Human-machine interface designs assisting drivers of automated vehicles during transitions: evaluation from end-user perspective

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Background

- This research was part of the Mediator project funded from the European Union’s Horizon 2020 research programme under the grant agreement no. 814735.

- Automation levels (AD: Assisted driving and PD: Piloted driving) and its transitions needs to be communicated.

- Need for novel HMI interfaces.

- Multimodality improve recognition, understanding and promotes faster reactions (van Erp et al., 2015; Petermeijer et al., 2016, Manawadu et al., 2017).

- Light displays (LED strips) for communicating automation mode & transitions (Yang et al., 2018, Muthumani et al., 2020, Wilbrink et al., 2020, Dziennus et al., 2016).

- Positioning the light displays inside vehicle interiors.
Objective

- Compare additional displays on two locations (steering wheel vs bottom of windshield).
- Use case: communicating automation levels (AD-Assisted Driving, PD-Piloted driving) and transitions between the levels including manual driving.
- Three multimodal HMI (HMI-1, HMI-2 with additional light display and baseline without it).
# Human-Machine Interface Designs Assisting Drivers of Automated Vehicles during Transitions: Evaluation from End-User Perspective

## HMI Design & Framework (HMI-1)

<table>
<thead>
<tr>
<th>Interfaces</th>
<th>Manual</th>
<th>Assisted available</th>
<th>Assisted activating</th>
<th>Assisted driving</th>
<th>Piloted available</th>
<th>Piloted activating</th>
<th>Piloted driving</th>
<th>Planned transfer initiation</th>
<th>Unplanned transfer initiation</th>
<th>Manual</th>
</tr>
</thead>
<tbody>
<tr>
<td>LED on SW</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>☑</td>
<td>✔</td>
</tr>
<tr>
<td>LED on windshield</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>☑</td>
<td>✔</td>
</tr>
<tr>
<td>Instrument cluster</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>☑</td>
<td>✔</td>
</tr>
<tr>
<td>Voice messages</td>
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<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>☑</td>
<td>✔</td>
</tr>
<tr>
<td>Seat belt pull</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>✔</td>
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<td>☑</td>
<td>✔</td>
</tr>
<tr>
<td>Touch pads</td>
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<td>✔</td>
<td>✔</td>
<td>✔</td>
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<td>✔</td>
<td>✔</td>
<td>✔</td>
<td>☑</td>
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</tbody>
</table>

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Experimental design

- Fixed base driving simulator.
- Three-lane motorway with no traffic.
- Assisted mode (AD): No feet on pedals, hands-on steering wheel and monitor.
- Piloted mode (PD): No feet on pedals, no hands-on steering wheel, engage in secondary task (DOTS game).
- 24 volunteers, 4 groups, drove 3 laps (16 min per lap) with one HMI design.
- Data collection: System Usability Score (SUS) score, HMI desirable aspects, HMI design ranking.

<table>
<thead>
<tr>
<th>Groups</th>
<th>Lap1</th>
<th>Lap2</th>
<th>Lap3</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>Bas</td>
<td>HMI-1</td>
<td>HMI-2</td>
</tr>
<tr>
<td></td>
<td>→ (P)→ (U)</td>
<td>→ (P)→ (U)</td>
<td>→ (P)→ (U)</td>
</tr>
<tr>
<td>G2</td>
<td>HMI-2</td>
<td>HMI-1</td>
<td>Bas</td>
</tr>
<tr>
<td></td>
<td>→ (P)→ (U)</td>
<td>→ (P)→ (U)</td>
<td>→ (P)→ (U)</td>
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<tr>
<td>G3</td>
<td>Bas</td>
<td>HMI-2</td>
<td>HMI-1</td>
</tr>
<tr>
<td></td>
<td>→ (P)→ (U)</td>
<td>→ (P)→ (U)</td>
<td>→ (P)→ (U)</td>
</tr>
<tr>
<td>G4</td>
<td>HMI-1</td>
<td>HMI-2</td>
<td>Bas</td>
</tr>
<tr>
<td></td>
<td>→ (P)→ (U)</td>
<td>→ (P)→ (U)</td>
<td>→ (P)→ (U)</td>
</tr>
</tbody>
</table>

Baseline = No LED, HMI-1 = Steering wheel LED, HMI-2 = Windshield LED, P = Planned TOR, U = Unplanned TOR
Results: SUS score

- Measure of people’s subjective perception of usability of the system.
- Baseline: 79
- HMI-1: 81
- HMI-2: 79
- No statistical significance (repeated-measure ANOVA between the HMI designs; F(2,69)=0.19, p = 0.834).

HMI desirable aspects

- Direct attention to vital information
- Influence mental workload to be at moderate level
- Avoid erroneous counter reactions
- Avoid confusion about driver's role
- Avoid mode confusion
- Provides appropriate trust

Baseline

HMI-1

HMI-2

<table>
<thead>
<tr>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Somewhat disagree</th>
<th>Neutral</th>
<th>Somewhat agree</th>
<th>Agree</th>
<th>Strongly agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0%</td>
<td>10.0%</td>
<td>20.0%</td>
<td>30.0%</td>
<td>40.0%</td>
<td>50.0%</td>
<td>60.0%</td>
</tr>
<tr>
<td>70.0%</td>
<td>80.0%</td>
<td>90.0%</td>
<td>100.0%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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HMI desirable aspects

Avoids mode confusion

- Strongly disagree
- Disagree
- Somewhat disagree
- Neutral
- Somewhat agree
- Agree
- Strongly agree

Direct attention to vital information

Baseline

HMI-1

HMI-2
HMI design ranking

<table>
<thead>
<tr>
<th>Rank</th>
<th>HMI-1</th>
<th>HMI-2</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rank 1</td>
<td>17%</td>
<td>17%</td>
<td>67%</td>
</tr>
<tr>
<td>Rank 2</td>
<td>13%</td>
<td>21%</td>
<td>71%</td>
</tr>
<tr>
<td>Rank 3</td>
<td>13%</td>
<td>17%</td>
<td>67%</td>
</tr>
</tbody>
</table>
Interview responses

- Activation routine is longer, could be simpler, now I must listen to voice, see light bar, see cluster to get one information, it could be improved, just one push button and I'm there (1).

- I do like the LEDs showing activated mode, I do like the LED showing progress towards taking control (count down).

- Not sure if I liked the LEDs indicating that the two modes were ready for activation. Think I would rather leave that function behind (1); animations could be avoided (1).
Summary

- HMI-1 received a higher mean SUS rating (81) than HMI-2 (79) and baseline (79).
- Desirability of HMI designs: HMI-1 received the high rating.
- HMI design ranking: 67% of participants preferred HMI-1 as rank 1.

Limitations

- No hazard or threat situation in the simulated environment.
- LED illumination patterns.
- Sample size.
Conclusion

- HMI-1 with visual cues on steering wheel for communicating automation levels and transitions, improve
  - perceived usability,
  - desirability and
  - user preference.

- Personalization of HMI elements can further improve the attractiveness of HMI design.
Thank you

Reach out
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