3D User Interface Evaluation III

Lecture #18: Example Evaluations
Spring 2009
Joseph J. LaViola Jr.

Usability Evaluation in 3DUIs
Example Evaluations

- Non-isomorphic rotation (3DUI 07)
- Interaction Offset (3DUI 07)

IEEE Symposium on 3D User Interfaces 2007

An Exploration of Non-Isomorphic 3D Rotation in Surround Screen Virtual Environments

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Motivation and Goals

- Rotating objects in 3D space is a fundamental task
- Want to understand how 3D rotation techniques perform
- Isomorphic and non-isomorphic approaches
- Explore these approaches in SSVE
  - extend and augment existing knowledge
  - does existing knowledge transfer?
Non-Isomorphic 3D Rotation

- Human-Machine interaction
  - input device
  - display device
  - transfer function (control to display mapping)
- Non-isomorphic – scaled linear/non-linear mapping
  - manual control constrained by human anatomy
  - more effective use of limited tracking range (i.e. vision-based tracking)
  - additional tools for fine tuning interaction techniques
- Isomorphic – one-to-one mapping
  - more natural

Non-Isomorphic Rotation Technique

- Quaternion – four-dimensional vector \((v, w)\) where \(v\) is a 3D vector and \(w\) is a real number
- Let \(q_c\) be the orientation of the input device \(q_d\) be the displayed orientation, and \(q_o\) be the reference orientation then
  \[ q_q = q_c^k, \quad q_d = (q_c q_o^{-1})^k q_o, \quad k = \text{CD gain coefficient} \]
- Using relative mapping
  \[ q_{d_i} = (q_{c_i} q_{c_{i-1}}^{-1})^k q_{d_{i-1}} \]
Related Work

- User performance with different 3D rotation techniques (Chen 1988, Hinckley 1997)
- Rotating real and virtual objects (Ware 1999)
- Framework, design guidelines, non-isomorphic effectiveness (Poupyrev 2000)
- GlobeFish and Globe Mouse (Froehlich 2006)
- Hybrid haptic rotations (Dominjon 2006)

Experimental Study

- Further explore non-isomorphic rotation of virtual objects
- Systematic evaluation of different rotation amplifications
- Understand benefits of non-isomorphic in SSVE
  - head tracking
  - stereoscopic vision
Experimental Design

- 16 subjects (13 male, 3 female)
- Conducted in Brown “Cave”
- Based on Poupyrev 2000 → Hinckley 1997 → Chen 1988
- 4 x 2 x 2 balanced, within-subjects design (16 conditions)
- Independent variables
  - amplification (1,2,3,4)
  - rotation amplitude (20-60, 70-180 degrees)
  - Error threshold (6, 18 degrees)
- Dependent variables
  - completion time
  - orientation error

Experimental Procedure

- Task – rotate house from random to target orientation
- Pre-questionnaire
- 16 practice trials
- 16 sets of 10 trials each
- Ordering was randomized
- Post-questionnaire
Results - ANOVA

Repeated measures, three way ANOVA

<table>
<thead>
<tr>
<th>Effect</th>
<th>Time</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>$F_{3,13}=3.26$, $p=0.056$</td>
<td>$F_{3,13}=4.8$, $p&lt;0.05$</td>
</tr>
<tr>
<td>T</td>
<td>$F_{1,15}=13.66$, $p&lt;0.05$</td>
<td>$F_{1,15}=22.96$, $p&lt;0.05$</td>
</tr>
<tr>
<td>A</td>
<td>$F_{3,13}=55.46$, $p&lt;0.05$</td>
<td>$F_{3,13}=0.001$, $p=0.98$</td>
</tr>
<tr>
<td>S x T</td>
<td>$F_{3,13}=0.29$, $p=0.83$</td>
<td>$F_{3,13}=1.575$, $p=0.243$</td>
</tr>
<tr>
<td>S x A</td>
<td>$F_{3,13}=0.87$, $p=0.523$</td>
<td>$F_{3,13}=0.562$, $p=0.649$</td>
</tr>
<tr>
<td>T x A</td>
<td>$F_{1,15}=5.03$, $p&lt;0.05$</td>
<td>$F_{1,15}=0.573$, $p=0.46$</td>
</tr>
<tr>
<td>S x T x A</td>
<td>$F_{3,13}=0.73$, $p=0.55$</td>
<td>$F_{3,13}=0.97$, $p=0.436$</td>
</tr>
</tbody>
</table>

$S =$ scaling factor  $T =$ error threshold  $A =$ angle

Results - Post Hoc Analysis

Pairwise comparisons on scaling factor using Holm’s sequential Bonferroni adjustment

Significant differences between S1 and S2 and S1 and S3

Significant difference between S1 and S4
Results – Subject Preferences

Results – Summary

- Subjects performed 11.5% faster with S2 and 15.0% faster with S3 with no statistically significant loss in accuracy.
- Appears to be correlation between subject preferences and mean completion time.
  - Scaling factor of 3 is preferable amplification coefficient.
Discussion - Error

- Interesting differences with previous studies
- Poupyrev – 6.8 degrees
- Hinckley – 6.7 degrees
- Ware (physical objects) -- 4.4 degrees
- Our study – 3.9 degrees
  - threshold of 6 – 3.41, threshold of 18 – 4.4

Discussion – Completion Time

- Poupyrev
  - 5.15 seconds for isomorphic
  - ≈4.75 seconds for non-isomorphic
- Hinckley
  - 17.8 seconds for isomorphic (no training, accuracy focus)
- Our study
  - 2.2 seconds for isomorphic
  - 1.96 seconds for non-isomorphic
Discussion – Implications

- Differences attributed to
  - different hardware configurations
    - previous studies on desktop
    - our study in SSVE
  - Poupyrev’s amplification factor (1.8)
  - Hinckley – “… accuracy of rotation less affected by interface than by difficulties in perception of error…”
    - head tracking
    - stereoscopic vision
- Others – display size, refresh rate, video game proficiency, tracking lag

Conclusion

- Presented experiment exploring non-isomorphic rotation in SSVE
- Rotation task completed 15% faster with amplification factor of 3 than with isomorphic rotation
  - no statistically significant loss in accuracy
  - subjects preferred this amplification factor
- Faster and more accurate performance in SSVE in general
  - perception of objects closely matched with physical reality
  - many other factors could contribute
- Further work needed
An Exploration of Interaction-Display Offset in Surround Screen Virtual Environments

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Talk Outline

- Motivation and Goals
- Display-Interaction Offset
- Related Work
- Experiment
- Results
- Discussion
- Conclusion
Motivation and Goals

- Want to build effective interfaces in VE applications
- Many different interaction technique choices
  - set parameters to optimize performance
  - guidelines needed
- Techniques centered around user’s body are common in VEs
- Where should virtual object be placed with respect to user?

Display-Interaction Offset

- What is display-interaction offset?
  - two frames of reference
    - display
    - interaction
- Display frame of reference
  - perceived location of rendered graphical feedback
- Interaction frame of reference
  - location of physical interaction
Display-Interaction Offset (HMD)

Projection surface occludes physical hand

Display-Interaction Offset (SSVE)

Physical hand occludes projection screen

Interaction in a SSVE
Related Work

- Virtual object manipulation for docking task
- With HMD – Mine(1997)
  - found users performed faster with collocation over positional offset
  - found collocation or minimal offset minimized time to completion

Experimental Study

- Hypothesis – Translational offset between interaction and display frames of reference would improve user performance for 3D widget-based task
- Chose color matching with HSV widget
**Experimental Design**

- 24 subjects (12 male, 12 female)
- Conducted in Brown “Cave”
- 3 conditions of display-interaction offset
  - collocated
  - 3 inches
  - 2 feet
- 15 trials per condition
- Within-subjects design
- Target color used as second factor to control for color difficulty

**Experimental Procedure**

- Pre-questionnaire & color vision screening
- 6 practice trials
- For each trial
  - centering task
  - color matching
- Post-questionnaire
- 15 more trials with subject chosen offset
Performance Metrics

- **Measurements**
  - Time to center hand
  - Time to chose matching color
  - Chosen color

- **Derived**
  - Distance between target and chosen
  - Accuracy per time

Results – Time to Match Color

![Box plot showing time to match color for different offsets.](image-url)
Results – Centering Time

Results – Distance Between Target and Chosen Color
Results – Accuracy per Time

![Box plot showing accuracy per time for different offsets.]

Results - ANOVA

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Factor</th>
<th>Df</th>
<th>F-value</th>
<th>Pr(&gt;F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Offset</td>
<td>2</td>
<td>1.297</td>
<td>0.283</td>
</tr>
<tr>
<td></td>
<td>Color</td>
<td>14</td>
<td>7.867</td>
<td>2.27 × 10^{-14}</td>
</tr>
<tr>
<td>Distance</td>
<td>Offset</td>
<td>2</td>
<td>4.13</td>
<td>0.0224</td>
</tr>
<tr>
<td></td>
<td>Color</td>
<td>14</td>
<td>20.7</td>
<td>&lt; 2.0 × 10^{-16}</td>
</tr>
<tr>
<td>Accuracy Per Time</td>
<td>Offset</td>
<td>2</td>
<td>1.655</td>
<td>0.202</td>
</tr>
<tr>
<td></td>
<td>Color</td>
<td>14</td>
<td>7.108</td>
<td>7.98 × 10^{-13}</td>
</tr>
<tr>
<td>Centering Time</td>
<td>Offset</td>
<td>2</td>
<td>8.2594</td>
<td>0.0008614</td>
</tr>
<tr>
<td></td>
<td>Color</td>
<td>14</td>
<td>0.7685</td>
<td>0.7033</td>
</tr>
</tbody>
</table>
Results – Paired Sample T-Tests

- **Bonferroni correction**

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short vs. Long offset</td>
<td>Time</td>
<td>2.2635</td>
</tr>
<tr>
<td></td>
<td>Distance</td>
<td>2.5266</td>
</tr>
<tr>
<td></td>
<td>Accuracy Per Time</td>
<td>2.1699</td>
</tr>
<tr>
<td></td>
<td>Centering Time</td>
<td>(1.689 \times 10^{-7})</td>
</tr>
<tr>
<td>Collocated vs. Long offset</td>
<td>Time</td>
<td>0.19872</td>
</tr>
<tr>
<td></td>
<td>Distance</td>
<td>0.0026733</td>
</tr>
<tr>
<td></td>
<td>Accuracy Per Time</td>
<td>0.1221</td>
</tr>
<tr>
<td></td>
<td>Centering Time</td>
<td>(1.944 \times 10^{-5})</td>
</tr>
<tr>
<td>Collocated vs. Short Offset</td>
<td>Time</td>
<td>0.3624</td>
</tr>
<tr>
<td></td>
<td>Distance</td>
<td>0.0027369</td>
</tr>
<tr>
<td></td>
<td>Accuracy Per Time</td>
<td>0.2526</td>
</tr>
<tr>
<td></td>
<td>Centering Time</td>
<td>1.2495</td>
</tr>
</tbody>
</table>

Results – Second Phase

- **Chosen offset**
  - mean – 1.34 feet
  - SD – 1.026
Post – Questionnaire Results

<table>
<thead>
<tr>
<th>Questions</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
<th>F-value, P(1,43)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I enjoyed using the color picker</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.4457, 0.0243</td>
</tr>
<tr>
<td>The distance I moved my hand was the same distance that the color picker</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.9787, 0.0519</td>
</tr>
<tr>
<td>cursor moved was collinear with the cursor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.0195, 0.0499</td>
</tr>
<tr>
<td>I was able to see the locations of color's names</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.334, 0.0182</td>
</tr>
<tr>
<td>I felt the color picker was within my reach</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6.0404, 0.02032</td>
</tr>
<tr>
<td>It was easy to line up the color discs before each matching trial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.426, 0.2499</td>
</tr>
<tr>
<td>I felt that color matching was difficult</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.3444, 0.2776</td>
</tr>
<tr>
<td>The volume in which I moved my hand was a comfortably space to reach</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.3601, 0.094</td>
</tr>
<tr>
<td>I was mainly looking at the color picker while trying to match colors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.7916, 0.07191</td>
</tr>
<tr>
<td>I saw my own hand while trying to match colors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.1031, 0.0297</td>
</tr>
<tr>
<td>Seeing my own hand was disturbing for matching colors</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.9571, 0.07999</td>
</tr>
<tr>
<td>I felt that I could move my hand into the color picker</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13.219, 4, 0.00077</td>
</tr>
<tr>
<td>Using the color picker felt natural</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.2209, 0.1137</td>
</tr>
</tbody>
</table>

Discussion

- Both offset conditions were significantly better than collocation
  - distance
  - user preference
- No significant difference between offset conditions
- For centering task
  - most similar to Mine and Paljic
  - collocation and minimal offset significantly faster
- Results agree and disagree with previous work
Conclusion

- Compared effect of positional offsets on user performance in SSVE
  - color matching
  - centering
- Centering task performance in line with previous work
- Color matching performance shows technique does not fit within established guidelines
- Further studies needed

Next Class

- Student Presentations Begin