Performance Effects of Multi-sensory Displays in Virtual Teleoperation Environments

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Urban Search-and-rescue (USAR)

- Who: a team of experts and a robot
- When: after a building collapsed
- Where: building debris area
- What: search for victims
Proposed Research

• Current interfaces are
  • Visually cluttered
  • Difficult to monitor data from

• Goal:
  • Make interface easier to understand
  • Operator better perform his task
  • More lives saved

• Experiments on multi-sensory interfaces
  • Simulated robot
  • Focus on output

Yanco et al., 2011
Yanco et al., 2004
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Remote real environment

Acts on environment

Senses the environment

Robot

Virtual representation of remote real environment

Carrying out action

Operator input-device commands

Human-readable environment data

Sensing the state of the robot and the remote environment

Robot-readable operator commands

HRI application

Robot-sensed environment data

Multi-sensorial Interfaces

Local real environment

Making sense of such data

Deciding on next action

Operator

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Previous Work

• Adding the sense of touch to visual interface
  – Vibro-tactile display for collision proximity feedback

• Compared touch display modes

• Conclusions:
  – Extra sense enhanced performance
Questions

• What is the impact of
  – Adding more senses to the interface?
  – Redundant feedback across senses?

• New study: tri-sensory display
  – Visual
  – Audio
  – Touch
Experiment

• Within-subjects design
• 18 subjects
  – 3 randomized treatments (one for each interface)
• Task: find red spheres in debris-filled environment
  – Find as many as possible as fast as possible
  – Avoid collision as much as possible
• Secondary task: Stroop text color matching

E.g.: Green Red
  “match!” “mismatch!”

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## Study Design

<table>
<thead>
<tr>
<th>Interface Treatments</th>
<th>Standard Visual Display</th>
<th>Vibrotactile display</th>
<th>Audio Display</th>
<th>Visual Ring and Speed Display</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>X</td>
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<td>2</td>
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<tr>
<td>3</td>
<td>X</td>
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</tr>
</tbody>
</table>

- **Within subjects**
- **Control case**
- **Audio added**
- **Rendundant visuals added**

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Hypotheses

• **H1.** Adding redundant and complementary sound feedback to the control interface should improve performance in the search task

• **H2.** Adding redundant visual feedback should lead to even further improvements in performance in the search task
Vibro-tactile Feedback

- 8 vibration units
- Around waist
- Directional collision proximity feedback
- The closer to an object, the more intense the vibration

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Audio Feedback

• Standard Headset
• Stereo sound
  – Spatialized bump sounds for robot collisions
  – Engine noise for robot speed
    • Varied in pitch based on speed
Input

• Standard game controller
  – Move Robot
    • differential drive
  – Rotate pan-tilt camera
    • $100^\circ H \times 45^\circ V$
    • Take pictures
  – Answer text-color matching questions
Interface

- Rotating panel with video feed from robot camera
- Chronometer (disabled during training session)
- "Real" remote robot
- Blue dots representing nearby object surfaces
- Collision proximity visual ring
- Robot avatar
- Speedometer
Dependent Variables

- Task time
- Number of collisions
  - Per minute, per path length
- Number of spheres found
  - Per minute, per path length
- Quality of the sketchmaps
  - 2 graders
- Stroop task performance
  - Response time
  - Number of unanswered questions
- Workload
  - NASA-TLX
- Subjective feedback
  - Per treatment, final questionnaire

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Subjects

• University students
  – Age: $N(25, 3.18)$
  – Varying experience levels

• Data Normalization per subject

• E.g.: $(UI1, UI2, UI3) = (10, 20, 30)$
  $\rightarrow (10/60, 20/60, 30/60)$
  $\sim (0.17, 0.33, 0.5)$

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Results
Results

• Feeling of Being There:
  – Control-case: $\mathcal{S} + \text{phone}$
  vs.
  – UI2: $\mathcal{S} + \text{phone} + \text{sound}$

• UI2 Wins!

$\dagger$ = Statistically significant difference

Same group members (No SSD$\dagger$)

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Results

• Feeling of Walking:
  – UI2: $+$ $+$
  vs.
  – UI3: $+$ $+$ $+$ $+$

• UI3 Loses!
Results

- **Difficulty:**
  - Control-case: 📦 + 🗣️
  - UI2: 📦 + 📦 + 🗣️

- UI2 Loses!
Results

• Positive Impact:
  – Control-case: $\mathcal{S} + \text{phone}$
  vs.
  – UI2: $\mathcal{S} + \text{phone} + \text{audio}$

• UI2 Wins!

Subjective Impact for Different Interface Types

Same group members (No SSD)

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Results

• Help in Understanding Data:
  – Control-case: $+$
  vs.
  – UI2: $+$
  vs.
  – UI3: $+$

• UI2 and UI3 Win!
Results

• Temporal Workload:
  – Control-case: $S + \mathcal{C}$ vs.
  – UI2: $S + \mathcal{C} + \mathcal{S}$

• UI2 Wins!
• Does this imply UI2 decreased cognitive load?!
Results

- **Performance Workload:**
  - Control-case: 📲 + 🎧
  - UI3: 📲 + 🎧 + 🎤 + 🙅

- **UI3 Loses!**
Results

• Stroop Response Time:
  – Control-case: $\mathcal{S} + \mathcal{K}$ vs.
  – UI2: $\mathcal{S} + \mathcal{K} + \mathcal{V}$ vs.
  – UI3: $\mathcal{S} + \mathcal{K} + \mathcal{V} + \mathcal{E}$

• UI2 and UI3 Win!

Same group members (No SSD)
Results

• Stroop Number of Unanswered Questions:
  – Control-case: $\mathcal{S} + \mathcal{V} + \mathcal{H}$ vs.
  – UI2: $\mathcal{S} + \mathcal{V} + \mathcal{H}$ vs.
  – UI3: $\mathcal{S} + \mathcal{V} + \mathcal{H} + \mathcal{E}$

• UI2 Wins!
Results

• Percentual Number of Collisions per Minute:
  – Control-case: $\text{\$ + \#}$ vs. $\text{\$ + \#}$
  – UI2: $\text{\$ + \#}$

• UI2 Wins!

Percentual Number of Collisions per Minute for Different Interface Types
Results

• Percentual Number of Collisions per Path Length:
  – Control-case: $\mathcal{S} + \mathcal{S}$ vs.
  – UI2: $\mathcal{S} + \mathcal{S} + \mathcal{S}$ vs.
  – UI3: $\mathcal{S} + \mathcal{S} + \mathcal{S} + \mathcal{S}$

• UI2 and UI3 Win!
Conclusions

• Adding audio still to visual-tactile interface improved performance
• Adding redundant feedback did not help

Redundant data display over multiple senses brings no benefit to the user of a multi-sensorial display that already maximizes the user’s omni-directional perception of relevant data
Future Work

- Validation of results with real robot
- Adding more types of feedback

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Future Work

**Num. Spheres Found per Minute for Different Interface Types**

- Visual
- Visual + Audio
- Visual + Audio + Touch
- Visual + Audio + Touch + Smell

**Number of Collisions per Minute for Different Interface Types**

- Visual
- Visual + Audio
- Visual + Audio + Touch
- Visual + Audio + Touch + Smell
Thank you

• Questions
• Comments
• Discussion

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