ANALYSIS OF THE INFLUENCE OF THE SAFETY ZONE ON THE EFFECTIVENESS OF THE SIDE CONTROL ALGORITHM FOR ROAD CONVERSION IN AUTONOMOUS VEHICLES

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Objectives

The development of Artificial Intelligence, as well as control systems and machine learning have made possible the process of automation of vehicle driving. Autonomous vehicles (AVs) aim at safe driving, presenting a more efficient vehicular driving behavior than a human driver. This study comparatively analyzes the impact of the use of a Safety Zone (SZ) on the efficiency, in relation to safety, of vehicle lateral control algorithms for the conversion of a dual carriageway. The SZ is a virtual region, just at the front and rear of the vehicle, which expands the physical dimensions perceived by the controller, in order to guarantee its safe movement.

Materials and Methods

This study has a computer modeling and simulation virtualization environment developed in collaboration between Ericsson and the Security Analysis Group (GAS/EPUSP), applied to investigate the behavior of AVs in traffic scenarios [1]. The framework integrates an open-source vehicle traffic simulator (OpenDS) and MATLAB, which runs the AV control algorithm to evaluate its behavior. The information generated by the simulator is transmitted and processed in the MATLAB environment, returning to the simulator the feedback with the handling information for the vehicle's mechanical actuators - pedal position and steering wheel angle.

A similar configuration of a two-way traffic crossing scenario was used (Fig. 1) to the one adopted in [2], [3]. However, in this scenario, the transversal path to be crossed was updated with a two-way approach, increasing the complexity of the scenario and enabling the use of previous control algorithms as a basis for the development of the new study.

The objective of the control algorithm is to determine the target (safe) speed of the AV - managed through acceleration and braking commands - as well as correct steering to ensure that the vehicle follows the path that results in a right (or left) turn. The algorithm controls only the AV that travels on Route 1, obtaining situational awareness from the communication between vehicles (V2V), in addition to the information acquired by the AV sensors themselves.

The determination of the target speed is made through comparisons between the current speed and the speed of the midpoint between each pair of consecutive vehicles (1st and 2nd vehicles, 2nd and 3rd vehicles, successively), taking into account the SZ dimension of all vehicles in the virtual environment (Fig. 1). To enable a comparison between the two approaches (between [2] and [3]), the same scenario parameters were kept. Thus, vehicles on Route 2 travel at 50 km/h, with a speed reduction to 30 km/h near the intersection. For V2V communication, a sampling frequency (F) of 10 Hz and an end-to-end latency of 1 second were adopted. The main variable of interest used as a proxy for the efficiency of the SZ influence was the number of correct conversions, without accident, calculated by: 100% - collision rate C. The emergency stops rate variables (total stop, S) and the average of the minimum distance (MD) between the geometric centers of the AV and any vehicle of Route 2, observed at the intersection, are also evaluated to appraise the dynamics of the experiments.

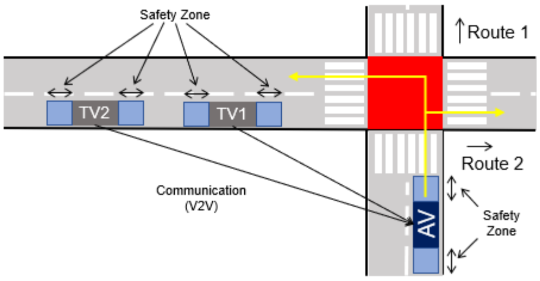

Fig. 1 - Crossing scenario used for right and left turns

Control adaptations were carried out to calculate the target speed in order to accommodate both safe right and left turns, also accommodating the different SZ configurations. For the AV, 3 fixed SZ configurations were tested (2, 3, 4 meters), and for the vehicles on Route 2, another 3 fixed SZ configurations (0, 1, 2 meters), in addition to the base configuration of 0 meters for all vehicles, resulting in 10 combinations of pairs of SZs. The experiment considered 3 maximum speeds (MS) for the AV and 10 pairs of combinations of SZs of the AV and the vehicles of Route 2, totaling 30 scenarios. For each scenario, 50 runs were performed (totaling 3000 runs - 1500 right and 1500 left turns). On each execution the result can be a successful conversion, collision C or stop S, allowing their respective calculations. Scenarios with different limits of AV MSs (12, 13 and 14 m/s) were used.

Results

Tab. 1 - Results of comparison between the conversion of controls - adoption of SZs (2020 - [2]; 2021 - [3])

AV's Maximum Speed (m/s)	Collision Rate (%)		Total Stop Rate (%)		Average Minimum Distance (m)		Standard Deviation Minimum Distance	
Base Control	2020	2021	2020	2021	2020	2021	2020	2021
Conversion to	Right							
12	100	3.03	0	2.8	3.27	5.83	0.19	0.65
13	0	5.01	0	1.15	8.64	4.89	0.24	0.27
14	0	0	0	0	8.03	13.1	0.25	0.05
Conversion to	Left							
12	96.2	0	0	0	3.54	5.87	0.31	0.27
13	95.2	98.9	0	1.13	4.24	3.71	0.35	0.29
14	98.2	0	1.8	0	4.73	5.92	4.33	0.25

Tab.1 summarizes the results of the experiments. It can be seen that the control 2020 - [2] has a small advantage for the case of conversions with an MS of 13 m/s. For speeds of 12 and 14 m/s, control 2021 - [3] has an advantage, with a reduction in the C rate and an increase in the average MD between the AV and the other vehicles, thus reducing the risk of C. The P rates were incipient for the totality of the experiments when compared with the results obtained in [2] and [3].

Conclusions

The adoption of SZs in all vehicles - base control [3] - reduced the risk of C for a range of speeds (12 and 14 m/s), when compared to the base control [2] - without the adoption of SZ, since the mean of the MD was reduced. For the conversion cases studied, the full stop mechanism was not effective, given the low S rates observed. Left turn experiments are considerably riskier, possibly due to the lane geometry, behavior of Route 2 vehicles and the AV turning approach. Based on the results, the use of SZ for all vehicles is favorable, although more studies are needed to evaluate the use of other safety mechanisms and control evolutions to improve the results obtained.

References

[1] L. F. Vismari et al., “A simulation-based safety analysis framework for autonomous vehicles – assessing impacts on Road Transport Systems safety and efficiency,” in Proceedings of ESREL 2018, pp. 2067--2075.

[2] G. K. G. Shimanuki, “Influence of the safety zone on risk of accidents with autonomous vehicles”, SIICUSP 2020

[3] G. K. G. Shimanuki, “Analysis of the influence of the safety zone on the effectiveness of the road crossing control algorithm for autonomous vehicles”, SIICUSP 2021