Evaluating Menu Techniques for Handheld AR with a Smartphone & Mid-Air Pen: Alternative Analysis

Philipp Wacker, Oliver Nowak, Simon Voelker, Jan Borchers

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1 Introduction

This document presents an alternative analysis of the data presented in the MobileHCI Paper: "Evaluating Menu Techniques for Handheld AR with a Smartphone & Mid-Air Pen" [1]. This analysis presents the data using the more common method of significance testing. For details on study design and measurements, please consult the main paper.

2 Analysis

For every participant, we calculated the rate of successful selections per condition (*successRate*) as well as averaged the time to open the menu (*timeToMenu*), the time to select an item (*timeToItem*) as well as the translation and rotation movement (*translation*, *rotation*).

To analyze the effect of the different *menuTechnique*s, we performed mixed-effect ANOVAs with the user as a random variable. We log-transformed the time and device movement measurements before the evaluation. All post-hoc pairwise comparisons were performed using Tukey HSD tests. The subjective Likert-Scale ratings were analyzed using the Kruskal-Wallis test and post-hoc comparisons using the Wilcoxon method with a Bonferroni correction.

2.1 Success

The *menuTechnique* had a significant effect on *successRate* ($F_{4,56} = 3.62, p < .05$). Post-hoc tests show that *two-handed touch* (M: 99.79 %, SD: 0.81 %) and *mid-air pen* (M: 99.17 %, SD: 2.2 %) achieved significantly more successful selections compared to *surface* (M: 96.46 %, SD: 4.7 %). *Device pointer* (M: 98.96 %, SD: 1.52 %) and *one-handed touch* (M: 98.75 %, SD: 1.98 %) are not significantly different to the other techniques.

2.2 TimeToMenu

The *timeToMenu* also shows significant differences based on *menuTechnique*: ($F_{4,56} = 58.56, p < .001$). *Surface* (M: 3.97 s, SD: 1.52 s) was significantly slower than the other techniques (*device pointer*: M: 2.76 s, SD: 1.27 s; *one-handed touch*: M: 2.57 s, SD: 1.09 s; *mid-air pen*: M: 2.33 s, SD: 0.54 s) with *two-handed touch* (M: 1.38 s, SD: 0.23 s) being significantly faster than all the other techniques.

2.3 TimeToItem

Similarly, the *timeToItem* is also significantly affected by *menuTechnique*: ($F_{4,56} = 122.41, p < .001$). The Post-hoc tests show that *surface* (M: 4.33 s, SD: 1.86 s) was significantly slower compared to *device pointer* (M: 2.41 s, SD: 1.32 s) and *mid-air pen* (M: 1.97 s, SD: 0.5 s). Both *one-handed touch* (M: 1.53 s, SD: 0.32 s) and *two-handed touch* (M: 1.37 s, SD: 0.35 s) performed significantly faster compared to the other techniques.

2.4 Device Movement

The *menuTechnique* also had a significant effect on both *translation* ($F_{4,56} = 112.94.09, p < .001$) and *rotation* ($F_{4,56} = 107.83, p < .001$).

Post-hoc tests show significantly more movement for *surface* for both *translation* (M: 86.55 cm, SD: 23.7 cm) and *rotation* (M: 91.8 degrees, SD: 26.63 degrees) compared to all other techniques. Also, with *device pointer*, the device was also moved significantly more compared to the remaining techniques (*translation*: M: 37.57 cm, SD: 28.67 cm, *rotation*: M: 46.46 degrees, SD: 42.74 degrees).

The order of the remaining techniques differs minimally between translation and rotation. For *translation*, *one-handed touch* (M: 18.38 cm, SD: 8.11 cm) required more movement than *two-handed touch* (M: 12.55 cm, SD: 3.93 cm) while *mid-air pen* (M: 15.91 cm, SD: 5.07 cm) is not different from either. For *rotation*, *one-handed touch* (M: 25.09 degrees, SD: 10.69 degrees) is significantly different to *mid-air pen* (M: 18.6 degrees, SD: 4.69 degrees) while *two-handed touch* (M: 19.94 degrees, SD: 4.62 degrees) does not differ significantly from either.

2.5 EaseOfUse

The *ease* to use the techniques was rated significantly different based on the *menuTechnique* used ($\chi^2(4) = 23.994, p < .001$). Post-hoc comparisons show that *two-handed touch* (M: 5.87, SD: 0.35) achieved significantly higher ratings compared to the other techniques (*mid-air pen*: M: 5, SD: 0.93; *one-handed touch*: M: 4.73, SD: 1.22; *device pointer*: M: 4.2, SD: 1.66; *surface*: M: 3.47, SD: 1.85).

2.6 ComfortOfUse

The participants rated the *comfort* of using the techniques significantly different ($\chi^2(4) = 12.995, p < .05$). Post-hoc comparisons indicate that only *two-handed touch* (M: 5.2, SD:

1.15) and *surface* (M: 3.33, SD: 1.54) were rated significantly different from each other while the remaining techniques show no significant differences (*one-handed touch*: M: 4.13, SD: 1.55; *mid-air pen*: M: 4.2, SD: 1.21; *device pointer*: M: 4, SD: 1.65).

2.7 CombinationOfSelectionTechniques

The combination of techniques to open the menu and select an item was also rated significantly different for the *menuTechnique* ($\chi^2(4) = 25.226, p < .001$). Both *two-handed touch* (M: 5.6, SD: 0.83) and *mid-air pen* (M: 5.6, SD: 0.83) achieved high results followed by *one-handed touch* (M: 4.6, SD: 1.12). *Device pointer* (M: 3.4, SD: 2.38) and *surface* (M: 3, SD: 2.04) achieved the lowest scores. Post-hoc comparisons indicate significant differences between the two highest scoring techniques (*two-handed touch* and *mid-air pen*) and the two lowest scoring techniques (*device pointer* and *surface*).

3 Comparison to Original Analysis

The results from the alternative analysis show mainly the same results as the original analysis. For *success*, the alternative analysis groups *two-handed touch* and *mid-air pen* together as being significantly more successful compared to *surface*. The original analysis also suggests that *surface* could be less successful than the other techniques but does not differentiate between the other techniques due to the low effect of differences (on average around 1 *percentage point* difference in success rate).

Analysis of the time measurements show that for *timeToMenu*, both analyses have the same grouping (*two-handed touch* fastest, *mid-air pen*, *one-handed touch*, and *device pointer* in the middle, and *surface* slowest). The same holds for *timeToItem* since both analyses state that *surface* is the slowest while *two-handed touch* and *one-handed touch* as well as *mid-air pen* and *device pointer* are closer together. The original analysis however, also shows that, while not significantly different, the range of *mid-air pen* seems to be narrower and more directed towards the faster direction compared to *device pointer*.

Regarding the movement of the device, the alternative analysis only differs by differentiating *one-handed touch* and *two-handed touch* for *translation* and *one-handed touch* and *mid-air pen* for *rotation*. The original analysis does not differentiate between these conditions due to the smaller differences of, on average, 5 cm between *one-handed touch* and *two-handed touch* as well as 7 degrees between *one-handed touch* and *mid-air pen*.

The analysis of subjective ratings also show similar results. While the alternative analysis of *easeOfUse* only states that *two-handed touch* was rated significantly higher, the original analysis also notes a trend between the remaining techniques. For *comfortOfUse*, the alternative analysis only differentiates between *two-handed touch* and *surface*, while the original analysis states that *two-handed touch* seems to be rated higher than the other techniques as well. The analysis regarding the *combinationOfSelectionTechniques* shows the same grouping and order in both analyses.

In summary, both analyses mainly come to the same results. The alternative analysis shows some significant differences between the menu techniques which were not mentioned in the original analysis since the effect is rather small. On the other hand, the alternative analysis does not mention potential differences or trends since the post-hoc tests are only close but not lower than the cut-off value for significance after the Bonferroni correction.

References

[1] Philipp Wacker, Oliver Nowak, Simon Voelker, and Jan Borchers. Evaluating menu techniques for handheld ar with a smartphone & mid-air pen. In *22nd International Conference on Human-Computer Interaction with Mobile Devices and Services*, MobileHCI '20, pages 1–15, New York, NY, USA, 2020. Association for Computing Machinery.