The Effect of Vehicle Automation on Road Safety

11th Workshop on Planning, Perception and Navigation of Intelligent Vehicles

2019 IROS 2019
MACAU, CHINA

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Vehicular Robots
Self-Driving Technologies in Use

• Drifting warning
  alerts by lane deviation
• Collision avoidance
  Radar-, laser-, or camera-based
• Blind-spot detectors
  camera or radar-based
• Enhanced cruise control
  adapted distance to vehicle ahead
• Self parking
  camera or sonar-based
Driving Task Complexity
Driving Subtasks
Driving Subtasks

- Speed
- Distance
- Steering
- Traffic observation
- Decision making

Subtask 1 Control Operational Level
- Steering, changing gear, accelerating, braking

Subtask 2 Guidance Tactical Level
- Observing traffic rules
- Maneuvers with other road users

Subtask 3 Navigation Strategic Level
- Vehicle and route choice

Driving Task

- Car controls
- In-vehicle information
- Traffic signs
- Rules awareness
- Risk evaluation

Driving Instruction for Autonomous Vehicles

By giving examples and training the vehicle

Recording data from humans sitting on vehicle

Vehicle learning

- Speed
- Driving tasks
  - Longitudinal direction
  - Lateral direction
- All driving subtasks
  - merging into moving traffic,
  - driving in roundabouts
  - negotiating intersections
- avoiding obstacles
- Interaction with other road users
Driving Instruction for Autonomous Vehicles

- Perception
- Expectations
- Judgement
- Memory
- Planning
- Decision making
- Risk assessment

Human Behavior

Unexpected situations

https://www.dolmanlaw.com/motorcyclists-steer-clear-aggressive-drivers/
Driving Instruction for Autonomous Vehicles

Emotional artificial intelligence through human monitoring and analysis

- gesture capture
- eye tracking
- head pose
- face detection
- body posture
- voice recognition
- vocal emotion
  - hesitations, frequency, variation, pitch, energy, speed


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Driving Instruction for Autonomous Vehicles

Unclear situations + Sudden events = How drivers respond to traffic situations

Human Errors

http://www.4autoinsurancequote.com/uncategorized/top-10-secrets-for-getting-cheap-car-insurance
Processing and Decision Making

Information interpretation

Traffic Light Assistance System

- Retrieves the traffic light timing program to calculate the optimal speed while approaching an intersection.

- Shows recommended velocity based on:
  - vehicle’s acceleration
  - speed,
  - phase state of traffic light
  - remaining phase duration

Increase in driving efficiency after the drivers adjusted their velocity to the speed calculated by the system

- improvement of traffic flow
- reduced gas emissions
- waiting time at traffic lights

<table>
<thead>
<tr>
<th></th>
<th>W/o TLA</th>
<th>W/ TLA</th>
<th>T-Test (α = 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Travel time (s)</td>
<td>398</td>
<td>52.57</td>
<td>370.2</td>
</tr>
<tr>
<td>Delay (s)</td>
<td>108.59</td>
<td>35.82</td>
<td>71.38</td>
</tr>
<tr>
<td>Speed (kmh⁻¹)</td>
<td>19.16</td>
<td>2.57</td>
<td>20.4</td>
</tr>
<tr>
<td>CO₂ (mg)</td>
<td>411.91</td>
<td>28.12</td>
<td>406.33</td>
</tr>
<tr>
<td>Stops no.</td>
<td>13.6</td>
<td>3.88</td>
<td>8.88</td>
</tr>
</tbody>
</table>
Interaction in a Vehicular Environment

Communication and Information Flow
Interaction in a Vehicular Environment

Social Traffic

Vehicular units
• share space
• take each other into account
• avoid a collision
Information Flow

Capacity of attentional resources and demand
Communication while Driving Information Location


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**Communication while Driving**

Information Location

<table>
<thead>
<tr>
<th>Metric</th>
<th>Baseline</th>
<th>In-Vehicle System</th>
<th>Leading-Vehicle System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Velocity (km/h)</td>
<td>31.44</td>
<td>4.85</td>
<td>31.95</td>
</tr>
<tr>
<td>Headway (m)</td>
<td>9.87</td>
<td>1.65</td>
<td>12.12</td>
</tr>
<tr>
<td>TTC (s)</td>
<td>1.20</td>
<td>0.22</td>
<td>1.46</td>
</tr>
<tr>
<td>LP (m)</td>
<td>0.52</td>
<td>0.09</td>
<td>0.50</td>
</tr>
<tr>
<td>Deceleration change rate (km/h/s)</td>
<td>0.43</td>
<td>0.17</td>
<td>0.62</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metric</th>
<th>Baseline vs. In-Vehicle</th>
<th>Baseline vs. Leading-Vehicle System</th>
<th>In-Vehicle vs. Leading-Vehicle System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t(19)</td>
<td>p</td>
<td>t(19)</td>
</tr>
<tr>
<td>Velocity (km/h)</td>
<td>-0.41</td>
<td>0.69</td>
<td>-0.07</td>
</tr>
<tr>
<td>Headway (m)</td>
<td>-4.90</td>
<td>9.93E-05</td>
<td>0.031</td>
</tr>
<tr>
<td>TTC (s)</td>
<td>-5.33</td>
<td>3.81E-05</td>
<td>-1.88</td>
</tr>
<tr>
<td>LP (m)</td>
<td>0.66</td>
<td>0.52</td>
<td>0.44</td>
</tr>
<tr>
<td>Deceleration change rate (km/h/s)</td>
<td>-2.90</td>
<td>0.009**</td>
<td>-2.35</td>
</tr>
</tbody>
</table>

Communication while Driving
Information Location


Connected and Automated Technologies
Driving and Interaction with other Road Users
V2X and ADAS effect on Road Safety

Technologies and applications that use data collected by sensors located in other vehicles, infrastructure or road users (V2X) to assist the driver

Key step toward a significant reduction of accidents
Autonomous vehicles represent an opportunity to continue working for increased road safety

- Human Intervention not required

- Congestion and air pollution reduction (platooning)

- Automation will be in charge of driving sub tasks

# Automation Levels

<table>
<thead>
<tr>
<th>SAE level</th>
<th>Name</th>
<th>Narrative Definition</th>
<th>Execution of Steering and Acceleration/Deceleration</th>
<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System Capability (Driving Modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>the driving mode-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>the driving mode-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the human driver perform all remaining aspects of the dynamic driving task</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
</tbody>
</table>

### Automated Driving System (“System”) monitors the driving environment

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<tr>
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<th>Monitoring of Driving Environment</th>
<th>Fallback Performance of Dynamic Driving Task</th>
<th>System Capability (Driving Modes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task with the expectation that the human driver will respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>the driving mode-specific performance by an automated driving system of all aspects of the dynamic driving task, even if a human driver does not respond appropriately to a request to intervene</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>the full-time performance by an automated driving system of all aspects of the dynamic driving task under all roadway and environmental conditions that can be managed by a human driver</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
</tr>
</tbody>
</table>


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Take Over Request (Level 3)

- Construction zones, orange signs, cones etc.
- Railroad crossing
- Cars stopped in the road
- Pedestrians, cyclists

- Narrow paths (mountain roads)
- Lidar problems due to sunlight
- Interferences with other electronic devices
Take Over Request (Level 3)

- Hit Detection Response Task (HDRT) performance prior to and after a spelling task per signal and phases (before, during and post) spelling task (N = 31)

- It takes about 0.8 seconds for a driver to shift attention so that their eyes are on the road

- It takes even longer to assess the situation to make a helpful response.

- Drivers can be distracted up to 27 seconds after finishing a “highly distracting task and up to 15 seconds after a moderate one”


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Hypovigilance (Level 3)

Task monotony

Driving performance decrease

Conditional Automation

Reduced driver workload

Road vigilance decrement

Hypovigilance (Level 3)

- Luminescence-based unobtrusive method
- Relying on peripheral vision, which is processed subconsciously

Tendency to respond faster to a TOR when peripheral vision detected stimulus

Take Over Request (Level 3)

- Baseline conditions: No IDCS system activated
- Scenario 1: TOR display activated
- Scenario 2: IDCS informs the driver through the three display panels
Take Over Request (Level 3)

- Baseline conditions: No IDCS system activated
- Scenario 1: TOR display activated
- Scenario 2: IDCS informs the driver through the three display panels

Significant decrease in
- response time to TOR
- number of collisions
Take Over Request (Level 3)

Vulnerable Road Users (VRU)

Pedestrian detection by pose estimation using Open-Pose

Pedestrians crossing from both sides

VRUs Response to Autonomous Vehicles

22 videos documented pedestrian behavior of 49 pedestrians in a marked crosswalk

Vehicle equipped with optical wheel encoders, a stereo-vision camera, a laser-range finder, a compass and GPS sensor


VRUs Response to Autonomous Vehicles

- Many pedestrians involved in the manipulation of their smartphones
- Vehicle attracted attention and curiosity
- Testing whether the vehicle really stopped
- Some pedestrians did not dare to approach it
- Uncertainty
  hesitation before crossing


VRUs Response to Autonomous Vehicles

Crossing uncertainty due to:

- lack of knowledge about detection
- whether the vehicle was going to slow down
- not trusting the functioning of the sensors
70% of people preferred the eyes image compared with 30% that selected the color coded.

No statistically significant differences ($2(1, N = 21) = 7.54, p = .006$).


VRU Response to Communication Signals from Vehicular Robots

<table>
<thead>
<tr>
<th>Metric</th>
<th>Baseline</th>
<th>Red/green color</th>
<th>Opened/closed eyes</th>
<th>T-Test ($\alpha = 0.05$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>6.14</td>
<td>3.56</td>
<td>7.38</td>
<td>3.48</td>
</tr>
<tr>
<td>TTC (s)</td>
<td>7.31</td>
<td>4.64</td>
<td>4.9</td>
<td>6.23</td>
</tr>
<tr>
<td>T-Test ($\alpha = 0.05$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>t(92)</td>
<td>p</td>
<td>t(92)</td>
<td>p</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>1.27</td>
<td>0.20</td>
<td>0.85</td>
<td>0.39</td>
</tr>
<tr>
<td>TTC (s)</td>
<td>1.51</td>
<td>0.13</td>
<td>1.07</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Effect of eye contact on interaction with the AV

<table>
<thead>
<tr>
<th>Metric</th>
<th>Without eye contact</th>
<th>Eye contact</th>
<th>T-Test ($\alpha = 0.05$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Distance (m)</td>
<td>6.93</td>
<td>3.28</td>
<td>7.81</td>
</tr>
<tr>
<td>TTC (m/s)</td>
<td>5.87</td>
<td>6.71</td>
<td>8.93</td>
</tr>
</tbody>
</table>

Distributions of walked or stopped variables with red or closed eyes not statistically significant.

The kind of display did not affect TTC neither the distance at which pedestrians crossed in front of the AV.

Visual communication cues for are not necessarily required for a shared space in which informal traffic rules apply.

3D Simulation  
Trigger Events  
V2V / V2P
V2X Traffic Simulation

Unity interacts with SUMO via TraCI

Visualization of Sumo with Unity

Traffic Simulation + V2X

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Unity as Simulation Tool for ROS

Unity as Visualization Tool for ROS

Autonomous Driving Based on AutoWare
Thank You!