POLITECNICO MILANO 1863

SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

Executive Summary of the Thesis

Characterization of drivers' visual perception through driving simulator tests

Laurea Magistrale in Mechanical Engineering - Ingegneria Meccanica

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1. Introduction

Autonomous vehicles could drastically improve the safety on the road, but they might be useless if people doesn't accept them [6]. When an ADAS takes control on the vehicle, it works autonomously from the driver, and this could be a trust issue, since drivers are used to have complete control on the car. For this reason it is essential to develop a model of driver "human-like" for 2 reasons:

1. Drivers may accept more easily an autonomous driver if it is expected to behave similarly to what they would also do during driving.
2. A model "human-like" could be useful to create environments of simulation in which autonomous vehicles interact with vehicles that behave in a similar way to real vehicles present on the road, driven by real drivers.

Since it's very useful to develop this model of driver, it's of fundamental importance to characterise the driving style of drivers with numbers and parameters, so that an algorithm has the basics to reproduce it. To do so, first it's essential to develop a model of perception of drivers. This is the starting point for the development of this thesis. To obtain this result, it is essential to employ a driving simulator like the one of Politecnico di Milano [4].

A driving simulator, thanks to its characteristics, it's particularly suitable to study autonomous vehicles (ADAS), because in first analysis they can be tested in a controlled environment and in complete safety. Autonomous vehicles can provide more safety compared to normal cars, in particular the active protection, since they work to prevent accidents. They gain information about the environment around the car with cameras, infrared, lidar, lane sensors and so on. All these sensors give information to the ECU, that can take decisions and intervene. For this reason, a driving simulator is quite useful in this sense, since the control strategy at the core of the ADAS (Advanced Driver Assistance Systems) can be applied in a virtual environment, to study how it will perform, what decisions will take etc. The driving simulator offers repeatability to each test, and so consistency in the initial conditions and external factors, which is fundamental in experimental research.

2. Preparation of the tests

To reach the goal proposed, it is essential to conduct tests at the simulator to gain information on the perception of drivers. For this reason a total of 6 scenarios were created using the software RoadRunner [2].

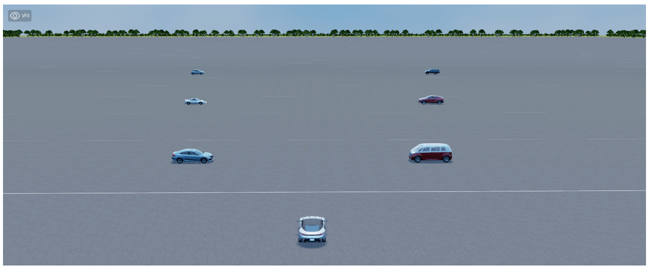

Figure 1: The 3rd scenario

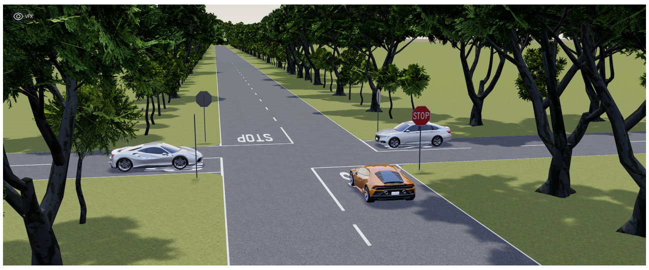

Figure 2: The 6th scenario

The 1st, 2nd, 3rd and 4th scenarios are similar in appearance, they just change in the number and position of cars. In the 1st scenario, there's one car that passes in front of the driver, for 3 different speeds and longitudinal distances. With this test it's possible to evaluate the width of the field of view of drivers. In the 2nd scenario, there is a parked car that disappears after some time, and drivers have to stop there. In this test it's evaluated the ability of drivers to estimate the position of vehicles. In the 3rd scenario (figure 1) there are 6 cars entering the field of view of drivers from both sides. This test allows to establish what are the main factors that influence the priority of perception of the cars: speed or distance. In the 4th scenario, a car moves in front of drivers, disappears for some time and then reappears again. This test allows to establish the ability of drivers to estimate correctly the speed of a moving car.
The 5th and 6th scenarios are different. The 5th is a long straight road with double lane. Drivers experience 6 different sub-cases with cars parked and cars moving along the opposite lane. In this case it's evaluated the probability that a driver looks in front of the car or in other directions. The 6th scenario (figure 2), is an intersection. Drivers experience 4 sub-scenarios, with cars approaching from both sides. Just like in the previous scenario, this test has the target to know where a driver looks mainly when performing a left turn maneuver in an intersection. To gain information from the 4th, 5th and 6th scenarios, during the tests drivers wear a special pair of electronic glasses called "eye-tracker" that allow to know exactly were drivers where looking.

3. Data collected

For the 1st scenario, when drivers see the car approaching from the side, they press the stop button, and so the last coordinate of the car represents the width of the field of view. For the 2nd scenario, the data collected is the coordinate of the parked car, and the coordinates where the drivers stop. For the 3rd scenario, a questionnaire is compiled by drivers, ranking the order at which they perceived the cars, from first to last. These rankings are grouped together to create histograms. For the 4th, 5th and 6th scenarios, it's collected the files of the eye-tracker and elaborated through its associated file. Then, the files are imported to MATLAB [1], for the final analysis.

4. Data processing

4.1. Scenario 1

From the 1st scenario, it emerged that the field of view is approximately 45° wide, and increases when the car approaches at higher speeds. This trend was observed for all drivers.

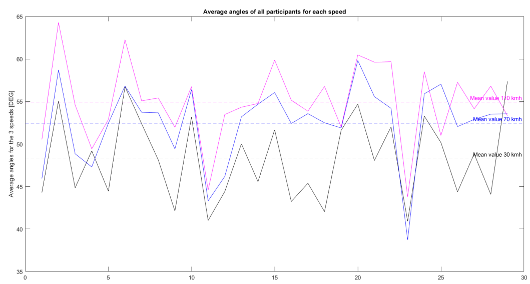

Figure 3: Average angles for all participants

- The average angle of the field of view at 30 km/h is 48,24°, with a standard deviation of 4,88.
- The average angle of the field of view at 70 km/h is 52,42°, with a standard deviation

of 4,63.

- The average angle of the field of view at 110 km/h is 54,91°, with a standard deviation of 4,60.

4.2. Scenario 2

From the 2nd scenario it emerged that generally drivers underestimate the position and angular position of parked cars.

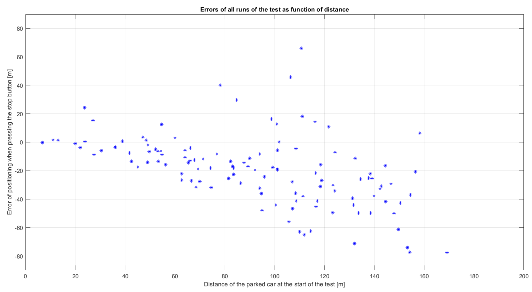

Figure 4: Error on distance

From the 2nd scenario it emerged that generally drivers underestimate the position and angular position of parked cars. It's also possible to see that generally drivers commit a lower error on the angle, compared to the distance. The max error for the distance is of 74,43 %, while the max error for the angle is of 57,15 %.

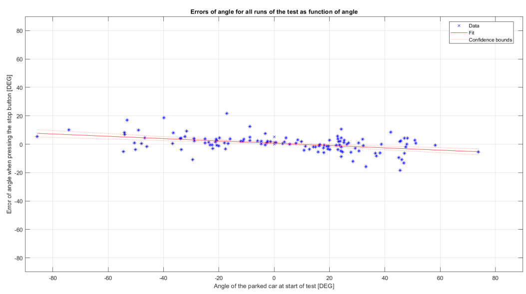

Figure 5: Error on angular position

4.3. Scenario 3

From the 3rd scenario it was possible to understand that generally the distance has more capacity than the speed to draw the attention of drivers, since the preference is more concentrated on the distance and on the speed it is more distributed.

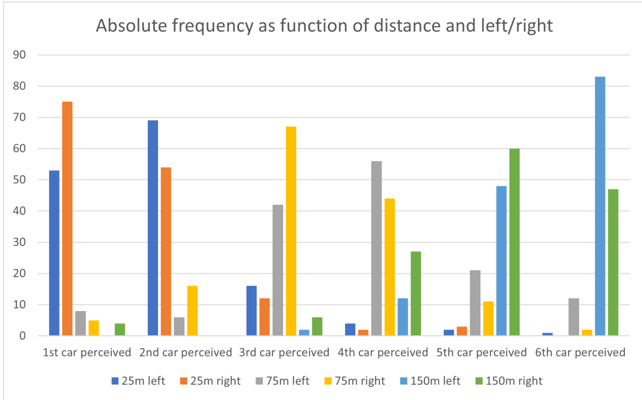

Figure 6: Influence of distance on perception

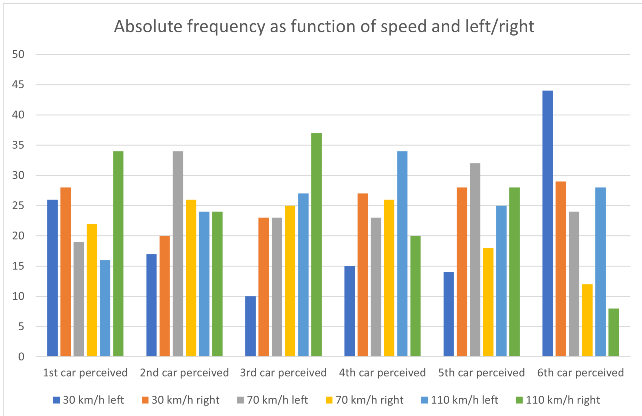

Figure 7: Influence of speed on perception

4.4. Scenario 4

Regarding the 4th scenario, it emerged that drivers generally overestimate the speed of cars. In fact the major part of the errors are positive, inside the bin 0 - 5 %. The errors usually don't exceed the limit of +-50 %, apart from a couple of takes of the test which result in complete misjudgments. The speeds considered are of +-30 km/h, +-70 km/h and 110 km/h.

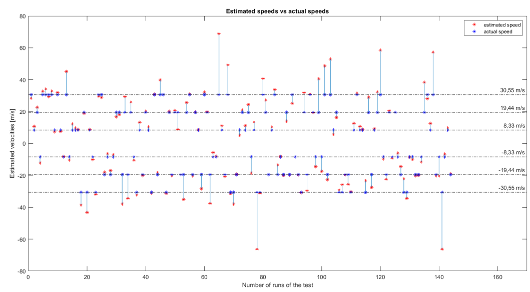

Figure 8: Estimated speeds

4.5. Scenario 5

For this test it was required to create "masks" to overlay on top of the registration of the test, in which each area of the car is identified with a different name. Thanks to the software of the eye-tracker [5], it was possible to extract tables, for each run of the test, in which is reported where the driver looks each instant of time. After some processing on MATLAB it was possible to extrapolate a table indicating the total time spent looking in each area. What emerged is that generally drivers, for the most part, look to the road in front of them, and occasionally to the side mirror if they perform an overtake.

	1	2	3	4	5	6	7	8	9	10
1	'road'	'lower left'	'road'	'dashboard'	'road'	'dashboard'	'road'	[]	[]	[]
2	3.1960	10.6290	11.0700	12.4720	13.0140	20.7670	21.2080	[]	[]	[]
3	10.5890	10.9900	12.4520	12.9930	20.7480	21.1880	21.9500	[]	[]	[]
4	7.3930	0.3610	1.3820	0.5210	7.7340	0.4210	0.7420	[]	[]	[]
5	[]	[]	[]	[]	[]	[]	[]	[]	[]	[]
6	'road'	'left road'	'right road'	'lower left'	'lower right'	'dashboard'	'roof'	'area'	[]	'side [s]'
7	17.2510	0	0	0.3610	0	0.9420	0	'tot time [s]'	[]	10.1320
8	4	0	0	1	0	2	0	'n° fixation'	[]	[]
9	4.3128	0	0	0.3610	0	0.4710	0	'mean time...	[]	[]

Figure 9: Sub-case with an overtake

In this case (figure 9) the driver looked to the left side mirror (here indicated as lower left) 1 time because it was required to perform an overtake. The driver also looked 4 times to the road ahead and 2 times to the dashboard.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1	'road'	'dashboard'	'road'	'dashboard'	'road'	'dashboard'	'road'	'dashboard'	'road'	'dashboard'	'road'	'dashboard'	'road'
2	6.9910	7.1310	8.6340	9.0740	11.3790	14.3040	16.5880	18.2310	18.9120	20.6150	21.4970	28.8500	29.9120
3	7.1110	8.5530	9.0540	11.2980	14.2840	16.5680	18.2110	18.8920	20.5950	21.4770	28.8300	29.8920	37.2050
4	0.1200	1.4220	0.4200	2.2240	2.9050	2.2640	1.6230	0.6610	1.6830	0.8620	7.3330	1.0420	7.2930
5	[]	[]	[]	[]	[]	[]	[]	[]	[]	[]	[]	[]	[]
6	'road'	'left road'	'right road'	'lower left'	'lower right'	'dashboard'	'roof'	'area'	[]	[]	[]	[]	[]
7	21.3770	0	0	0	0	8.4750	0	'tot time [s]'	[]	[]	[]	[]	[]
8	7	0	0	0	0	6	0	'n° fixation'	[]	[]	[]	[]	[]
9	3.0539	0	0	0	0	1.4125	0	'mean time...	[]	[]	[]	[]	[]

Figure 10: Sub-case without overtake

It's possible to notice that in other cases in which no overtake is required, drivers just look straight ahead and to the dashboard to check the speed limit (figure 10). In this case the driver looked 7 times to the road ahead and 6 times to the dashboard.

4.6. Scenario 6

In this case a similar procedure to the 5^{th} scenario was adopted. In this case drivers approach an intersection, stop at the sign, check that the road is free and then take a left turn. Since in this case drivers have to check on both sides of the road, it is possible to see that differently from the previous case, drivers look in different areas much more frequently.

	1	2	3	4	5	6	7	8	9	10
1	'dashboard'	'road'	'dashboard'	'road'	'dashboard'	'road'	'dashboard'	'road'	'dashboard'	'road'
2	2.5420	2.8030	3.6640	4.0450	5.3470	5.6880	6.9900	7.3910	9.5750	9.8760
3	2.7830	3.6440	4.0250	5.3270	5.6680	6.9700	7.3710	9.5550	9.8560	10.8370
4	0.2410	0.8410	0.3610	1.2820	0.3210	1.2820	0.3810	2.1640	0.2810	0.9610
5	[]	[]	[]	[]	[]	[]	[]	[]	[]	[]
6	'road'	'left road'	'right road'	'dashboard'	'roof'	[]	[]	'area'	[]	'stop [s]'
7	15.7450	4.6280	2.4240	4.1500	0	[]	[]	'tot time [s]'	[]	13.7330
8	17	5	5	11	0	[]	[]	'n° fixation'	[]	[]
9	0.9262	0.9256	0.4848	0.3773	0	[]	[]	'mean time...	[]	[]

Figure 11: Results for the 6^{th} sub-case

For example in this case (figure 11) the driver looked 17 times on the road ahead,5 times to the left window, 5 times to the right window and 11 times to the dashboard.

5. Model of perception

All the data collected from these tests made possible the creation of a model of perception of drivers. In particular, this model is focused to reproduce the perception that real drivers have of vehicles in their surroundings.

5.1. Field of view

This model, first of all, defines the field of view of a vehicle. The field of view is shaped like an isosceles triangle, with the vertex positioned at the center of the car, the two sides inclined with respect to the longitudinal direction with an angle that depends on the speed. These angles are the ones calculated from the first scenario:

- The average angle of the field of view at 30 km/h is equal to 48,24°.
- The average angle of the field of view at 70 km/h is equal to 52,42°.
- The average angle of the field of view at 110 km/h is equal to 54,91°.

The base of the triangle is positioned transversal with respect to the car, in front of it, at a distance

d=Vcar*Ld

Ld represents the look ahead distance, parameter used to describe how far away the driver looks, in this case selected as 2,5 s.

5.2. Bias on distance and angle

This model calculates the field of view each instant of time. It receives as input the coordinates of the vehicles in their surrounding and if they are inside the field of view the model of perception of real driver is applied, otherwise nothing happens. If the vehicles are inside the field of view, the model applies a bias on the distance and angular position of the cars, exploiting the results obtained from the tests. To create the bias on distance, the first thing to do is to plot the errors on distance committed by drivers. Then the distances are divided in intervals of 20m each. Inside these intervals it is calculated the 25th, 50th, 75th percentile, the min and the max value, like in figure 12.

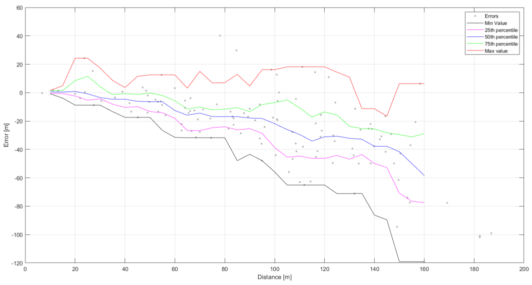

Figure 12: Percentiles for the distance

Now from these percentiles it is possible to calculate 5 linear interpolations that start from the origin. The reason is that for lower distances the errors decrease. Since they pass fro the origin, they are characterized by just an angular coefficient.

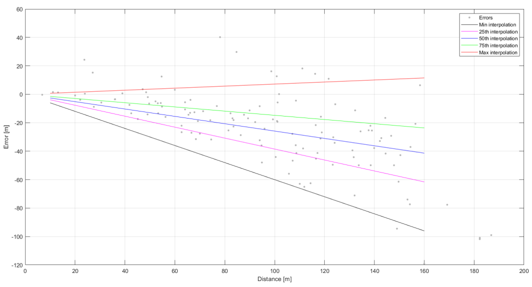

Figure 13: Linear interpolations on distance

These are the angular coefficients:

- m = -0,6003
- m = -0,3850
- m = -0,2586
- m = -0,1478
- m = +0,0719

The same procedure is repeated separately for angles to the left and for the angles to the right. They are considered in a separate way since there isn't a perfect symmetry.

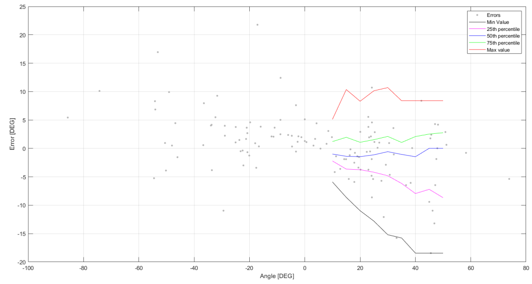

Figure 14: Percentiles for right angles

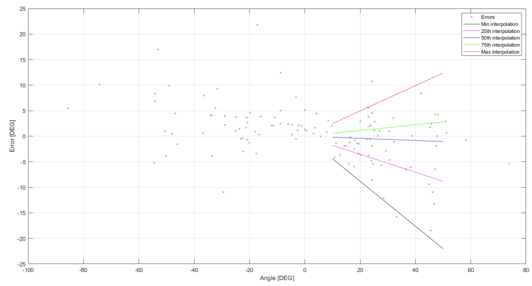

Figure 15: Interpolations for right angles

These are the angular coefficients:

- m = -0,4401
- m = -0,1763
- m = -0,0206
- m = +0,0560
- m = +0,2474

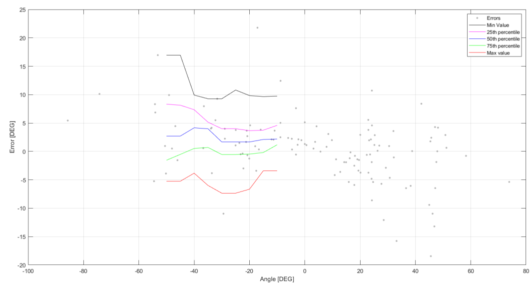

Figure 16: Percentiles for left angles

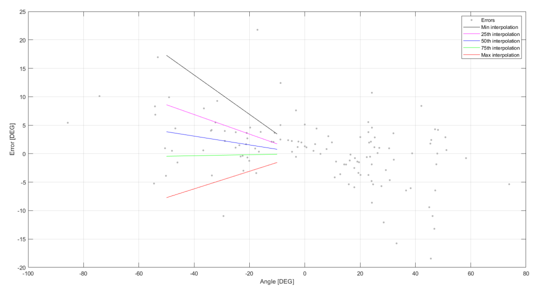

Figure 17: Interpolations for left angles

These are the angular coefficients:

- m = -0,3458
- m = -0,1720
- m = -0,0772
- m = +0,0090
- m = +0,1546

6. Application of the model of perception

Before starting the simulation, a random number between 0 to 1 is chosen. This value will select a linear interpolation for the distance and the angles. A value of 0 means taking the lower interpolation, a value of 1 will select the max interpolation, a value of 0,5 will select the median interpolation and so on. These values are then sent to the Simulink [3] block of the model, that calculates, based on the distance ego car-traffic car, the bias to apply on the distance and angular position of the traffic car. It was applied the model in a case of an average driver (so a coefficient of 0,5) and the result is consistent with the expectations: the model positioned the traffic car closer to the ego car, at a lower angle of positioning.

Figure 18: This is the ego car at the start of the test

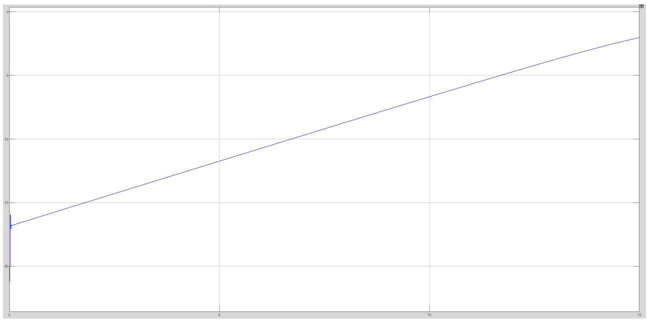

Figure 19: This is the bias applied to the distance

As it is possible to see, the bias applied is negative, since it reduces the distance, and progressively decreases in magnitude since the ego car gets closer to the traffic car.

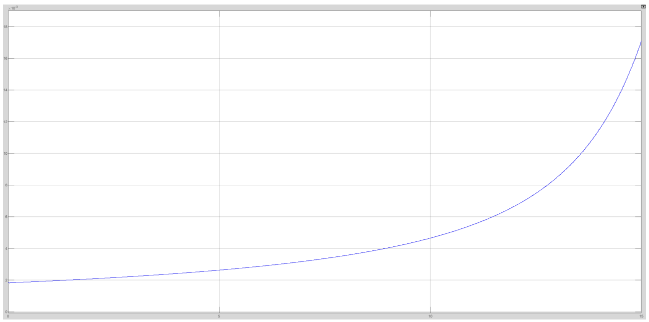

Figure 20: This is the bias applied to the angle

Here it's possible to notice that the same thing happened to the angle: since the driver selected underestimates the inclination,a positive rotation is applied to the traffic car to put it closer to the longitudinal direction. The magnitude of the bias increases because when the ego car gets closer, the traffic car goes progressively more to the side.

Figure 21: This is the result of the model

Figure 21 shows, from the top, the result of the application of the model. The white car is the traffic car unbiased. The black car is the traffic car with the superimposition of the model of perception. The green car is the ego car. The perception is calculated with respect to this car.

7. Conclusions

This research has shown the possibilities offered by a driving simulator to study in depth the driving style of drivers and characterize them through tests. It was possible to draw conclusions on the visual perception of drivers regarding: the depth of their field of view, the ability to identify correctly the position of vehicles, what parameters influence the most the perception, what is the ability to estimate the speed of vehicles and what are the main areas of interest of drivers when facing common situations.

References

[1] https://it.mathworks.com/products/matlab.html.

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[6] S.B. (TU Delft Human-Robot Interaction) Kolekar. *Driver's risk field: A step towards a unified driver model.* PhD thesis, Delft University of Technology, https://doi.org/10.4233/uuid:a118e35c-dec9-4c1f-9ed7-8b65a5ca77a3, 12 2021.