Pseudo-haptic Controls for Mid-air Finger-based Menu Interaction

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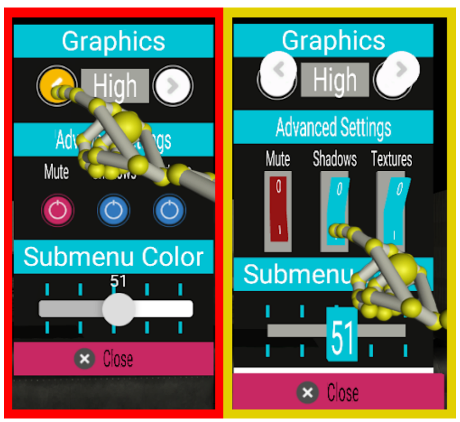

Figure 1: Appearance of the same menu controls (here: buttons, switches, sliders) in the two UIs used and evaluated in the experiment: *planar* (left, red), *pseudo-haptic* (right, yellow). Both UIs were designed for the same purpose: allow users of a VR environment to choose items from a menu using finger-based interaction.

ABSTRACT

Virtual Reality (VR) is more accessible than ever these days. While topics like performance, motion sickness and presence are well investigated, basic topics as VR User Interfaces (UIs) for menu control are lagging far behind. A major issue is the absence of haptic feedback and naturalness, especially when considering mid-air finger-based interaction in VR, when "grabbable" controllers are not available. In this work, we present and compare the following two visual approaches to mid-air finger-based menu control in VR environments: a planar UI similar to common 2D desktop UIs, and a pseudo-haptic UI based on physical metaphors. The results show that the pseudo-haptic UI performs better in terms of all tested aspects including workload, user experience, motion sickness and immersion.

KEYWORDS

Virtual Reality; User Experience; Finger-based Interaction; Menu Interfaces; System Control.

INTRODUCTION

Nowadays, the major part of our population is familiar with GUIs (Graphical User Interfaces) on desktop computers or smartphone apps. Over the last decades, menu metaphors have been widely

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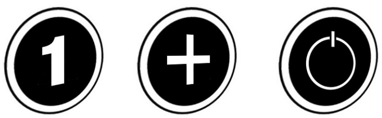

Figure 2: With the *Simple* button (left), a simple touch triggers an action. The *Stepper* (center) increments or decrements a value discrete, or continuously through long press. The *Switch* (right) can be used to switch through states (e.g., on or off).

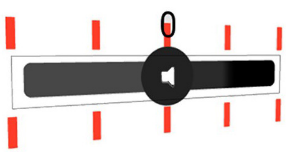

Figure 3: Our planar *Slider* control includes two parts: a *handle* indicating the currently selected value, and *ticks* indicating the selectable values. The handle can be moved and dragged while touching it with the finger. Here, we distinguish between *discrete* and *continuous* control.

established when designing 2D UIs and engraved into the user's mind: e.g. buttons, switches, or sliders. With the rising popularity of VR applications, planar UI elements have been directly adapted from 2D UIs and used for menu control in VR (e.g. Leap Motion Input Module). Here, the common case is to render planar 2D controls in a VR 3D environment. But previous research has taught us not to assume that transferring conventional UIs into VR environments would be accepted by the users [7]. Direct manipulations are hard to imagine without proper tactile feedback [8], in particular for controller-free and mid-air finger-based gestures (i.e. without haptic gloves or hand-held controllers). In these cases, the remaining feedback channels (auditive, visual) have to compensate for the lack of haptics. In general, VR enables UI designers to benefit from its multi-dimensionality, and in particular the stereoscopic view provides users with "pseudo-haptic" feedback for direct manipulations. So why to use planar controls at all? And where do they have advantages and limitations concerning users' preferences compared to a pseudo-haptic UI?

In this paper, we present our study to answer which UI approach is best suited to our criteria, i.e. user preference (user experience, task workload, motion sickness, immersion). To this end, we first designed and set up two different UIs: a simple planar UI as baseline, and a pseudo-haptic UI based on physical metaphors (see Figure 1). In particular, for the pseudo-haptic UI, we exploited the three-dimensionality of VR, in combination with visual and aural feedback, to provide the pseudo-haptic feedback. The planar UI is based on common VR and mobile UIs and is implemented using the standard controls from the Leap Motion SDK and its Interaction Engine. We used the two UIs to carry out a within-subject experiment, in which we investigated what influence they have on user experience, workload, sickness and immersion. Here, the pseudo-haptic UI was preferred in all aspects.

RELATED WORK

In this work, we investigated whether mid-air finger-based UIs in VR should portray real-life experiences in virtual form, or design a novel type of experience that builds on the affordances of the virtual medium. Concerning VR UIs in general, Hezel and Veron [4] stated that the human eyes' accommodation and convergence make it possible to comfortably display objects starting at a distance of about 0.25 meters. Shupp et al. [9] examined the effects of viewport size and distance in the context of geospatial tasks, like searching or route tracing. Furthermore, the findings of Ha et al. [2] helped to classify four arrangement options for UI and controls in virtual environments (VEs): world-, view-, body- and hand-fixed. Based on NASA's Man-System Integration Standards, interactive objects should be between 50 and 60 cm in front of the user and 70 to 80 cm away from his dominant side, depending on the arm's reach. In summary, we place our virtual controls at a world-fixed location in front of the user in a comfortable distance at ~80% of the arm's reach, which was confirmed during pilot tests. Concerning intuitive VR UIs, Knöpfle and Voß [5] presented a VR UI to support experts in the automotive industry. They stated that a menu interface was essential for changing object properties

Figure 4: Pseudo-haptic buttons consist of a circle fixed in space and a protruding disc. Pushing the disc through the circle triggers a button press, which is also confirmed to the user through visual and audio feedback. Continuous input is done by holding the disc behind the trigger circle.

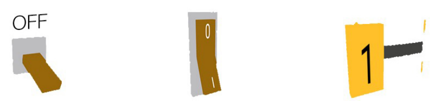

Figure 5: *Toggles (left)* are adapted from cockpits of airplanes. The *Rocker (middle)* resembles the *Toggle*, but its representation and feedback is based on conventional light switches. The *Slider (right)* is a special discrete 3D slider with two states.

Figure 6: With the pseudo-haptics *Slider* (left), the user can manipulate the value by simply pushing the handle to the left or right like a real physical object. The pseudo-haptic *Wheel* (right) is based on picker controls in mobile UIs and is visualized by a decagon-shaped wheel.

and system control, e.g. switching between functions and modes. Their first prototype resembling a standard planar desktop interface resulted in high workload and low user experience, which overshadowed the benefits of its simplicity, lower instrumentation and higher familiarity. Consequently, after using a pie menu and a jog dial instead, the feedback could be improved, but not significantly.

EVALUATED USER INTERFACES

We have studied mid-air finger-based menu control in VR using Leap Motion mounted on an HMD. We designed and implemented two UIs including menu control elements. Both UIs use direct manipulation as interaction mode, which is well known from touchscreens.

Planar User Interface. The concept of our planar and adapted 2D menu controls supports direct manipulation and serves as the baseline in our study. It mimics a typical planar interface as it is common for touchscreens or smartphones. Our planar UI controls are represented by simple images without depth and include two different menu control elements: buttons (see Figure 2) and slider (see Figure 3). When the user touches the virtual elements, a sound is played and the color of the object changes. As there is no physical resistor, the virtual finger can point through all menu parts.

Pseudo-haptic User Interface. The pseudo-haptic UI was created with the aim of maximizing affordance and underline their three-dimensionality of the controls. We assumed that widgets based on physical metaphors, such as knobs or switches, could help to address the common issue of lacking feedback. The shape of the controls should suggest the required action to interact with them, e.g. pushing a protruding button or pulling a lever. Physical haptic cues suggest that they are solid, interactive and touchable. While common virtual controls let the user pass through when pressing them, pseudo-haptic controls are pushed along a pre-defined axis according to its underlying physical metaphor. They might move back to its original position after the finger has been released, like hitting piano keys. Our pseudo-haptic UI includes six menu control elements: button (see 4), slider & wheel (see 6), and toggle, rocker & slider switch (see 5). Overall, those controls utilize feedback through a combination of physical metaphors and feedback substitutions.

EXPERIMENT

We conducted the experiment in controlled laboratory conditions within one session (~ 60 min). Our main hypotheses were defined as:

- H_1 *Pseudo-haptic* allows for better user experience than *Planar*.
- H_2 *Pseudo-haptic* UI requires a lower task workload than *Planar*.
- H_3 *Pseudo-haptic* allows for lower motion sickness than *Planar*.
- H_4 *Pseudo-haptic* allows for higher immersion than *Planar*.

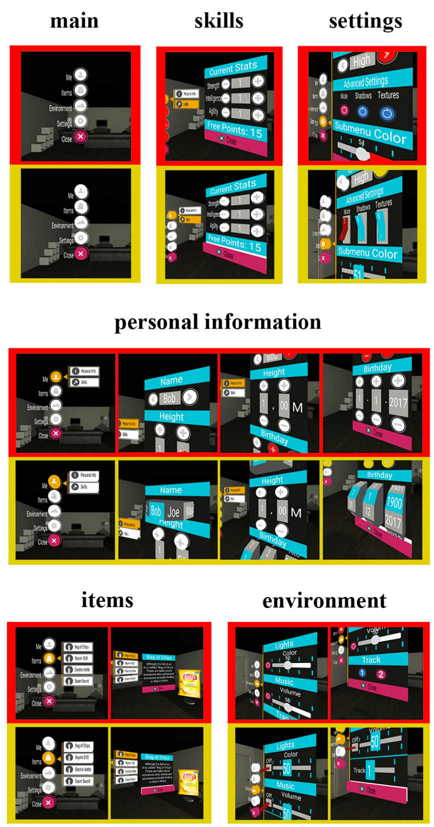

Figure 7: Planar (red) and pseudo-haptic (yellow) UI controls in the main menu, as well as the five subtasks for each submenu used in the experiment.

The VR system used an Oculus Rift CV1 as a head-mounted display (HMD) and ran on a Windows 10 machine with Unity 5.5.4, which was also used to fill out the questionnaires and control the experiment. For finger tracking, we used a Leap Motion mounted on the front of the HMD. For auditory feedback, the participants got audio feedback from the HMD headphones when interacting with the control elements. We chose an apartment scene as the virtual environment, in which the participants interact with a virtual smart-home menu interface. A total of 31 unpaid participants (11 female) volunteered for this experiment, aged between 18 and 47 years ($M = 24.90$, $SD = 6.34$). For compensation, the participants were asked to enjoy a VR experience in return for their participation after the experiment. All participants were right-handed. 41.9% have worn glasses or contact lenses, but none were color blind. On average, 61.3% of the participants had prior VR experience.

The experiment was a within-subjects design, with one independent variable (User Interface) with two levels (Planar, Pseudo-haptic), and four dependent variables related to the user's preference (User Experience, Task Workload, Motion Sickness, Immersion). In total, 26 trials per condition were counterbalanced using Latin square order. Aside from training, this amounted to: 31 participants $\times$ 2 user interfaces $\times$ 26 trials = 1612 trials.

At the beginning of the experiment, the participant was welcomed by the experimenter and was asked to fill out an informed consent form. Before each condition, the UI and its interaction technique was explained and practiced in a training phase of five minutes maximum. During the training, the system was calibrated by the experimenter, i.e. adjusting the distance (~80% of the arm's reach) and the height of the targets (center of the menu at the shoulder's height) to be more comfortable for the participant. The experimenter gives a brief overview about the handling of all included widgets and menu controls to ensure that every control has been seen and tried out. Then the main phase of the experiment starts, i.e. 26 different trials per interface, which were shuffled in random order within the five subtasks. Every single trial proceeds as follows: (1) the experimenter reads the trial goal aloud, e.g. "Turn the lights on" or "Return to the main menu", (2) the participant confirms that she understood the instructions, (3) the participant starts carrying out the task, and (4) the participant notifies the experimenter that the trial has ended. After all trials of one interface are finished, the participant is asked to take off the HMD and to fill out the post-task questionnaires (UEQ [6], NASA-TLX [3], MSAQ [1], Slater-Usoh-Steed (SUS) [10]). Finally, after all tasks have been performed, the participant fills out a final post-study questionnaire to gather demographic data (age, gender, experiences).

RESULTS AND DISCUSSION

Currently, novel VR UIs are mostly based on guidelines and standards from non-VR areas. Therefore, we combined typical 3D evaluation metrics [7] used for measuring users' preferences (user experience,

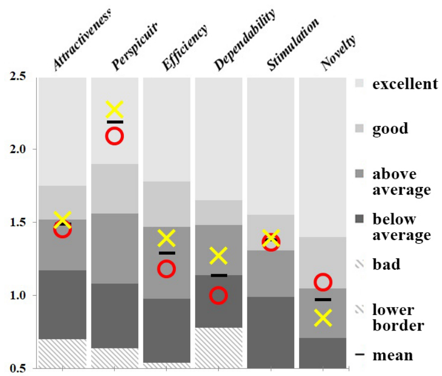

Figure 8: User Experience Questionnaire (UEQ) results for *planar (red, circle)* and *pseudo-haptic (yellow, cross)* with respect to comparison benchmarks (see shaded boxes). For readability, this figure shows a detail of the range between 0.0 and 2.5, while the original ranged from -3 to 3.

workload, motion sickness, immersion). We use the following abbreviations for the evaluated UIs: planar UI (2D) and pseudo-haptic UI (3D).

The UEQ scales [6] cover classical usability (efficiency, perspicuity, dependability) and user experience (UX) aspects (attractiveness, novelty, stimulation). The higher the score, the better. A univariate ANOVA showed significant differences between the two UIs regarding overall UX ratings ($p < 0.01$, $F_{(1,1610)} = 10.20$, $\eta^2 = 0.01$). Averaged over both UIs, 3D was rated higher at 1.75 ($SD = 0.89$) than 1.61 ($SD = 0.87$) for 2D on a scale between -3 (very bad) to 3 (excellent), which proves H_1. Both UIs have Stimulation ratings "above average", as well as "excellent" Perspicuity ratings; Participants found it more exciting and motivating to use the 3D UI, because of its affordance-oriented design.

NASA-TLX is a commonly used questionnaire to assess task workload based on six factors (mental, physical and temporal demand, effort, performance and frustration) [3]. The lower the rating, the lower the workload. When analyzing the workload using a univariate ANOVA, we found a significant difference between the two UIs ($p < 0.01$, $F_{(1,1610)} = 36.71$, $\eta^2 = 0.02$). The task workload of the 3D UI was rated lower ($M = 33.23$, $SD = 18.48$) than the 2D UI ($M = 39.30$, $SD = 21.65$). This proves H_2, but it is worth mentioning that many participants had problems using the sliders, in particular for precise input. Releasing the slider, micro movement caused a change of the entered value at the last moment.

The Motion Sickness Assessment Questionnaire (MSAQ) assesses the motion sickness based on 16 questions rated on a 9-point scale [1]. The lower the score, the better. A univariate ANOVA showed significant differences regarding motion sickness between the UIs ($p < 0.05$, $F_{(1,1610)} = 4.03$, $\eta^2 = 0.01$), with 3D UI ($M = 0.18$, $SD = 0.10$) lower than the 2D UI ($M = 0.19$, $SD = 0.10$), which proves H_3. Finally, we used the common Slater-Usoh-Steed (SUS) questionnaire to measure the user's immersion in a virtual environment [10]. The higher the score, the higher the immersion and presence. 3D UI was rated at 5.77 on average ($SD = 1.73$), followed by 2D UI ($M = 5.65$, $SD = 1.54$), which proves H_4. Finally, a univariate ANOVA showed a significant effect between the UIs regarding immersion ($p < 0.05$, $F_{(1,1610)} = 3.98$, $\eta^2 = 0.01$).

All scores indicate that participants felt quite comfortable and the virtual environment we used provided high immersion. Moreover, we decided to use the same environment and devices for all conditions, and short interactions to ensure that motion sickness would not influence the results.

CONCLUSION AND OUTLOOK

Designing intuitive UIs can be challenging for VR system developers and human factors specialists. And menu control in VR is an essential part of human-computer interaction and there are still open questions for research to address. We have studied mid-air finger-based menu control in VR using Leap Motion mounted on an HMD. Despite the simplicity, acceptance and familiarity of the planar UI, due to the widespread use of smartphones and desktop computers, the general conclusion is to choose pseudo-haptic controls for menu interfaces in VR. But its use is dependent on certain criteria and limitations, e.g. tracking and calibration, or unintended inputs resulting from too many UI elements, which are too small and too close to each other. Ultimately, we see the major benefit of pseudo-haptic controls over planar controls for finger-based menu control in VR due to the familiarity, predictability and intuitiveness given by the physical metaphors.

Our results and observations should help designers to build more usable and effective VR menu interfaces and move towards a stronger theoretical basis using principled design guidelines. Future VR systems may be designed to enable the user to remain in VR for longer periods of time, demanding menu interfaces to increase usability and intuitiveness. Finally, the qualifying UIs and controls need to be evaluated in a longitudinal study in the context of interactive immersive virtual environments. In this work an extensive library of UI widgets has evolved, which expand beyond standard UI widgets available in Unity for VR development. Although commercial packages exist that provide similar UI widgets, a free package would be useful for the research community. Therefore, we plan to publish the widgets as an open source package on GitHub and a free Unity Asset Store package.

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