haptic interaction can help address limitations of the employed Ultrabits device including limited sensory feedback and restricted interaction area. Integrating more advanced ultrasonic transducers will allow for a natural user interaction, while reducing reliance on a graphic interface.

7 CONCLUSION

Based on the findings, it can be concluded that the presence of a visual UI influences gesture selection and increases task completion time and error occurrence. However, it also contributes significantly to enhancing user experience and self-explanatory interactions. In summary, future efforts should be focused on developing a intuitive gesture language, which draws inspiration from gestures chosen in the no UI condition, and only offering visual feedback when necessary, e.g. to balance out shortcomings of current mid-air haptic technology.

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