Evaluation of Display Methods for Teleoperation of Road Vehicles

Frederic Chucholowski
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Introduction

- Driverless vehicle delivery (car-sharing or charging)
- Control via live video feed
Press event at TUM
Time delays in signal chain decrease driving performance
Predictive Display

- Mitigate time delay effects
- Additional information
Finding the best display method

Source: Arnold 1963

Source: http://www.mitre.org/news/digest/defense_intelligence/12_09/feedback.html

Source: Davis 2009
Frame Prediction Method

- Size of frame indicates vehicle boundaries
- Frame position indicates predicted vehicle front position
- Length of Trackmarks indicates velocity
- Trackmarks indicate trajectory

Source: FTM
Display Methods

<table>
<thead>
<tr>
<th>3 Methods</th>
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<tbody>
<tr>
<td><strong>Delayed Display (DD)</strong></td>
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<tr>
<td>▪ Delayed visual feedback</td>
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<tr>
<td><strong>Perfect Prediction (PP)</strong></td>
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<tr>
<td>▪ Video images altered to show no delay</td>
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<tr>
<td><strong>Frame Prediction (FP)</strong></td>
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<tr>
<td>▪ Frame displayed at predicted position</td>
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User Study With Driving Simulator

- Vehicle 1
- Vehicle 2
- Vehicle 3

Stop line & Goal
Participants

- Students and employees of TUM
- ♀: 1 ♂: 21
- Age: 21 to 35 (average 24.91) years
- Experience with driving simulators: 4
- Good or very good experience with computer games: 15
Results

11 km/h

16 km/h
Overall performance improved

- 2/3 Lane accuracy
- 1/3 Task completion time

![Overall performance comparison graph](image.png)
**Number of steering wheel changes DD>PP>FP**
Reduced workload with prediction

City Course

City Course

Handling Course

Handling Course

Workload

1 (lowest) – 10 (highest)

Number of steering wheel changes

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Additional measurements

- Task Completion time reduced
- Sensation of velocities improved
- Distance to stop line reduced with FP
Comparison

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<tr>
<th>Delayed Display</th>
<th>Perfect Prediction</th>
<th>Frame Prediction</th>
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<tr>
<td>+ No Implementation effort</td>
<td>+ Driving Performance</td>
<td>+ Driving Performance</td>
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<tr>
<td>- Bad driving performance</td>
<td>+ Workload</td>
<td>+ Workload</td>
</tr>
<tr>
<td>- High workload</td>
<td>+ Higher velocities</td>
<td>+ Higher velocities</td>
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<td></td>
<td>- Implementation effort</td>
<td>- Preview distance for higher velocities</td>
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Conclusion

- Negative influence of time delays on driving performance and operator workload
- Mitigation possible with predictive displays
- FP sometimes even better than PP
- High implementation effort for PP not necessary
Frame Prediction is the preferred method
Outlook

- Further improve FP
- Prediction of other traffic participants
Thank you!

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