3D Virtual Hand Pointing with EMS and Vibration Feedback

Max Pfeiffer*
Human-Computer Interaction Group
University of Hannover, Germany

Wolfgang Stuerzlinger**
School of Interactive Arts + Technology
Simon Fraser University, Vancouver, Canada

ABSTRACT

Pointing is one of the most basic interaction methods for 3D user interfaces. Previous work has shown that visual feedback improves such actions. Here we investigate if electrical muscle stimulation (EMS) and vibration is beneficial for 3D virtual hand pointing. In our experiment we used a 3D version of a Fitts' task to compare visual feedback, EMS, vibration, with no feedback. The results demonstrate that both EMS and vibration provide reasonable addition to visual feedback. We also found good user acceptance for both technologies.

Keywords: 3D pointing, feedback, vibration, EMS.

Index Terms: H.5.2 User Interfaces: Haptic I/O, Input devices and strategies

1 INTRODUCTION

Pointing in 2D is well understood. In comparison, 3D pointing and selection is both more complex and less well investigated. One of the largest differences is that pointing at a 3D location with virtual hand/cursor techniques requires control over three degrees of freedom (3DOF), i.e., require movements in all 3 axes of 3D space. In standard 2D user interfaces, selection requires only control of 2DOF and is typically associated with either a mouse or a touch input device. Currently, there is no standard 3D input device or selection technique.

Virtual reality (VR) systems that use 3D cursors typically also use 3D displays, which introduces additional issues. Current stereo displays introduce the well-known conflict vergence-accommodation conflict [10]. Consequently, selection of targets in 3D space, e.g., via direct touch, is difficult [3,16], even with the additional depth cues afforded by stereo.

Other forms of feedback are also helpful. General user interface guidelines frequently include feedback as a desirable criterion. Many 3D pointing experiments use highlighting to provide additional feedback when the cursor/finger intersects a potential target object. Another option is haptic feedback, which helps participants "feel" target depths and may improve performance [6]. Yet, its absence may affect one's ability to find the true depth of targets [16].

Another factor that affects selection is that the user may occlude small targets with the finger, or other body parts. The "fat finger" problem [18] in 2D touch input is also due to the occlusion of targets by a finger. The problem applies also to 3D. Yet, when moving a finger to a 3D target, the situation is worse, as a finger that is behind an object floating in space may still appear to be in front of it from the viewpoint of the user, due to the occlusion of the display by the finger.

* max@hci.uni-hannover.de
**w.s@sfu.ca

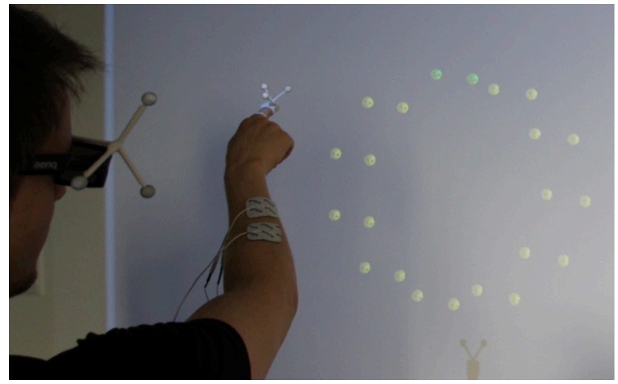

Figure 1 User interacting with a 3D scene. The head and finger trackers are visible, as well as the EMS "pads".

Most recent studies of in this area use a 3D extension of the ISO 9241-9 methodology [19]. Such a standardized methodology improves comparability between studies. With this methodology, the benefits of visual feedback have been demonstrated [17].

Due to the lack of standardized experimental methodologies, the effect of haptic feedback with vibration or EMS has not been investigated. Our current work targets this issue with a system depicted in Figure 1.

2 RELATED WORK

One of two main approaches to 3D selection is virtual finger/hand/3D cursor-based techniques [1,2]. The other approach is ray-based, outside the scope of our current work. Virtual hand-based techniques rely on the 3D intersection of the finger/hand/3D cursor with a target and thus require that the user picks the correct distance, i.e., visual depth. In such techniques, color change is the most commonly used visual feedback mechanism [1]. We employ a 3D extension of the ISO 9241-9 standard [19] based on Fitts' law [8], as illustrated in Figure 2. This paradigm has been used in recent 3D pointing studies, e.g., [5,16]. The movement time (MT) is proportional to the index of difficulty and depends on the size W and distance A of targets. Throughput depends on effective measures, and captures speed-accuracy tradeoff.

The effect of haptic feedback has been evaluated in the past, typically with force feedback devices or with vibration [7]. The results show that haptic feedback increases performance, but that vibration was slightly slower than the non-feedback condition.

EMS offers a broad application range for haptic feedback, ranging from tactile sensations (titillation) up to large physical movements. EMS has been tested as a feedback method in games [11], for controlling finger-joints [14] for learning and for gestures such as touch and grasp [13]. The effect of haptic feedback through EMS for selection tasks has not yet been investigated.

3 Issues Around Feedback in 3D Pointing Studies

Issues affecting 3D pointing studies have been studied before [17], we review the relevant ones, such as occlusion, the "fat finger" problem, and stereo viewing.

Occlusion and the "Fat Finger" Problem: Large displays suffer from an inherent cue conflicts. First, the finger/hand of the user can occlude objects shown on the display, even if they are positioned to "float" in front of the user's finger/hand relative to the viewer – even in monoscopic, head-tracked displays. The reason is that the user's hands are lifted up to interact or to select such objects. The tip of the finger can occlude targets of similar size or smaller. This is well known as the "fat finger" problem in touch interaction [18], and applies directly to 3D selection.

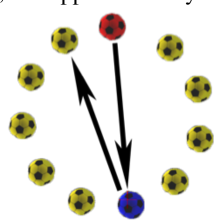

Figure 2 ISO 9241-9 reciprocal selection task with eleven targets.

Stereo Viewing: Stereo displays introduce additional cue conflicts. Moreover, the human visual system is unable to focus simultaneously on objects at different distances (e.g., a finger and a target). Given that the display is typically further away than the content that the user can interact with directly, such stereo systems suffer from the vergence-accomodation conflict. Also, when focusing on a 3D target displayed on the screen, viewers see a blurred finger or the other way around[4].

Selection Feedback: Recent work [16] used target highlighting. When the target is touched, it changes color. This provides feedback that selection (e.g., via a button) will be successful, and helps the user choose between multiple targets and/or if they are within the target or in front or behind it. This form of visual feedback has a positive impact on pointing performance [17]. In our work we focus on haptic feedback, and exclude other forms.

Haptic feedback: Haptic feedback is a viable alternative, which can complement or even replace visual cues. It also can increase realism. Haptic feedback can be provided with different devices, including robotic arms. Yet, only vibration and EMS are currently lightweight and mobile enough to be practical. Both consume only very little power (milli-Watts) and work even for fast motions. Research on 3D pointing has used vibration for feedback modality on different body locations (lower arm, hand and fingertip) [7]. EMS provides another form of haptic feedback. We are interested in comparing it to vibration and visual feedback for selection.

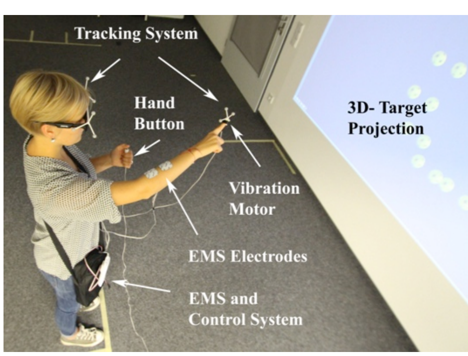

Figure 3 A participant standing in front of 3D projection and performing a task.

4 Methodology

To compare the different forms of feedback we consider, none, visual, vibrational, and EMS, we built an appropriate apparatus and designed a Fitts' law study based on ISO 9241-9 [19].

Participants: We recruited 12 participants (3 female) from a local university mailing list. Ages ranged from 21 to 32 (mean = 25.5, SD =3.1). All participants were right handed. Except for one, all had used 3D technology before and watched at least one 3D movie at the cinema in the last year. Seven participants had used haptic feedback devices (such as game controller or joysticks) before, six of them in 2D games and two in 3D games. Six of the 12 participants had experienced EMS before, four of them for physiotherapy and massage purposes.

Hardware: To perform this experiment, we set up a virtual reality system and added vibration and EMS feedback. We used a BenQ W1080 ST short throw 3D Projector at 1280x800 (3.26 m x 1.9 m projection size) with shutter glasses. The user stood 2 m away from the screen. For 3D tracking we used ten Naturalpoint Optitrack Flex13 cameras, calibrated to an accuracy of 0.32mm. The visual feedback condition had an end-to-end latency of 54.6 ms (SD = 5. 24), the EMS condition 61.8 ms (SD = 4.76) and the vibration condition 66.6 ms (SD = 6.39). Latency was measured by recording both a finger and the display with a camera, computing the delay in terms of frames and then averaging the results [12]. For the haptic feedback we used a LED to show when the EMS is on or the motor vibrates. Note that this excludes any delays in the transmission of the haptic signal through the body. The differences in latency are small enough that they should not be a confounding factor for any main effects [12].

To enable the participant to indicate selection, we fabricated a 3D printed handle with a mouse button inside it. The tracking targets were mounted onto a custom, 3D printed finger sleeve. This sleeve contained also the vibration motor. For head-tracking more tracking targets were attached to the stereo glasses, see Figure 3. The user wore a small shoulder bag, which contained the control electronics for the vibration motor and the EMS, driven by an Arduino Uno for access via WiFi (seen in Figure 4). We created custom Unity 4 scripts for the study and used the iminVR MiddleVR 1.4 plugin for stereo display.

Visual Feedback: In all conditions the user sees a 1x1x1 cm cross as cursor approximately 1cm above the finger sleeve. For the visual feedback condition, when the cursor is inside the target the target is highlighted in red.

Vibrational Feedback: We mounted a 1 cm long KF2353 vertical vibration motor (9,000 rpm, 90 mA at 2.3V) below the fingertip. We attached the motor through the finger sleeve and hook-and-loop fasteners to the finger to reduce sound. The sound of the motor is very low, too small to be easily audible in the lab environment. The motor is controlled with an Arduino Uno.

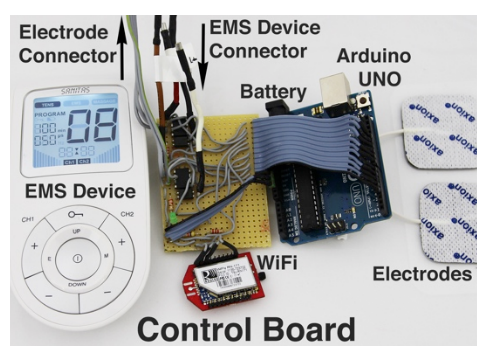

Figure 4 EMS feedback unit, Arduino Uno, WiFi and control board.

Electrical Muscle Stimulation (EMS) Feedback: For our EMS feedback system we used an off-the-shelf device (Beurer SEM43 EMS/TENS, Figure 4 on the left), connected to the Arduino Uno. The 40x40mm self-sticking electrodes were connected to the galvanic isolated part of the control board. In previous studies we found that impulses with 50μs duration and a frequency of 80 Hz are suitable for a large range of users. We calibrated the EMS intensity for each user individually to account for different skin resistance and the variance of the contraction effect.

5 User Study

Study Design: Our study had two independent variables: 4 feedback types and 3 target depths, for a 4x3 design. The four feedback types where: none, EMS, vibration and visual feedback. To reduce complexity we did not test combinations, such as visual and EMS.. Target depth varied from 40 to 60 cm from the users position. We used target sizes of 1.5, 2, and 3 cm arranged in circles with 20, 25, and 30cm diameter. Following previous work [15], we positioned targets within the same circle at the same target depth. The order of all of the above conditions and factors was determined by Latin squares. In total, our experiment had thus 4x3x3x3 = 108 target circles with 11 targets each.

Procedure: We introduced the participants to the context of the study and asked them to fill a background questionnaire about their relevant experience and an informed consent form. Then, we connected them to EMS device, by placing the electrodes on the Musculus extensor digitorum and put the tracking target onto their index finger. We demonstrated the vibration feedback first. Then we increased the current for the EMS-feedback system step-by-step, until we could see the index finger of the participant lifting up by approximately 1 cm. We asked participants verbally during this procedure to confirm that the stimulation through the EMS was still a comfortable level. Subsequently, we decreased the voltage again until the finger was *not moving* anymore.

We placed the participants 2 m in front of the screen. We then equipped them with the 3D glasses and made sure that the finger sleeve was placed correctly. Participants wore the finger sleeve and EMS pads in all input conditions (Figure 3). The software turned haptic or visual feedback on as long as the cursor was within the target. If the user clicked the button held in the other hand while the cursor was in the target, we registered a "hit". Otherwise a selection error was recorded. In the "none" condition, no feedback was provided. Before the start of the main study, users were given a few training trials (one to three), until they felt comfortable with the conditions. After each participant had completed all trials they were asked to fill a second questionnaire.

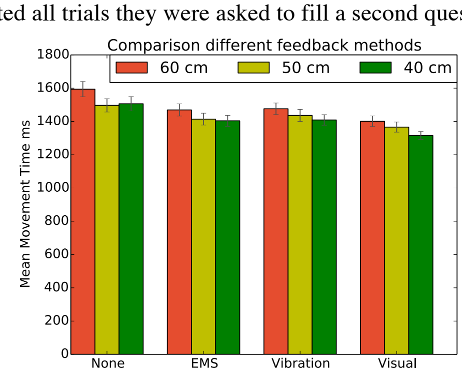

Figure 5 The average movement time for all conditions and three depths level.

6 Results

As the data for movement time was not normally distributed, we log-transformed that data. Also, we filtered outliers beyond 3 standard deviations from the mean in terms of time and target position. This removed 350 trials or 2.46% of the data, which typically corresponded to erroneous double-selection episodes. Then we used repeated measures ANOVA to analyze results.

Movement Time: The ANOVA identified a significant effect for movement time $F_{3,33}$=5.9, p<0.005. According to a Tukey-Kramer test, only the no-feedback and visual feedback conditions were significantly different. The average movement times for the no-feedback, EMS, vibration and visual feedback conditions were 1522ms, 1449ms, 1465ms, and 1387ms, respectively. In terms of target depth, there was also a significant effect $F_{2,22}$=10.86, p<0.001, with the two levels closest to the user being significantly faster to select than the "deep" level (Figure 5).

Error Rate: An ANOVA identified a significant effect for error rate $F_{3,33}$=6.05, p<0.005. According to a Tukey-Kramer test, the no-feedback condition was significantly worse than all others. The average error rates for none, EMS, vibration and visual feedback conditions were 15.3%, 11.3%, 9.8%, and 10.5%, respectively (Figure 6). For target depth, there was no significant effect on errors $F_{2,22}$<1.

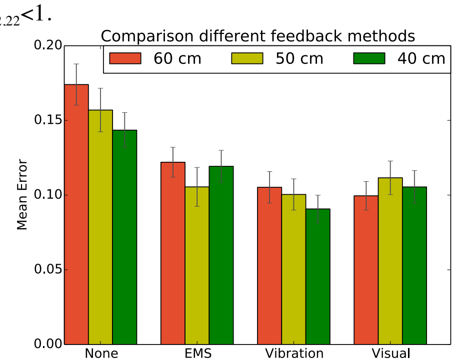

Figure 6 The Error rate of all condition and three depths level.

Throughput: The ANOVA identified a significant effect for throughput $F_{3,33}$=3.58, p<0.05. According to a Tukey-Kramer test, the only the no-feedback and visual feedback conditions were significantly different. The average throughput values for the none, EMS, vibration and visual feedback conditions were 3.19, 3.28, 3.29 and 3.37, respectively (Figure 7). For target depth, there was a significant effect on throughput $F_{2,22}$=6.73, p<0.01. The further targets had significantly less throughput than the closer two levels.

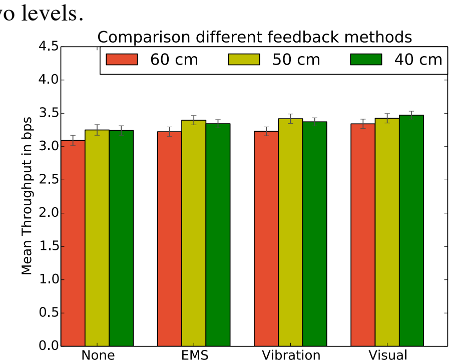

Figure 7 The throughput of all conditions and three different depths level.

Subjective Results: Both haptic feedback methods were ranked as reasonable realistic with a median of 2 (median absolute deviation MAD = 1, 1 = very realistic to 5 = very unrealistic). When we asked for the perception on delay in the feedback, the EMS feedback and visual feedback was ranked with a very low delay (median = 1, MAD = 0), followed by the vibration feedback (median =1.5, MAD = 0.5, where 1 = very low delay and 5 very high delay). Also the position of the feedback was ranked as well fitting with a median of 2 for EMS feedback at the lower arm (MAD = 1) and median of 1 for the vibration motor at the fingertip (MAD = 0, where 1 = very good and 5 = very bad). We also asked how well the participants were able to map the EMS impulses to the virtual 3D object. Participant almost universally agreed to this (median = 1.5, MAD = 0, where 1 = total agree and 0 = total disagree). We also asked if the participants got used to the EMS impulses and again found agreement (median = 1, MAD = 0, where 1 = total agree and 0 = total disagree). While most of the participants were very comfortable with the EMS impulses, four of them reported at the end of the study that the EMS impulses sometimes moved the finger out of the targets.

7 Discussion

Overall, the visual feedback conditions performed better than the haptic feedback conditions, but not significantly so. This is not unexpected, as it has already been shown that the visual feedback is faster than the haptic feedback [9]. The results for vibration and EMS feedback are not significantly different from those of visual feedback, nor from the condition without feedback. Different to the study in [7], we found that vibration was more effective that no feedback, but again not significantly so.

Although the lack of a significant difference does not "prove" equality, these results still indicate that vibration and EMS both provide viable alternatives for feedback in 3D pointing and that both alternatives do not have a significant cost in terms of throughput. Users ranked both conditions very positively. Thus, we see both modalities as reasonable additions or alternatives to visual feedback. Additionally, some users mentioned that they would like to use EMS feedback in games.

EMS as a feedback technology still has some drawbacks. A minority of participants report that their finger was pushed away from the target in the EMS condition. Yet, we calibrated the stimulation to elicit no actual movement. One potential explanation is a potential change of skin resistance over time, which could be addressed with recalibration.

8 Conclusion and Future Work

This work presents a first evaluation of a lightweight, low-energy haptic feedback system to assist 3D virtual hand selection. Overall we found that both vibration and EMS are reasonable alternatives to visual feedback.

As we found no large, significant effects we are planning to repeat this study with tasks where the targets have different visual depths, i.e., are not in the same plane, and with more participants. We will also investigate combinations of the feedback methods and other feedback modalities, such as audio. Another interesting situation we are planning to explore is when targets are straight behind each other, which poses challenges for the visual condition. We will also look more deeply into the issue that some users reported their finger being pushed back, away from the target. Finally, we will also investigate how using more than one muscle group can be used to realize a technique that attracts the finger to the target.

9 Acknowledgements

We thank all participants and Beurer GmbH for their support.

References

[1] Achibet, M., Marchal, M., Argelaguet, F., and Lecuyer, A. The Virtual Mitten: A novel interaction paradigm for visuo-haptic manipulation of objects using grip force. *IEEE 3DUI*, (2014), 59–66.

[2] Bowman, D.A., Kruijff, E., LaViola, J.J., and Poupyrev, I. *3D User Interfaces: Theory and Practice*. Addison-Wesley, (2004).

[3] Bruder, G., Steinicke, F., and Stuerzlinger, W. To Touch or not to Touch ? Comparing 2D Touch and 3D Mid-Air Interaction on Stereoscopic Tabletop Surfaces. *ACM SUI*, (2013), 9–16.

[4] Bruder, G., Steinicke, F., and Stuerzlinger, W. Touching the Void Revisited : Analyses of Touch Behavior on and above Tabletop Surfaces. INTERACT (2013), 278–296.

[5] Bruder, G., Steinicke, F., and Stuerzlinger, W. Effects of visual conflicts on 3D selection task performance in stereoscopic display environments. *IEEE 3DUI*, (2013), 115–118.

[6] Chun, K., Verplank, B., Barbagli, F., and Salisbury, K. Evaluating haptics and 3D stereo displays using Fitts' law. *IEEE Conference on Creating, Connecting and Collaborating through Computing*, (2004), 53–58.

[7] Corbett, B., Yamaguchi, T., and Liu, S. Influence of haptic feedback on a pointing task in a haptically enhanced 3D virtual environment. *HCII*, 1954 (2013), 561–567.

[8] Fitts, P.M. The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology*. *47*, (1954), 381–391.

[9] Gerovichev, O., Marayong, P., and Okamura, A.M. The Effect of Visual and Haptic Feedback on Manual and Teleoperated Needle Insertion. *MICCAI,* (2002), 147–154.

[10] Hoffman, D.M., Girshick, A.R., Akeley, K., and Banks, M.S. Vergence-accommodation conflicts hinder visual performance and cause visual fatigue. *Journal of Vision 8*, 3 (2008), 33.1–30.

[11] Kruijff, E., Schmalstieg, D., and Beckhaus, S. Using neuromuscular electrical stimulation for pseudo-haptic feedback. *ACM VRST*, (2006), 316.

[12] Pavlovych, A. and Stuerzlinger, W. The tradeoff between spatial jitter and latency in pointing tasks. *ACM EICS*, (2009), 187.

[13] Pfeiffer, M., Alt, F., and Rohs, M. Let Me Grab This : A Comparison of EMS and Vibration for Haptic Feedback in Free-Hand Interaction. *Augmented Human*, (2014), 1–8.

[14] Tamaki, E., Miyaki, T., and Rekimoto, J. PossessedHand: Techniques for controlling human hands using electrical muscles stimuli. *ACM CHI* (2011), 543.

[15] Teather, R.J., Pavlovych, A., Stuerzlinger, W., and MacKenzie, I.S. Effects of tracking technology, latency, and spatial jitter on object movement. *IEEE 3DUI*, (2009), 43–50.

[16] Teather, R.J. and Stuerzlinger, W. Pointing at 3D targets in a stereo head-tracked virtual environment. *IEEE 3DUI*, (2011), 87–94.

[17] Teather, R.J. and Stuerzlinger, W. Visual aids in 3D point selection experiments. *ACM SUI* (2014), 127–136.

[18] Vogel, D. and Balakrishnan, R. Occlusion-aware interfaces. *ACM CHI,* (2010), 263.

[19] ISO 9241-9:2000 - Ergonomic requirements for office work with visual display terminals (VDTs) - Part 9: Requirements for non-keyboard input devices. *International Organization for Standardization*, (2000).