

Human Interaction in Industrial Tele-Operated Driving: Laboratory Investigation

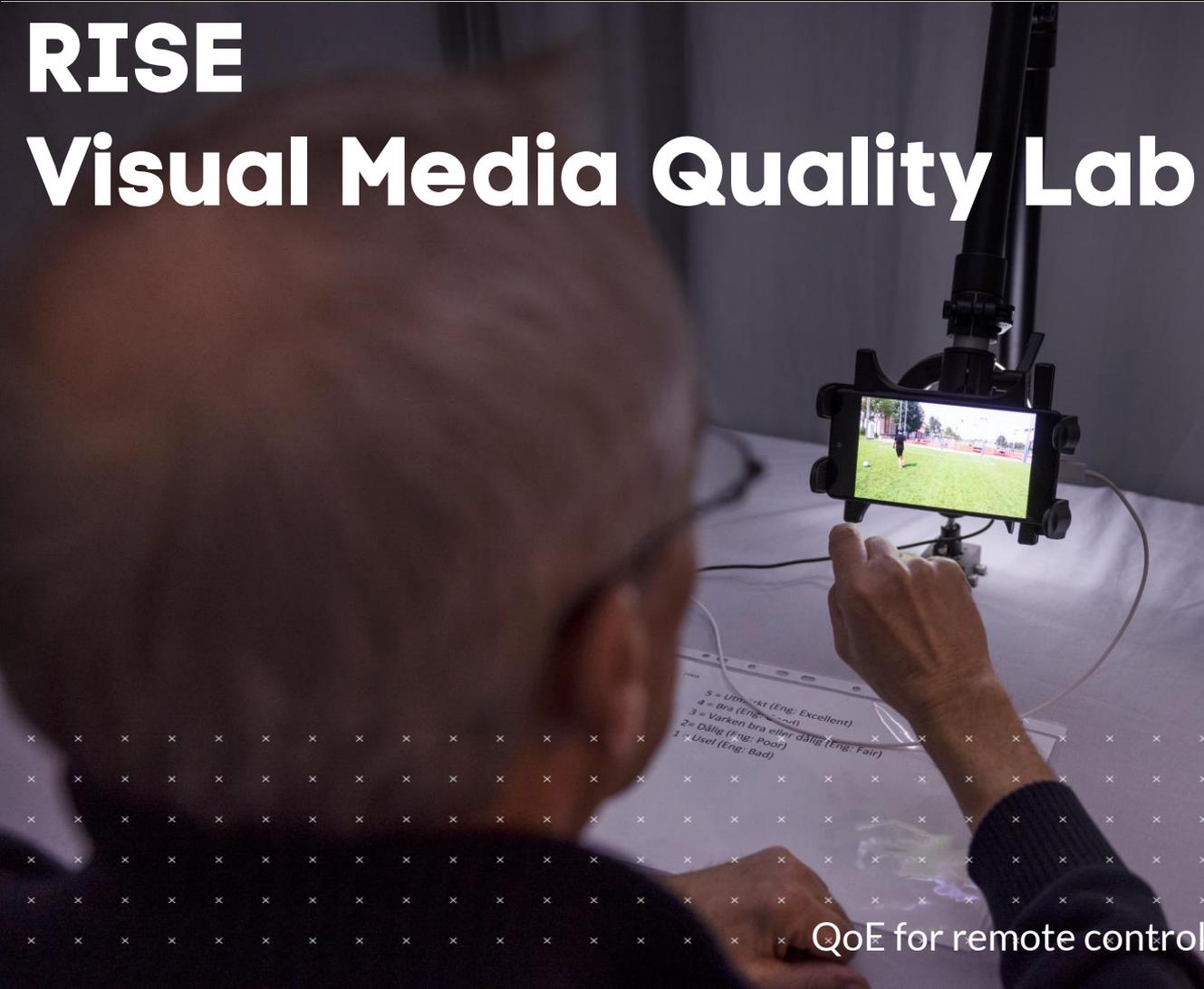
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RISE Visual Media Quality Lab



5 = Utmärkt (Eng: Excellent)
4 = Bra (Eng: Good)
3 = Varken bra eller dålig (Eng: Fair)
2 = Dålig (Eng: Poor)
1 = Usvet (Eng: Bad)



QoE for remote control (tele-operation) of machines

Background of remote-control industrial applications

Collaboration with Volvo CE to test 5G enabled on remote-controlled wheel loaders



<https://www.pitandquarry.com/volvo-ce-to-test-5g-enabled-remote-controlled-wheel-loaders/>

Collaboration with HIAB to test latency impacts on remote-controlled log lift forestry cranes



Enabled Teleoperated driving in industries



How well users experience the quality of visual information delivery in ToP?

On-going work:

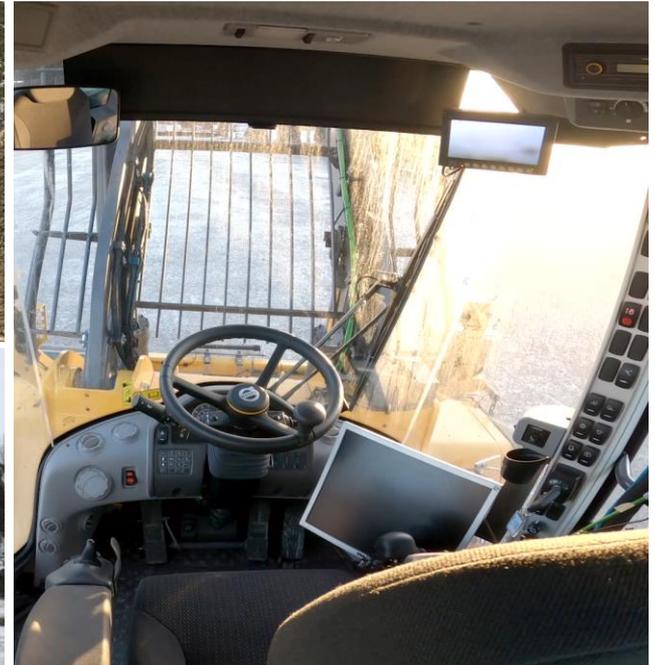
Collaboration with Volvo CE: Remote control of heavy machines

Investigating video manipulating impacts on drivers' performance

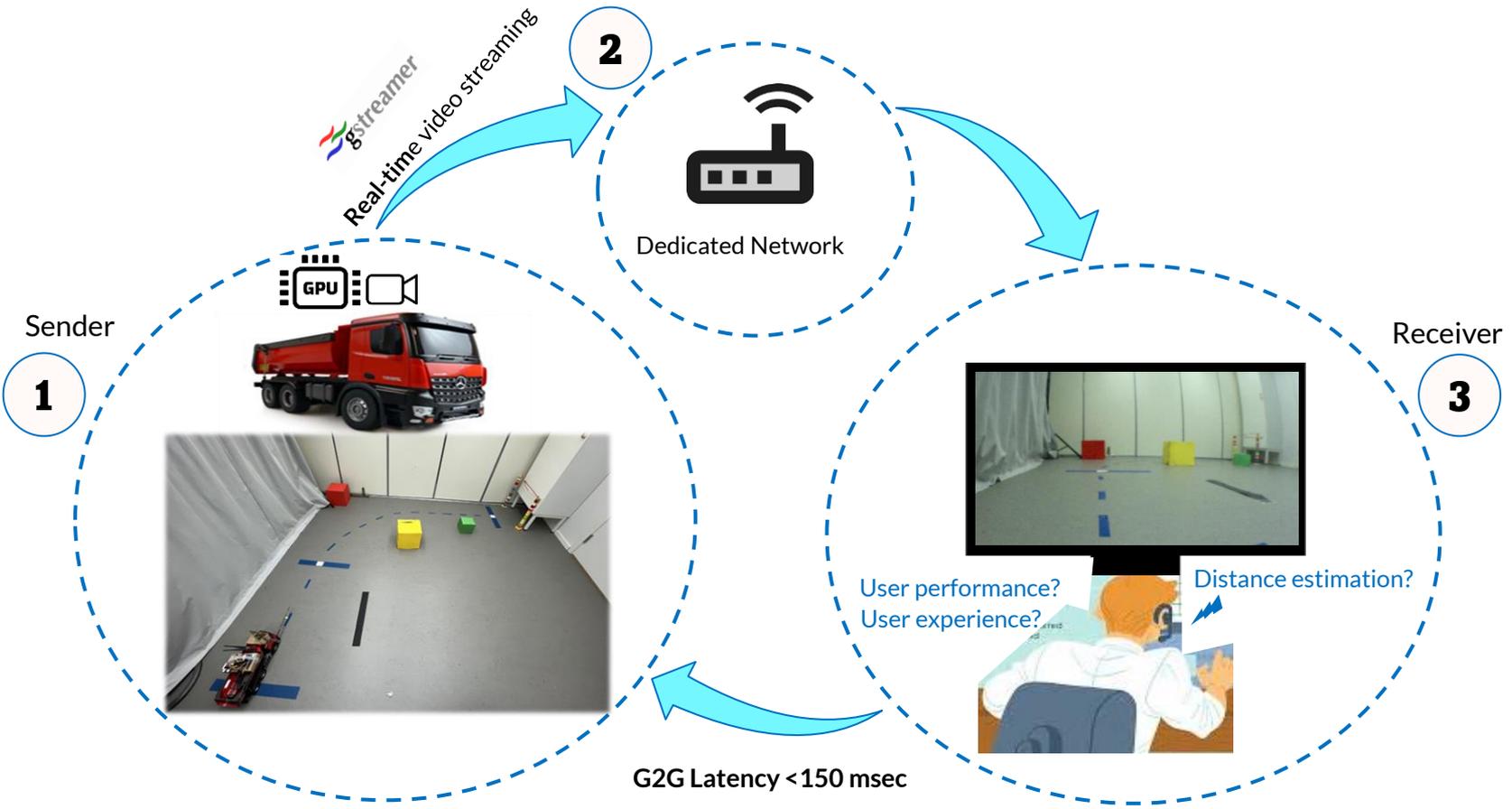
Plan developed for a field test

Study to be performed in early 2023
Postponed to after summer

Study latency impacts



Lab-based tele-operated platform (LTP)



Test set up

VQ: Video Quality levels (Frame rate 30 fps)	L: Video Latency	FoV: Field of view (Degrees)
Q1: $720 r_w \times 640 r_h$	L1: 150 ms	F1: 120
Q2: $640 r_w \times 480 r_h$	L2: 400 ms	F2: 105
Q3: $480 r_w \times 320 r_h$	L3: 650 ms	-

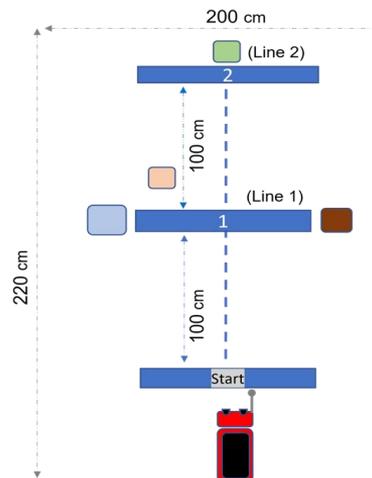
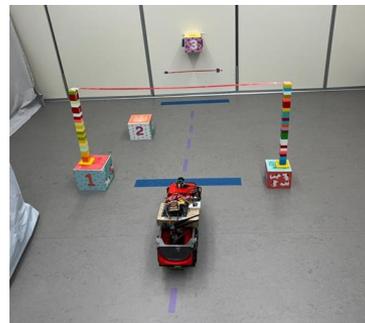
RQ1) Impact of VQ and FoV on depth perception
 RQ2) Impact of VQ, FoV and L on Overall User experience
 RQ3) Impact of VQ, FoV and L on Use's performance

Participants: fourteen naive participants took part, four in the pilot, and ten in the main test (four female, ten male, mean age 29 +/- 5).

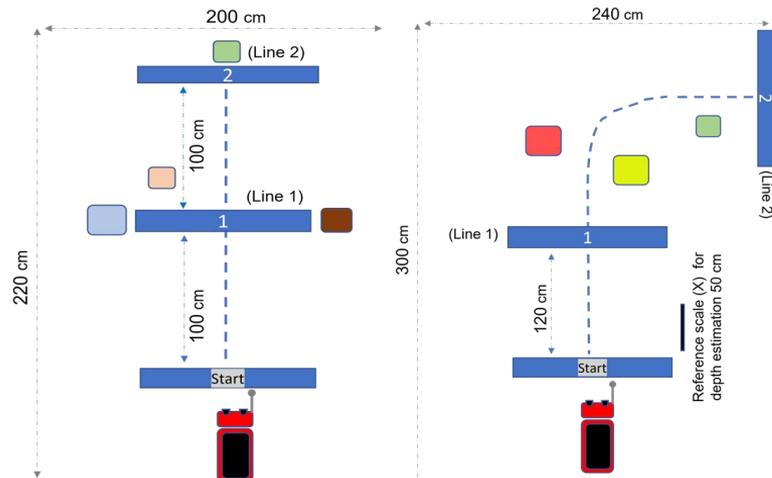
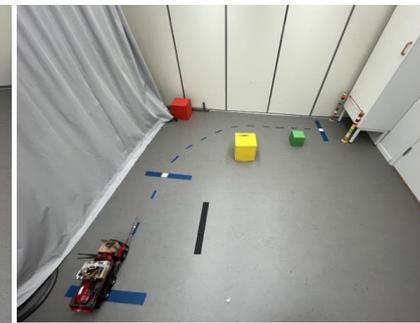
Experiment condition:

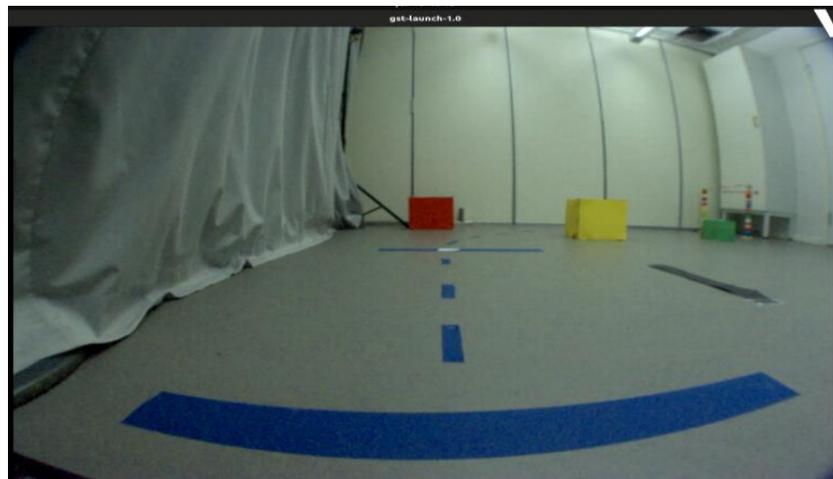
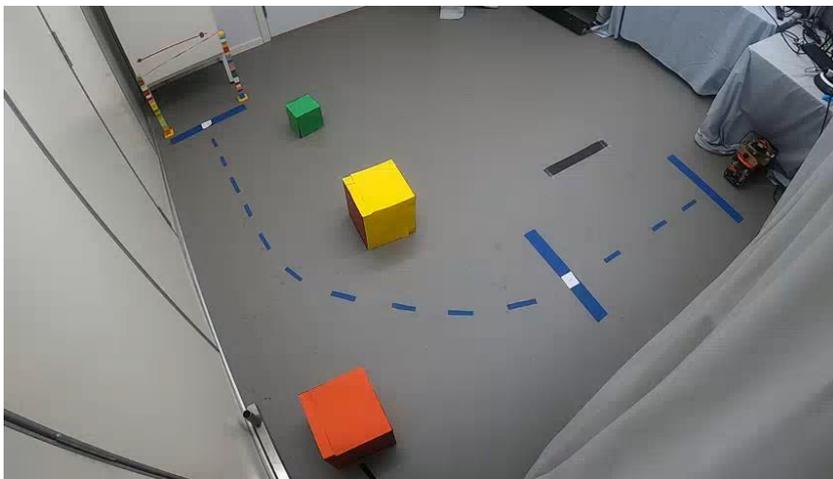
- 1) Location: Perception lab, RISE office, Kista.
- 2) Number of Trials (T): Eighteen randomized T.
- 3) Total time: 1 to 1.5 hours including breaks.

Pilot test



Main test





Questionnaires:

- 1) Background + Simulator Sickness Questionnaire (SSQ).
- 2) Recurring questionnaire consisting three sections.
- 3) Interview questionnaire + SSQ.

TEST CONFIGURATIONS WERE RANDOMLY APPLIED TO 18 TRIALS, THE COMBINATION OF LATENCY, FIELD OF VIEW, AND VIDEO QUALITY).

Trials	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18
Quality levels	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3	Q1	Q2	Q3
Latency levels	L1	L1	L1	L2	L2	L2	L3	L3	L3	L1	L1	L1	L2	L2	L2	L3	L3	L3
FoV levels	F1	F2																

Results

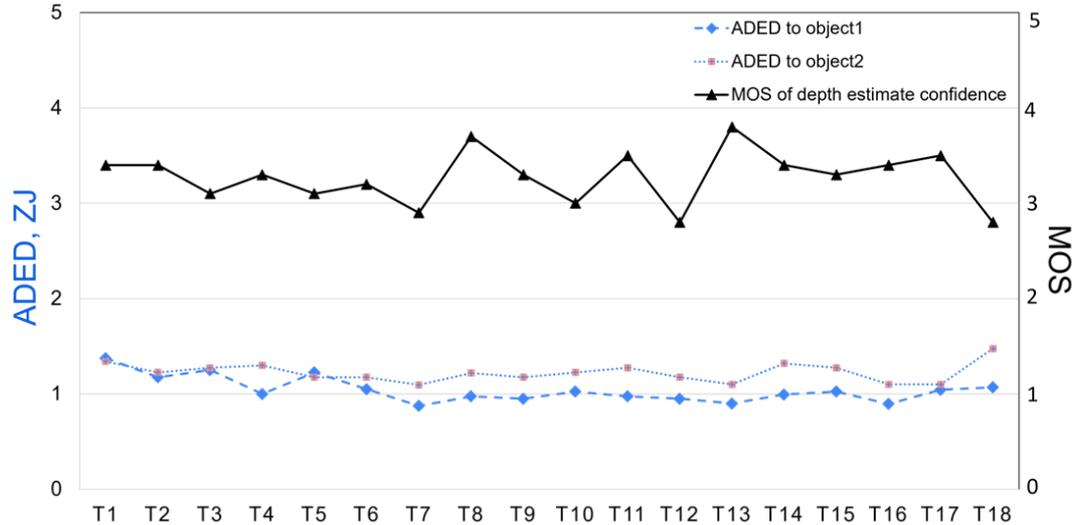
Depth perception:

Depth perception-a: Average Depth Estimate Difference (ADED)

Depth perception-b: Users confidence rating (5-point Likert scale) to the estimated depth.

$$Z_{j,K} = \frac{\sum_{i=1}^N a_{i,j,k}}{N}$$

ADED metric ← $Z_{j,K}$ = $\frac{\sum_{i=1}^N a_{i,j,k}}{N}$ → Differences between the estimated depth and actual distance for participant i and trial j
 ← N → Number of participants

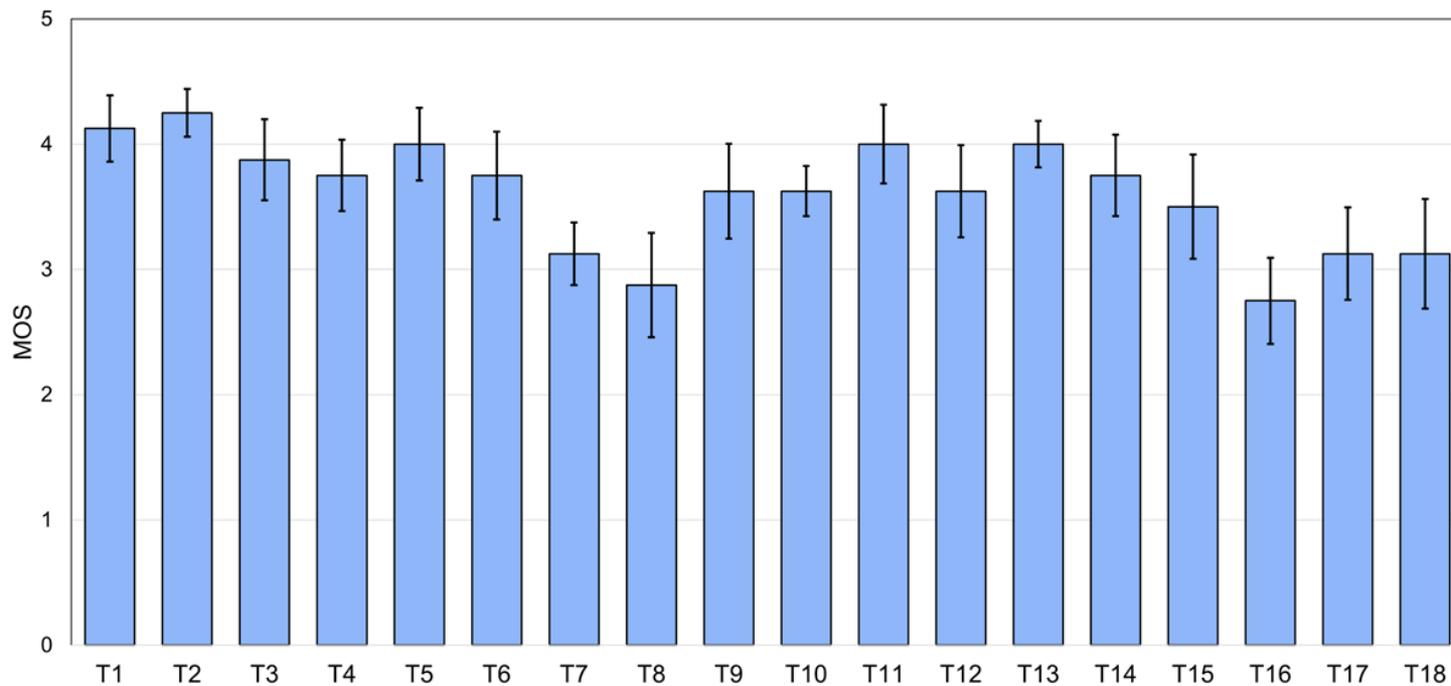


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Latency levels	L1	L1	L1	L2	L2	L2	L3	L3	L3	L1	L1	L1	L2	L2	L2	L3	L3	L3
FoV levels	F1	F2																

User experience:

Including user's comfort and **overall UX** (5-point Likert scale).

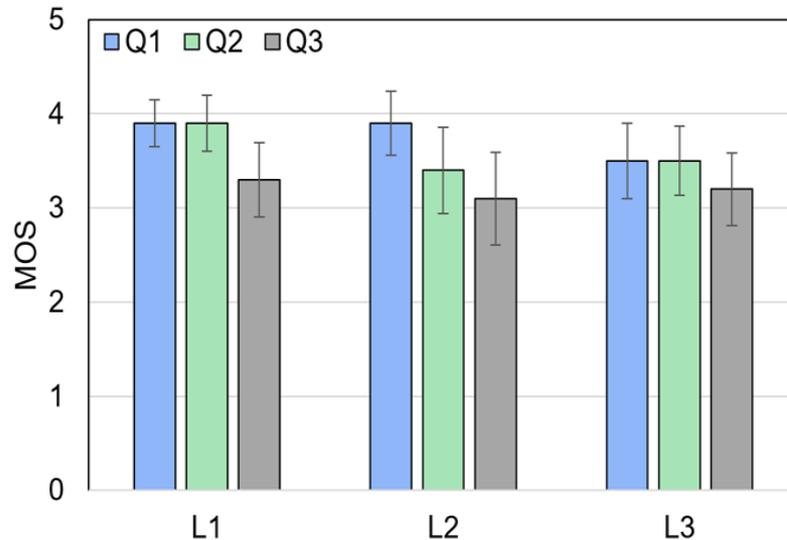
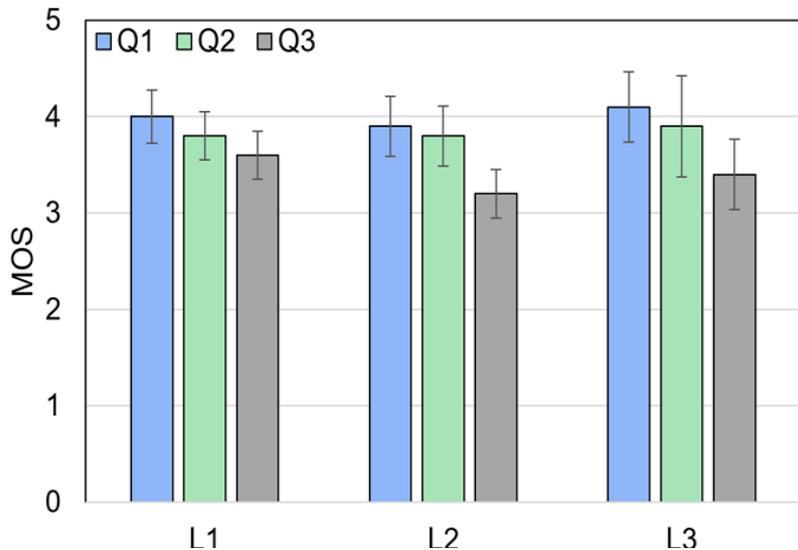


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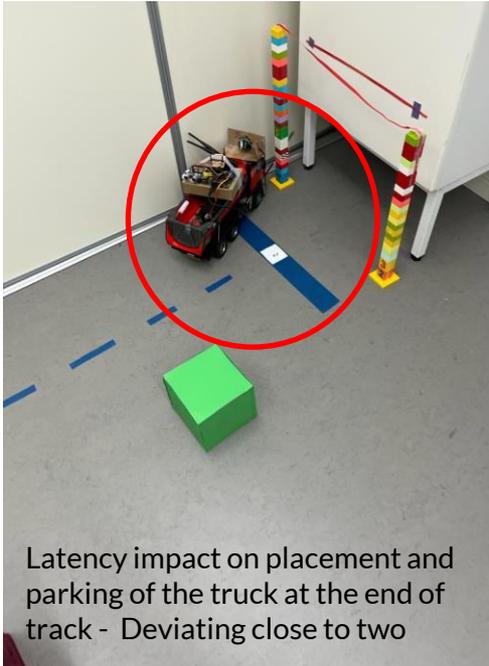
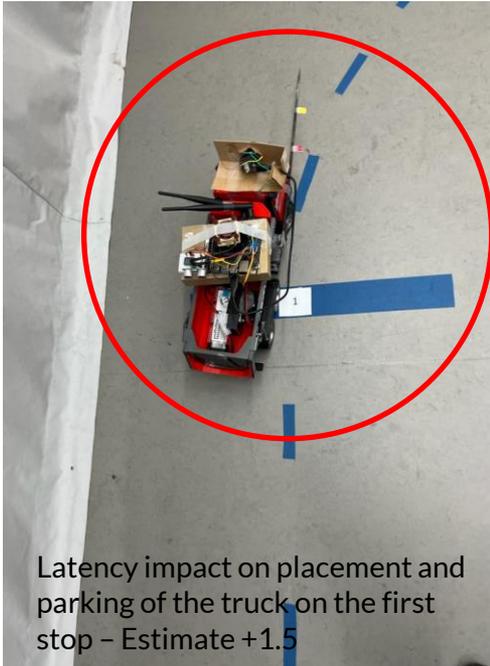
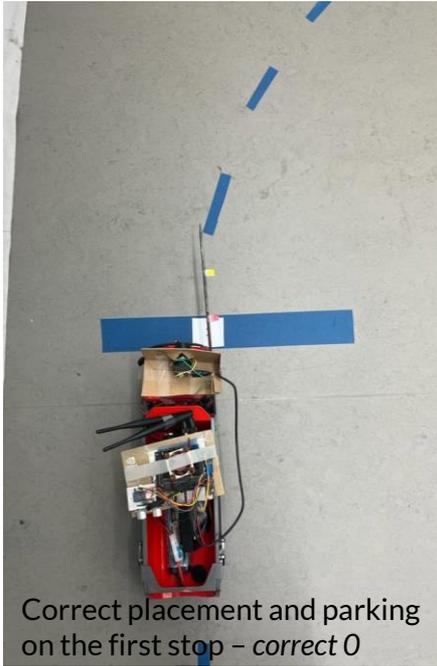
Including user's comfort and overall UX (5-point Likert scale).



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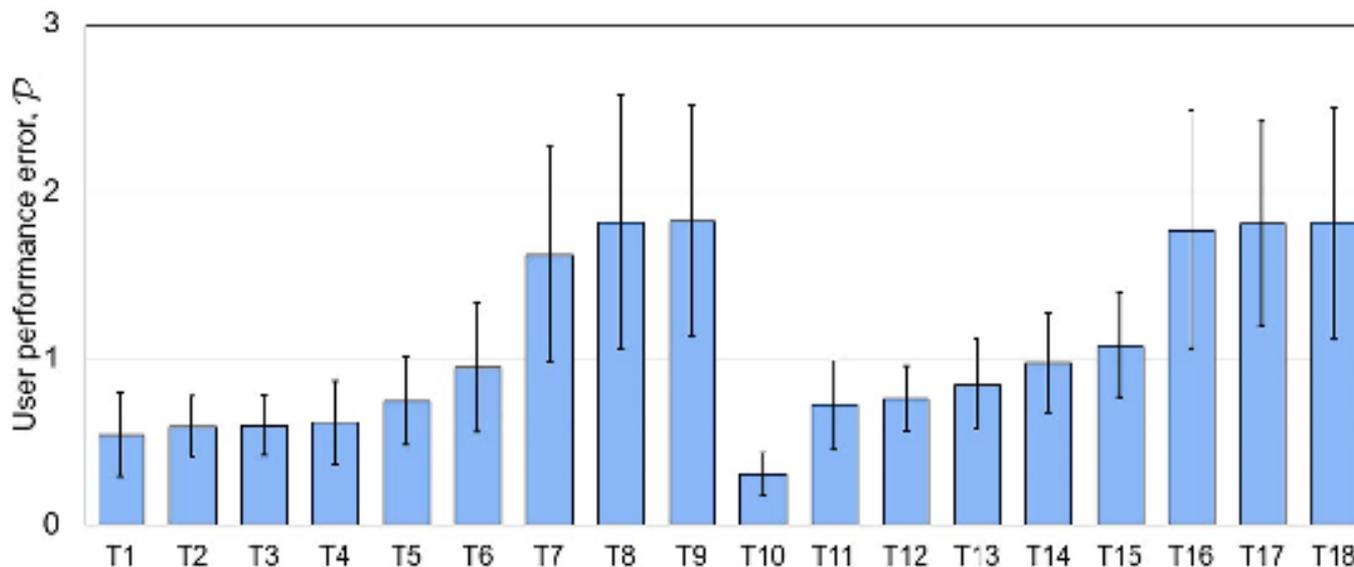
User performance error:



Average user performance error $\leftarrow \mathbb{P}_j = \frac{\sum_{i=1}^N d_{i,j}}{N} \rightarrow$ The deviation of the stopping point from the defined point before the Line 2

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Latency levels	L1	L1	L1	L2	L2	L2	L3	L3	L3	L1	L1	L1	L2	L2	L2	L3	L3	L3
FoV levels	F1	F2																

Conclusion:

- The study meets **ecological validity** in the following ways:
 - The real-time video feed and remote interaction are similar to the real-world ToP systems.
 - The test setup, truck speed, and camera position are similar to the real-world ToP setup.
- Results shown:
 - A degradation in user performance, experience, and comfort with increased G2G latency.
 - The users' comfort improved with the increased video quality (i.e., spatial resolution).
 - Users' depth estimation and performance differed slightly for different fields of view.

Future study:

- This study will extend to determine the entire QoE and UX to be adjusted as a user-centered design.

Thank you!

Looking forward to your comments and feedback!

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