Coming In! : Communicating Lane Change Intent in Autonomous Vehicles

Seong Hee Lee
Cornell University
Ithaca, NY, USA
sl994@cornell.edu

Nicholas Britten
Virginia Tech
Blacksburg, VA, USA
brittenn@vt.edu

Avram Block
Motional
Boston, MA, USA
aviblock@msn.com

Aryaman Pandya
Motional
Boston, MA, USA
aryaman.pandya@motional.com

Malte Jung
Motional
Boston, MA, USA
malte.jung@motional.com

Paul Schmitt
MassRobotics
Boston, MA, USA
pauls@massrobotics.org

ABSTRACT

Lane changes of autonomous vehicles (AV) should not only succeed in making the maneuver but also provide a positive interaction experience for other drivers. As lane changes involve complex interactions, identification of a set of behaviors for autonomous vehicle lane change communication can be difficult to define. This study investigates different movements communicating AV lane change intent in order to identify which effectively communicates and positively affects other drivers' decisions. We utilized a virtual reality environment wherein 14 participants were each placed in the driver's seat of a car and experienced four different AV lane change signals. Our findings suggest that expressive lane change behaviors such as lateral movement have high levels of legibility at the cost of high perceived aggressiveness. We propose further investigation into how balancing key parameters of lateral movement can balance in legibility and aggressiveness that provide the best AV interaction experience for human drivers.

CCS CONCEPTS

• **Computing methodologies → Robotic planning**; • **Applied computing → Transportation**; • **Human-centered computing → Interaction techniques**.

KEYWORDS

Autonomous Vehicles, Human Robot Interaction, AV Lane Change, Expressive and Legible Robotics

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1 INTRODUCTION

In this study, we explore the influence of Autonomous Vehicle (AV) movements in negotiating lane changes in densely populated urban environments. This research focuses on a high-traffic-density setting to simulate events in which an AV would need to alter its behavior specific to an urban landscape. AV motion planning behaviors to execute lane changes have largely been designed to allow the AV to change lanes when there is an acceptable gap between the rear and lead vehicles in the target lane. This approach performs well under certain sets of conditions in which the AV has the time to anticipate such a gap. In higher-pressure driving conditions, for example, when the AV needs to execute a lane change before the end of the block to be able to make a turn, this behavior can result in increased ride time. We tested the efficacy of expressive AV behaviors in the task of persuading the rear vehicle to allow a lane change in the absence of a gap. We conducted a within-subjects study in which participants were placed in the driver's seat of a vehicle on a traffic-dense urban street in VR [3]. Each participant encountered 5 different scenarios (including a control scenario) in which an adjacent AV requested a lane change by exhibiting unique behaviors. The primary objective of this study was to optimize lane changes to be legible and intuitive (natural) for other human drivers.

2 BACKGROUND

For AV lane change features to improve performance - specifically to execute lane changes quicker and reduce the number of lane changes rejected it is important to identify a set of behaviors for autonomous vehicle lane change communication. In order to make AV lane change intent more human-like it is important to first establish how human drivers communicate and execute lane changes during real-world driving [1][10]. An observation of real-world lane changes in Germany found that the most commonly used communication cues to indicate a lane change are movement toward the target lane and activation of the turn signal [4]. Other observed communication cues included: movement away from the target lane, steering angle/inclination angle, and acceleration. Interestingly, the drivers in this dataset had a much higher frequency of turn signal use (79%) compared to reported turn signal use among U.S. drivers, who only signal 44% of the time [7]. Drivers used three main sequences to communicate their intent to change lanes, with most sequences beginning with either turn signal activation or

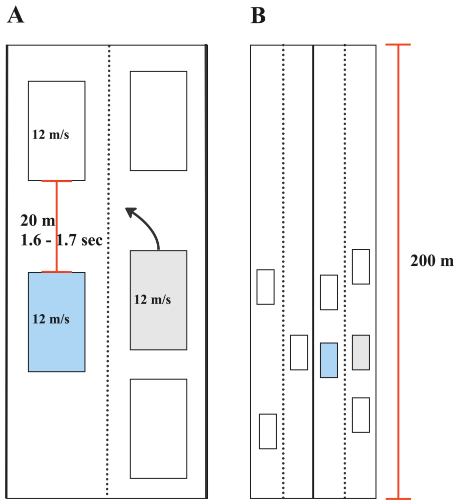

Figure 1: Diagram of the VR environment. Blue square: participant's car,gray square : lane changing vehicle, white squares, other cars in the road environment.

lateral movement. Outside of observational studies, many human-participant based studies have established the effectiveness of altering AV movement profiles to communicate intent [11] of lane changes several experimental studies have examined methods for communicating AV lane intention to other road users and passengers. Specifically, active roll [2], lateral offset in the travel lane [9][6], turn signal timing [9][8], timing of communication cues [5], longitudinal acceleration [9][8], and lane change duration[6][5] have been evaluated as lane change communication signals. However, there is a lack of research that observes a comparison of these different lane change movements to identify which is most effective in a high-density traffic scenario. Additionally, no research has looked into how these different lane change communication affect the the human driver's interaction experience.

3 STUDY METHODOLOGY

Our study aims to identify lane change signals on autonomous vehicles that are legible to drivers while providing a satisfactory interaction experience. We prototyped four different types of lane change signals - (1) Active Roll, (2) Turn Signal, (3) Lateral Movement, and (4) Gap Matching on a vehicle and observed the interaction experiences of drivers experiencing a lane change request. This study was conducted to investigate ways in which autonomous vehicle lane change features could be used to improve its performance - specifically to execute lane changes quicker and reduce the number of lane changes rejected because they could not be safely conducted during the lane change window. To study realistic scenarios, we focused on a high density traffic scenario.

3.1 Setup

We contracted a professional animation studio, TUMBA and created a lane change VR environment of a stressful traffic situation with heavy traffic sounds and additional cars in surrounding roads. In the virtual reality environment, the participant is seated in the driver's seat driving down a two lane road (Figure 1). The participant experienced driving along a 200 meter length road inspired by a stretch of road near where our headquarters are located. The gap between the vehicle the participant is seated in and the car in front is 20 meters. All vehicles including the vehicle the participant is placed in are driving at 12 meter per second. One vehicle is located in front of the participant's car and there are two other vehicles on the left lane. The car A, a Hyundai IONIQ 5 (the gray car in Figure 1), will be the car requesting a lane change to the participant. The participant can look around the environment using a VR headset, but they cannot move around the scenario and are seated on a chair throughout the study.

3.2 Participants

We recruited a total of 14 participants for this study from Boston, MA and Ithaca, NY. All participants had driver's licenses and had experiences driving on real road scenarios. The study was conducted throughout late October to November of 2022.

3.3 Procedure

The study was conducted in-person using a Meta Quest 2 VR headset. Participants were given an overview of the study and asked for consent. The study started off by helping participants ease into the VR experience by adjusting the headset and familiarizing the controls of the VR. Participants were told that they would be experiencing a VR scenario of driving in a car in the driver's seat. They were instructed that they would not be required to drive because the car has an ADAS (Advanced Driver Assistance System) that would assist them throughout the study. Participants were instructed that they could press the X button to allow a car to make a lane change if they noticed a lane change request from another car. Finally, we informed participants that if they did not notice a car requesting a lane change, or if they did not want to allow a lane change, they did not need to press the X button. We received consent to have a voice recording of the study and to be able to use the recordings to analyze the results of the study. The study took a total of 20 minutes.

3.4 Experimental Conditions

3.4.1 *Active Roll Left.*

Actively rolling the vehicle has been evaluated as a means for communicating an AV's intention to change lanes to the vehicle occupants. To date active roll has not been evaluated from the perspective of other drivers. However, vehicle occupants consider roll motions as feedback for announcing automated lane changes to be useful and perceptible. Research on the design of effective active roll motion found that a roll angle of 2.5° with a time duration to reach the maximum angle was 3.96s [2]. In accordance with this, we developed an active roll motion of a vehicle tilting to the left by 2.5° in the virtual reality scenario. The maximum roll angle was reached 2 seconds after the turn signal was activated. To test if the active roll motion itself was enough to communicate to participants a lane change intent, we placed a turn signal light following the active roll motion of the vehicle.

3.4.2 *Turn Signal Light.*

As turn signal lights themselves are often strong cues of an intended lane change, we created a condition that

	Condition	Scene
1	Active Roll (L/R)	
2	Turn Signal	
3	Lateral Movement	
4	Gap Change	
5	Control Condition	

Figure 2: Five experimental conditions of the car requesting lane change.

looked at a flickering turn signal in isolation. The time for drivers to process the intention to change lanes significantly decreases when the turn signal is activated prior to the initiation of a lane change movement [9]. Further, activating the turn signal earlier is associated with significantly higher perceived cooperation compared to activating the turn signal later [8][9].

3.4.3 Lateral Movement. In accordance with research evaluating the impact of offsetting the vehicle 0.2 m, 0.5 m, and 0.75 m on lane changes for automated driving that found that an offset of 0.5 m was rated significantly more cooperative [5]. Based on this information, we created a VR experimental condition that displayed a vehicle moving laterally towards the lane changing vehicle by an offset of 0.75 meters. 0.75 meters was selected because it was more visible in the scenario. Once again, to test if the lateral movement motion itself was enough to communicate to participants a lane change intent, we placed a turn signal light following the lateral movement motion of the vehicle.

3.4.4 Gap Matching. Beyond examples from past research, we identified from pilot studies that participants viewed the vehicle's movement toward and subsequent driving next to the target gap as a clear signal the vehicle was intending to change lanes. In accordance with this, our VR scenario simulated a vehicle requesting a lane change by driving up to the car in front of the participant and then slowing down to match the target gap for lane change. To test the effectiveness of the movement in communicating a lane change intent in isolation, the turn signal was activated after the movement was performed.

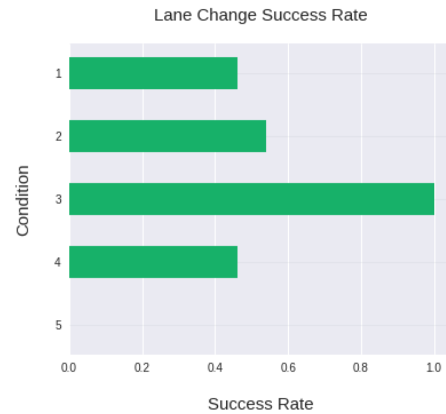

Figure 3: Lane change success rate. (1) Active Roll, (2) Turn Signal, (3) Lateral Movement , (4) Gap Matching, (5) Control Condition

3.4.5 Control Condition. Finally, we added a control condition where vehicle A did not express any lane change but simply drove on the right side of the lane to the participant. The control condition was intended to counter learning effects across trials. Without this condition, participants might assume that the vehicle on the right of the road is always requesting a lane change and learn to allow for lane change in each condition. Participants were exposed to the control condition once in each round of the study.

3.5 Measurements

After experiencing each of the lane change intent scenarios, participants were asked 4 questions that were answered on a 7-point Likert scale ranging from completely disagree (1) to completely agree (7). The four questions included questions on legibility, willingness to allow lane change and perceived aggressiveness of the lane change request. The four questions were asked to participants after interacting with each of the scenarios (1) The vehicle was requesting a lane change (2) It was clear that the vehicle was requesting a lane change (3) I wanted to allow the vehicle to make a lane change (4) The lane change request of the vehicle was aggressive.

4 RESULTS

4.1 Interaction Experiences

4.1.1 Lane Change Success Rate. We observed that all participants successfully made a lane change quest for lateral movement of the vehicle (3). For the other conditions, turn signal proved to be effective in succeeding in making a lane change while gap matching and active roll succeeded with some confusion. (Success rates : (1) Active Roll : 46.1 %, (2) Turn Signal : 53.8 %, (3) Lateral Movement : 100% , (4) Gap Matching : 46.1% , (5) Control : 0%)

4.1.2 Recognition and Clarity. In accordance with all participants allowing a lane change for lateral movement, responses to the question "I recognized the lane change intent of the car" and "The lane change request of the AV was clear" was highest. However, not all expressive movements were recognized and proven to be clear.

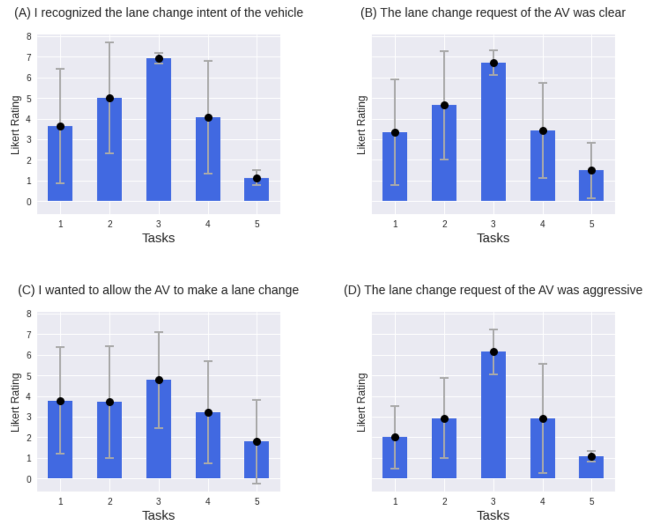

Figure 4: VR Experience Likert Scale Ratings. (1) I recognized the lane change intent of the vehicle. (2) The lane change request of the AV was clear. (3) I wanted to allow the AV to make a lane change. (4) The lane change requested by the AV was aggressive.

Participants who recognized the lane change intent of the Active Roll movement responded that they confirmed the intent through the turn signal indicating that the active roll movement was a poor indicator of a car wanting to make a lane change. Additionally, participants responded to the Gap Matching movement that they did not recognize a lane change intent or that they confirmed the intent through a turn signal. One participant responded that they recognized the car driving to match the gap but did not perceive this as a lane change intent.

4.1.3 Perceived Aggressiveness and Willingness to Allow Lane Change. Lateral Movement received the highest score for lane change willingness despite having higher levels of aggressiveness. However, we observed negative interaction experiences reported by participants. One participant reported to feeling angry at the movement of the car trying to make a lane change when there wasn't a wide enough distance to do so. Other participants reported to feeling unsafe due to the sudden aggressive movement of the car. Our findings suggest that expressive lane change movement such as lateral movement have high levels of legibility at the cost of high aggressiveness. In the turn signal condition, we observed lower levels of aggressiveness but also lower levels of willingness to allow for lane change due to factors such as the small distance between cars

5 DISCUSSION

Overall, we found the need to balance aggressiveness and legibility in AV lane change. Key parameters that should be considered when designing lane change intent in AVs are velocities of lateral movement, offset distances, angles, and turn signal timing. While more aggressive behaviors can be more legible they come at the cost of negative experiences reported by participants. Despite lateral movement having the highest levels of legibility, participants negatively responded to this movement. Additionally, participants responded that if they were interacting with an autonomous vehicle, they would be more cautious and willing to allow a lane change. One participant was unsure whether the AV would be able to recognize her intent. "I would allow the lane change more often if it was an AV because it won't be able to recognize that I don't want to make the lane change." Beyond the lane change movement itself, factors such as the distance between cars and traffic density influenced the participants decision in allowing for a lane change. "The space between me and the car is important. If it isn't big enough, I wouldn't let them come in". These findings reveal the need for autonomous vehicles to identify effective methods of lane change communication through balancing aggressiveness and legibility.

6 CONCLUSION

The findings from this preliminary study of how to optimize lane changes to be legible and intuitive for other drivers and riders support incorporating lateral offset into the AV's lane change behavior. We investigated the effects of four different communications of an AV lane change intent on the interaction experiences of drivers receiving the lane change request. We found that lateral movement scored the highest in terms of recognition, clarity, willingness, and aggressiveness. Given these comments and the small sample size of this study, future research should be conducted to identify the optimal parameters of the lateral movement behavior. While lateral movement yielded positive results in terms of allowing lane changes, alternative expressive behaviors such as Active Roll and Gap Matching received positive reactions from participants in terms of their level of comfort. We propose that future work also looks into developing movements that not only find optimal lateral movement parameters, but also experiment with combining it with alternative expressive behaviors to investigate whether their benefits compound. Another key finding from this study was that lane change was affected by various situational factors such as the knowledge of the car being an AV and traffic density.

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