InMotion

Light-based communication between automated vehicles and other road users
InMotion:
„Development of light-based communication between automated vehicles and other road users“

Funding: BMVI, Total Budget 1,1 M €
Duration: 10/2017 - 06/2020 (33 Month)
Coordination: TUC (Matthias Beggiato)

Consortium:
- Chemnitz University of Technology (Cognitive and Engineering Psychology + Communications Engineering)
- Ford Werke GmbH (Aachen)
- Intenta GmbH Chemnitz (SME)
Aims InMotion

• Development of **light-based communication** between automated vehicles and other road users, particularly Vulnerable Road User (VRU; cyclist and pedestrians)

• Analysis of existing communication procedures as basis

• Develop and test Human-Machine Interfaces as external communication solution (**eHMI**), user centered approach, Wizard-of-Oz study, Field study, Lab studies using augmented video

• Prototypical **Hard- and Software solution and demonstrator vehicle** with sensors, C2X-comm., light-based communication

• Focus on urban setting (low speed), 3 potential use cases:
  1) VRU crossing at crosswalks, mixed traffic environment
  2) Automated valet-parking, communication with user
  3) Communication with passengers of automated taxis
**Work packages** (01.10.2017 – 30.06.2020)

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
<th>Q7</th>
<th>Q8</th>
<th>Q9</th>
<th>Q10</th>
<th>Q11</th>
</tr>
</thead>
<tbody>
<tr>
<td>WP1: Analysis communication existing datasets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WP2: User studies eHMI (Lab, Field, Wizard-of-Oz)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WP3: Development and test sensors systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WP4: Modelling communication</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WP5: Setup demonstrator vehicle</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) Wizard-of-Oz study  
2) Field study  
Both with Light Bar Ford as eHMI
Results WP 2:
Wizard-of-Oz study/ Field study

Chemnitz, 19.11.2018
Matthias Beggiato, Isabel Neumann, Ann-Christin Hensch
Wizard-of-Oz study
Method | study design

- Aim: effects of light signals on uninformed passing pedestrians
- Setting: parking area on the campus of Chemnitz University of Technology
- Wizard-of-Oz technique (driver hidden by seat suit); between-subject-design
- Applied methods: questionnaires, interviews, videos

<table>
<thead>
<tr>
<th>Drivers' visibility</th>
<th>Use cases (color: turquoise)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver visible</td>
<td>No signal</td>
</tr>
<tr>
<td></td>
<td>Automation mode</td>
</tr>
<tr>
<td></td>
<td>Crossing mode</td>
</tr>
<tr>
<td></td>
<td>Starting mode</td>
</tr>
<tr>
<td>Driver invisible (seat suit)</td>
<td>Video data</td>
</tr>
</tbody>
</table>

Questionnaires, Interview data, video data
Method | use cases
Method | procedure and depended variables

- Demographic data: age, gender

- Scale:
  - [1] "I completely disagree" to [7] "I completely agree"

- Subjective safety during the interaction with vehicle

- Usefulness of signals
- Trust in signals
- Comprehensibility of signals

1. Drive in respective mode (randomized light signals/driver visibility)

2. Agreement for interview

3. 1st part of the interview: Uninformed participants

4. 2nd part of the interview: Informed participants

*data also collected in the field study
1 uninformed
2 informed
Results | sample and general data

- Video data: 98 drives
  - $\approx 6.5$h
  - $\approx 1800$ pedestrians

- Interview data: 173 participants
  - 113 (66.1%) men, 58 (33.9%) women
  - Age: $M = 29$ ($SD = 10.65$)
  - Completed questionnaires: $N = 147$
Safety
When interacting with the vehicle I felt safe.

• Regarding subjective safety during the interaction with the vehicle there is no difference between the light signals \(F(3,161) = 1.59, p = .193, \eta_p^2 = .03\).

• The participants felt **significantly** safer during the interaction with the vehicle when the driver was visible \(F(1,161) = 4.03, p = .046, \eta_p^2 = .02\).
Usefulness

The presented signal is useful.

- The presented light signals were only partially assessed as useful by the participants.

- Regarding the usefulness of the presented light signals there is no difference ($F(2,126) = 2.91, p = .058, \eta^2 = .04$).

- The presented light signals were assessed as equally useful by the participants despite driver’s visibility ($F(1,126) = 0.28, p = .598, \eta^2 = .00$).
Usefulness
A Signal that indicates... is **generally** useful.

- In general light signals as external HMI were assessed as useful by the participants.

- Regarding the usefulness of the general signal use there is no difference between the light signals ($F(2,140) = 1.26, p = .286, \eta^2_p = .02$).

- The general use of the light signals was assessed as equally useful by the participants despite driver’s visibility ($F(1,140) = 2.39, p = .124, \eta^2_p = .02$).
**Trust – Overall item**

- In general the light signals were only partially assessed as trustworthy by the participants.

- Regarding trust there is no difference between the light signals ($F(2,127) = 0.04, p = .964, \eta^2_p = .00$).

- The light signals were assessed as equally trustworthy by the participants despite driver’s visibility ($F(1,127) = 0.04, p = .838, \eta^2_p = .00$).
Comprehensibility
The signal is comprehensible.

• In general the light signals were assessed as **not comprehensible** by the participants.

• Regarding comprehensibility there is no difference between the light signals ($F(2,126) = 0.00, p = .997, \eta^2_p = .00$).

• The light signals were assessed as equally (not) comprehensible by the participants despite driver’s visibility ($F(1,126) = 0.03, p = .859, \eta^2_p = .00$).
### Interview data

#### Closed-ended questions

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did you perceive the light signal on top of the vehicle?</td>
<td>$N = 133$ (88.7%)</td>
<td>$N = 17$ (11.3%)</td>
</tr>
<tr>
<td><strong>The light signal was perceived by the majority of participants (88.7%).</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you believe that the light signal was addressed to you?</td>
<td>$N = 19$ (14.3%)</td>
<td>$N = 114$ (85.7%)</td>
</tr>
<tr>
<td><strong>Despite the low spatial distance in the parking area setting the majority of participants (85.7%) did not believe that the light signal was addressed to themselves.</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Did you see any driver inside the vehicle?</td>
<td>79.2% of participants did <strong>not</strong> see any driver when the seat suit was worn.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>When the driver was visible 51.6% of participants did see the driver (20.3% were unsure; 28.1% did not see any driver).</td>
<td>$N = 170$</td>
</tr>
</tbody>
</table>
Interview data (including all conditions)
Open-ended question: What do you think was indicated by the signal?

Communication to other drivers
No meaning
Illumination
Driverless vehicle

Warning/caution
Giving right of way
Priority/precedence/privilege
Police

Emergency/rescue vehicle in general
Communication in general

Communication to pedestrians

Mapping

Indicating risks and hazards

Sensor as driver assistance systems

Attention

Detection and tracing of obstacles

Ambulance

No idea

Qualitative data analyzed over all conditions; $N = 138$
Study 2: Evaluation of light signals
Method | study design

• **Aim:** Evaluation of light signals to communicate between VRU and automated vehicle
• **Setting:** field study (Elsasser Straße, Chemnitz)
• **Independent variables:**
  - **3 light signals:** AUTOMATED, STARTING, CROSSING
  - **3 colors:** WHITE, TURQUOISE, PURPLE
• **Dependent variables:** visibility and trust, acceptance, comprehensibility of signals, appropriateness of signal colors
• **Applied methods:** questionnaires, interviews, evaluation of visibility
• **Sample:** $N = 38$ (18 men, 20 women; mean age: 50 years ($SD = 23.49$))
Method | procedure

1. Welcome and socio-demographics

2. Visibility of colors (distance measurement; 470m condition)

3. Visibility of colors (100m, 50m, 20m and 5m distance)

4. Assumed meaning of light signals (uninformed)

5. Evaluation of light signals; appropriateness of colors (informed)

6. Closure and goodbye

- Laboratory (uninformed)
- Test site (uninformed)
- Test site (informed)
RESULTS I
Visibility of signals depending on color
Participants detected the signal from significant different distances depending on signal color.

Purple > Turquoise > White

(* significant pairwise comparisons)

For all distances analysis of subjective evaluations results in the same ranking:

Purple > Turquoise > White

(Single Item;)

Luminous flux for all conditions: 2 lumen
RESULTS II
Evaluation of signals & color
What do you think about the meaning of the signal? (uninformed)

**Signal has no meaning**
- Warning/caution
- Problems/hazards
- Vehicle is driving particularly slow
- No idea

**Better visibility/part of daytime running light**
- Attention
- Stop/ give right of way
- Open way
- No idea

**Warning/caution**
- No idea
- Advertisement
- Vehicle is driving particularly slow
- Emergency vehicle

**Stop/ give right of way**
- Attention
- Lane guidance
- Signal has no meaning

**Problems/hazards**
- No idea
- Vehicle is driving particularly slow
- Emergency vehicle

**Open way**
- Vehicle is driving particularly slow
- No idea

**Road closed**
- Better visibility/part of daytime running light
- No idea

**Joke**
- Vehicle is driving particularly slow

**Better visibility/ part of daytime running light**
- Attention
- Stop/ give right of way
- Open way
- Problems/hazards

**Warning/caution**
- Tuning
- Vehicle is driving particularly slow
- Communication with pedestrians/ other drivers

**Starting mode**
- Open way/ pedestrians can cross

heuristic analysis of interviews, frequent answers bold
STARTING

What do you think about the meaning of the signal? (uninformed)

heuristic analysis of interviews, frequent answers bold
CROSSING
What do you think about the meaning of the signal? (uninformed)

- Corridor for emergency vehicle access
- Emergency vehicle
- Warning/ caution
- Problems/ hazards
- Attention
- Tuning/ fun
- Stop/ give right of way
- Drive slowly
- Road closed
- Don’t overtake
- Hazard warning lights
- No meaning

heuristic analysis of interviews, frequent answers bold

WP 2 external HMI
Matthias Beggiato, Isabel Neumann, Ann-Christin Hensch
The appropriateness of signal color is evaluated differently for the different signal types.

(Single Item, * significant pairwise comparisons)
RESULTS III
Evaluation of signals regardless of color
Signals regardless of color

Trust and comprehensibility (informed)

On average participants agree to trust all of the presented signals of automated driving.

(Trust Scale; Jian, Bisanz & Drury, 2000)

On average participants agree that all signals are comprehensible.

(Single Item)
Signals regardless of color

Acceptance of the signal (informed)

Ratings of participants indicate a rather high acceptance of all presented signals.

(Acceptance Scale, van der Laan, Heino & De Waard, 1997)
Signals regardless of color
Usefulness (informed)

"The presented signal is useful."

<table>
<thead>
<tr>
<th></th>
<th>Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated</td>
<td></td>
</tr>
<tr>
<td>Starting</td>
<td></td>
</tr>
<tr>
<td>Crossing</td>
<td></td>
</tr>
</tbody>
</table>

Error bars represent 95% CI

N = 38

"The signal is generally useful."

<table>
<thead>
<tr>
<th></th>
<th>Agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated</td>
<td></td>
</tr>
<tr>
<td>Starting</td>
<td></td>
</tr>
<tr>
<td>Crossing</td>
<td></td>
</tr>
</tbody>
</table>

Error bars represent 95% CI

N = 37

On average participants agree.
Participants assess the presented signals to be useful.

(Single Item)

Results reveal an averaged agreement for all 3 signals.
Participants assess the presentation of signals for automated driving generally as useful.

(Single Item)
Implications

• Differences between passing-by pedestrians and invited participants regarding assessed usability, trust and comprehensibility → potential reasons: amount of explanation, directedness

• The presented light signals are not comprehensible by intuition.

• In general, light signals as a form of communication in automated driving is evaluated as useful. → possible form of external HMI in automated driving from user perspective

• Visibility: Clear ranking: purple > turquoise > white → But: What is an optimal visibility in this context?
KIVI - Cooperative interaction with vulnerable road users in automated driving


Chemnitz University of Technology
Cognitive and Engineering Psychology
matthias.beggiato@psychologie.tu-chemnitz.de
Observation of interaction behavior, video labeling and analysis of interaction sequences
(Witzlack, Beggiato & Krems, 2016)

Video simulation studies to identify parameters, e.g. expected moment of braking, perception of deceleration, influencing factors...
(Beggiato, Witzlack, Springer & Krems, 2017a; 2017b)

Focus group discussions and video simulation studies on explicit external communication, e.g. projections, displays...
(Ackermann, Beggiato, Schubert & Krems, submitted)

On-road test with partner from communication engineering and automated BMW i3
(summer 2018)
**Study design**

- **7x2x2 mixed design:**
  - **IV1** within-subject: vehicle speed from 10 to 40 km/h in 7 steps of 5 km/h. Exactly manipulated by accelerating/decelerating video playback speed
  - **IV2** within-subject: daytime, midday (11:13 AM) and dusk (19:25 PM at 2nd of April)
  - **IV3** between-subject: age, two age groups from 20-30 and 50+ years
  - Each of the 14 within-conditions presented in randomized order, 3 repetitions to stabilize results (mean calculated) → 42 trials per participant
  - **DV:** last accepted time gap in seconds of the oncoming vehicle, i.e. last moment of crossing comfortably before the vehicle
  - **Instruction:** press a defined key at the last moment, when you would cross the street comfortably (without running) before the vehicle.
Results – speed x age

<table>
<thead>
<tr>
<th>main effects and interaction</th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F$</td>
</tr>
<tr>
<td>speed</td>
<td>$F(1.59, 61.84) = 67.22$</td>
</tr>
<tr>
<td>age</td>
<td>$F(1, 39) = 4.46$</td>
</tr>
<tr>
<td>speed $\times$ age</td>
<td>$F(1.62, 63.32) = 7.95$</td>
</tr>
<tr>
<td>daytime $\times$ age</td>
<td>$F(1, 39) = 0.30$</td>
</tr>
</tbody>
</table>

![Graph showing the relationship between vehicle speed (km/h) and accepted time gap (s) for older (> 50 years) and younger (< 30 years) drivers. Error bars represent ±1 SE.](image-url)
## Results - speed × daytime

<table>
<thead>
<tr>
<th></th>
<th>ANOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$F$</td>
</tr>
<tr>
<td>main effects and interaction</td>
<td></td>
</tr>
<tr>
<td>speed</td>
<td>$F(1.59, 61.84) = 67.22$</td>
</tr>
<tr>
<td>daytime</td>
<td>$F(1, 39) = 29.28$</td>
</tr>
<tr>
<td>speed × daytime</td>
<td>$F(4.86, 189.55) = 1.63$</td>
</tr>
</tbody>
</table>

### Graph

![Graph showing the relationship between vehicle speed (km/h) and accepted time gap (s) for dusk and day. Error bars indicate ±1 SE.](image)

- Red triangles: dusk
- Blue squares: day

**Error bars: ±1 SE**
Potential

Dedicated video simulation environment (progr. in LabView)
- Exact play rate control of the videos, speed profiles, blanking, pedestrian overlay, logging of participant’s reactions, experimental control of instructions, randomized trials, messages etc.
- Easy configuration by separate Excel files: videos, instructions, speed, randomization trials, speed profiles... → also used in teaching for bachelor students

Variations of video simulation studies
- Type/size of cars
- TTA estimation by blanking the video (perception / estimation)
- Augmented pedestrian controlled by study participants
- Perception of braking / accelerating → speed profile
- Formal communication / HMI solutions, evaluated by participants


Thank you for your attention!

Contact:
Matthias Beggiato
+49 371 531 38654
matthias.beggiato@psychologie.tu-chemnitz.de

Isabel Neumann
+49 371 531 37767
isabel.neumann@psychologie.tu-chemnitz.de

Ann-Christin Hensch
+49 371 531 35419
ann-christin.hensch@psychologie.tu-chemnitz.de