Analysis of Bicyclist Communication in a Simulator Environment

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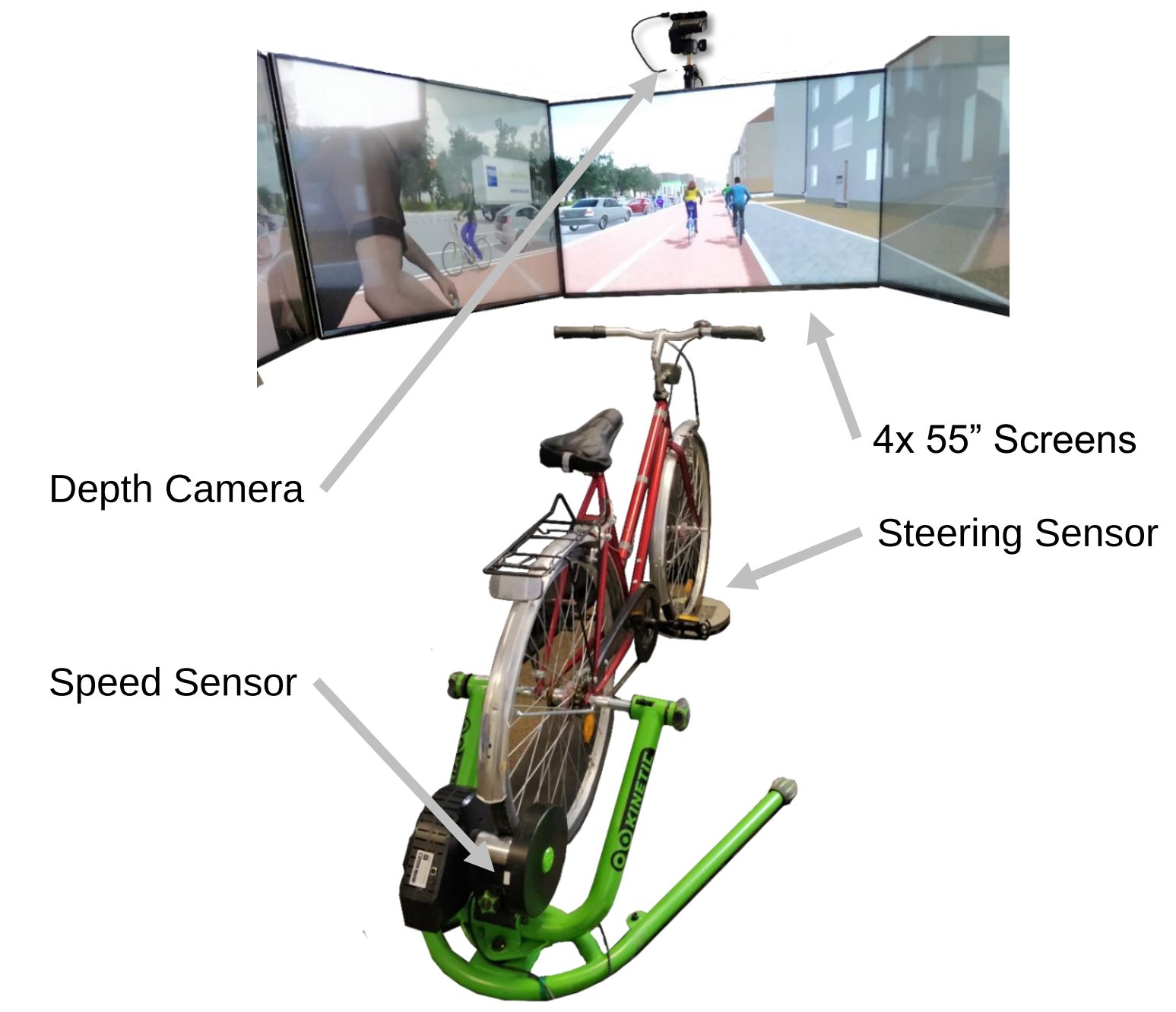
Analysis of Bicyclist Communication in a Simulator Environment

Patrick Malcolm[1], Georgios Grigoropoulos[1], Andreas Keler[1], Heather Kaths[1], Klaus Bogenberger[1]

1) Technical University of Munich, Chair of Traffic Engineering and Control

Abstract

Urban roads are a dynamic environment in which formal and informal communication are crucial. In order for autonomous vehicles to operate effectively in such an environment, they must be able to deal with this complexity. In particular, an understanding of the communication patterns of bicyclists is crucial because of their vulnerability and lack of standardized indicators, which allows greater variability and subtlety in the way they communicate. In this study, participants rode a bicycle simulator through various urban traffic scenarios in which explicit and implicit communication behaviors are expected. Participants were recorded with a depth camera, and a markerless motion capture technique was used to record their movements in three dimensions. From this data, hand signal, head movement, and leaning events were extracted, analyzed, and compared. Analyses showed that even in clearly regulated scenarios, not all participants performed a hand signal, with between 80 and 95 percent of participants signaling before turning at a four-way intersection and approximately 60 percent before changing lanes. Participants were also significantly more likely to glance over their left shoulder preceding a left lane-change or left turn compared to other scenarios. The arm shape while performing a hand signal was found to be almost entirely governed by individual preference, rather than scenario. Based on these results, it is clear that cyclist communication behavior frequently does not adhere strictly to traffic regulations and varies from person to person. However, implicit cues such as head movements can be used to supplement behavior prediction models in certain situations.



Bicycle Simulator Hardware

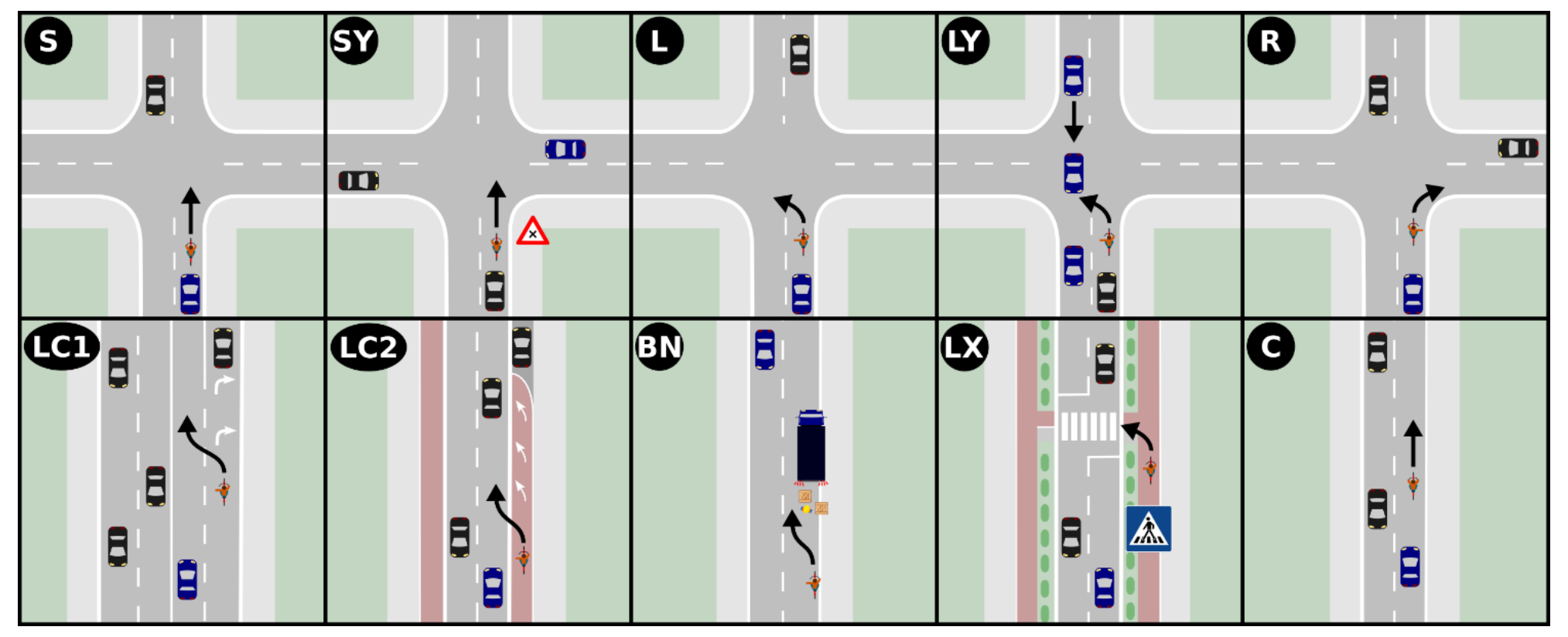
Methodology

The bicycle simulator of the Chair of Traffic Engineering and Control at the Technical University of Munich was used in this study. It consists of a bicycle mounted on a stationary bicycle trainer stand surrounded by four 55-inch monitors: one directly in front of the bicycle, one to either side angled at 74 degrees, and one on the left side behind the bicycle angled at 148 degrees. Sensors mounted on the bicycle provide speed and steering information, which are fed into a vehicle dynamics model in order to allow for one to navigate through the virtual simulator environment. The primary software used for vehicle simulation and graphics display was DYNA4, while the simulation of traffic was performed by SUMO, with a simulation step size of 0.1 seconds. The behavior of vehicles for each scenario was controlled via SUMO's TraCI API.

Nine scenarios plus one control scenario were constructed within a single network, through which each participant rode, guided by automatically displayed directional messages. The intersection used for the scenarios was a 4-way right-angle intersection of two two-lane roads with right-before-left right-of-way. The lane widths were 3.3 meters for all vehicular lanes and 2 meters for all bike lanes. Sidewalks were present on both sides of the roadway in all scenarios, and the surrounding 3D environment was modeled after a typical medium density urban/suburban European neighborhood.

In total, 31 participants took part in the study. During each trial, participants were recorded by an Intel RealSense D435 depth camera mounted just above the front monitor. Body and arm movements were then extracted from the recordings by applying a pre-trained convolutional neural network to the color image in order to obtain a skeletal representation of the participant in 2D pixel-space, and then using the depth information to project these coordinates into a 3D world-space coordinate system. In order to more precisely track participants' head movements, a bicycle helmet fitted with a fiducial marker was employed.

Sample Screenshots of Scenarios



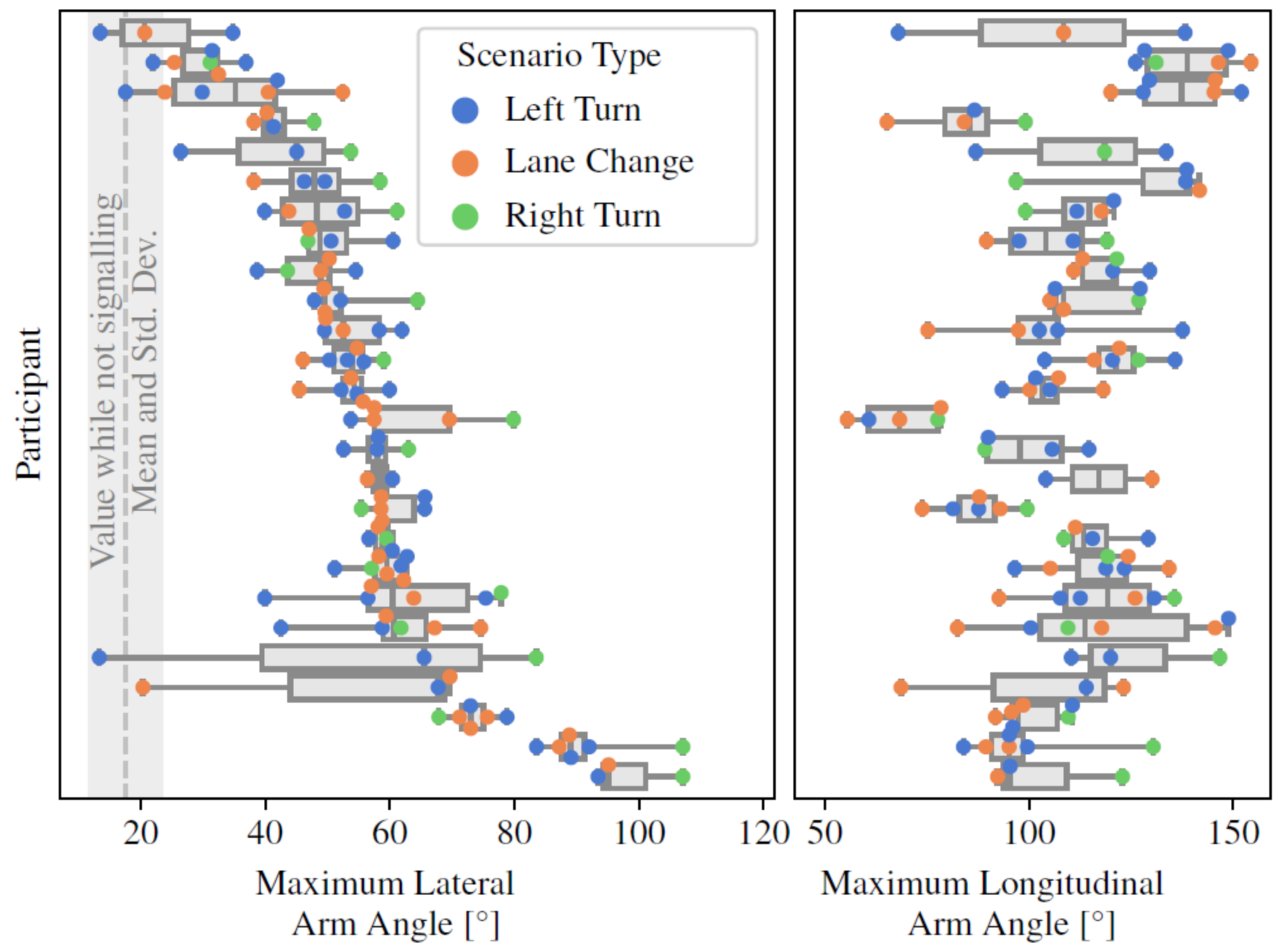
Scenario Depictions

Color (left) and Depth (right) images with detected pose

Poses were clustered based on angle-based geometrical descriptors using the k-means algorithm with k=3. Cluster assignments were then grouped temporally, resulting in a list of discrete arm signals performed in each scenario with starting time and duration information. Discrete head movement events were extracted by applying a hysteresis thresholding technique to the head yaw angle. In total, five types of gestures were extracted and analyzed: left arm signal, right arm signal, left glance, right glance, and left over-shoulder glance. The timing of each gesture event was normalized to the time at which the participant either arrived at the intersection stop line (for intersection scenarios) or crossed the lane marking (for lane change scenarios).

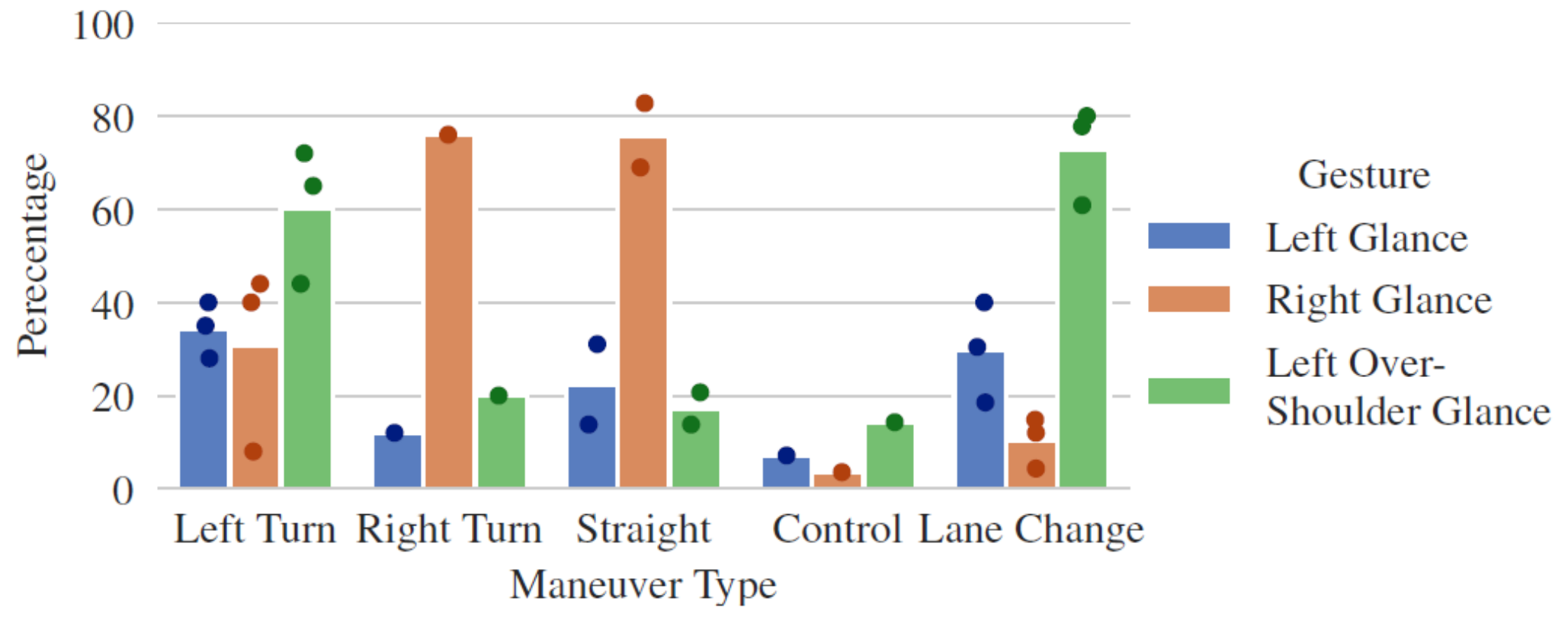
Results

The shape of the arm signals given, represented as a maximum observed longitudinal arm angle (with 0° representing straight forward and 90° representing straight to the side) and lateral arm angle (with 0° representing straight down and 90° representing horizontal), was analyzed across all scenarios, and no statistically significant difference was found. However, there was a significant amount of variance present between different participants.



Arm Signal Angle Distributions

From this data, it is clear that most participants were relatively consistent in the position of their arm across all scenarios, particularly with respect to the lateral arm angle, but also to a lesser extent the longitudinal arm angle. We also observed that in a number of cases, the lateral angle of an arm signal did not differ significantly from the lateral angle observed when no signal was being given, with six observations falling within one standard deviation of the mean. In other words, the signals were performed by only moving the arm backwards, and not raising it significantly.



Head Gesture Occurrence by Maneuver Type

Clear patterns were also observed in head gesture use. Most notably, left over-shoulder glances were significantly more common in all left turn and lane-change scenarios. Similarly, right glance gestures were significantly more common in right-turn and continue-straight scenarios.

Regarding the timing of head gestures, we observed that for the static bottleneck scenario, arm signals were given on average 5.6 seconds earlier and left over-shoulder glances performed on average 5.4 seconds earlier than in the other lane change scenarios. This is likely due to the difference in flexibility in the timing of the respective maneuvers, where the cyclist is forced to make tactical decisions earlier in a static bottleneck scenario.

Conclusions

We observed a number of patterns in the explicit and implicit communication behavior of our study participants. Among the most notable are:

- The lateral and longitudinal arm angles when giving a hand signal did not vary based on scenario, but were rather dependent on the individual
- In some cases, lateral arm angle during a signal did not vary significantly from that when no signal was being given, meaning 3D gesture information is important for detecting gestures with high accuracy.
- Left over-shoulder glances were highly correlated with left turns and lane changes. Right glances were correlated with straight and right turn maneuvers.
- Both left over-shoulder glances and hand signals occurred sooner in the static bottleneck scenario than in the lane change scenarios.

These and our other findings have implications for the development of the behavioral prediction models of autonomous vehicles. While simulator studies are limited in the extent to which their results are applicable to real-world scenarios, these observations point to areas of potential future in-situ research into cyclist communication and behavioral patterns, which will in turn allow for safer and more reliable interactions between road users on the streets of the future.

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Contact Information

Patrick Malcolm
Chair of Traffic Engineering and Control
Technical University of Munich
patrick.malcolm@tum.de

Technical University of Munich
Department of Civil, Geo and Environmental Engineering
Chair of Traffic Engineering and Control

Patrick Malcolm
✉ patrick.malcolm@tum.de