IHSAN DOĞRAMACI BILKENT UNIVERSITY
MECHANICAL ENGINEERING DEPARTMENT

ME 440 - AUTOMATIVE ENGINEERING

COMPARISON OF HUMAN AND NON HUMAN DRIVERS IN SIMPLE TRAFFIC MANEUVERS

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Submission Date:
January 1, 2021

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1 Introduction

Automotive industry and technology have been one of the most affected areas by the developments in various fields of technology. Since an automotive is a product where many fields of technology can contribute, improvement in these branches also affect vehicles. For instance, when an existing or new, high-tech sensor technology used by cars is developed, many car companies want to use this technology to increase the comfort and safety of their cars. These kinds of improvements are driving cars towards a more autonomous future, where the affect of human factor is completely removed. Despite the huge number of researches in the artificial intelligence and developing algorithms that can drive the vehicle fully automatically, the fully autonomous level for vehicles has not achieved yet [1]. Therefore, in the current applications, rather than providing a fully autonomous vehicles, many companies are providing vehicles with advanced driver assistance systems.

Although, the main goal of providing these advanced driver assistance systems or autonomous systems is decreasing mistakes that can lead fatal injuries or severe consequences in the highways, there are side goals as well. For instance, optimal movement of the vehicle in the traffic environment is a quite important issue. Driving in the optimal route not only can increase the safety, but also it can decrease the fuel consumption by avoiding unnecessary maneuvers. Especially in the auto-racing, drivers are trained to use the optimal route of the road to decrease their fuel consumption and lap times while increasing the driving safety, since at such high speeds, crushes are much riskier than a usual car crash. However, not all drivers around the world are skilled and trained as well as professional racing drivers.

Today, many drivers are making unnecessary movements or maneuvers while driving, because of their response and sense time. They sometimes lose the lane that they are driving or use the steering wheel unnecessarily and do under-steering over-steering or so called "Driver-Induced Steering Oscillation"[2]. These maneuvers are increasing the risk of crash. Furthermore, generally these situations are forcing drivers to slow down and lose driving tempo, which will cause increase in the fuel consumption. These situations are quite likely to happen because of the number of elements in the car can lead distraction in the driver is quite high, i.e cell-phones, traffic signs, navigation, radio etc.

In this project report, three different human models and a non-human PID based controller have been investigated for the simple "S" maneuver in a traffic situation, where humans or controller decides on the steering angle of the vehicle in order to avoid crash. The vehicle that is specifically designed in this project is "Mercedes CLS 63 AMG", its features such as mass, length, center of mass position, etc. was used in the lateral dynamics. Humans are modeled as controllers with varying reaction times and error rate. As it was mentioned above, there are still not fully autonomous vehicles and humans are still in the loop. Therefore, it is important to consider human effect in the driving scenarios. In this project, by defining and modeling different types of humans and a non-human controller can provide a statistical data for errors, in this case defined as the deviation of pre-determined optimal route. The total or local error amount between human models and non human controller can also be obtained from this work, which can be later used for virtual testing programs where autonomous pilots and human pilots are present. Moreover, the offered non-human controller method can be investigated further to make use of it in the advanced driver assistance technologies.

It is important to notice that, the PID control is not a new technology but the optimal route determination could not be done until the latest technological developments where the usage of sensors as well as navigation systems, where they can get the traffic data constantly and find the optimal route for the vehicle. Therefore, a proper defined controller can optimize the vehicle movement without changing its speed much, because of the given live data of the road constantly.

2 ME 440 and Other Courses Perspective

This project is directly related with the two subjects of ME 440: Lateral Vehicle Dynamics and Human Factors in Vehicle Dynamics.

Firstly, in the Simulink model, the transfer function for the bicycle 2-dof vehicle car model is calculated using lateral dynamics state space equations. The transfer function input is the steering angle whereas the output is the lateral position (y) of the vehicle. Therefore, the car model was an application of theory that was taught in the Lateral Vehicle Dynamics part of the ME 440.

The human modeling was also a ME440 related subject, where human models were based upon theory (PD controller based humans with time delay) that was taught in the course. There were other additions, such as error likelihood, to the given theory and the resulting human models were an application of the theory that was taught in the Human Factors in Vehicle Dynamics part of the ME 440.

Since a control system in Simulink environment was built for doing the simulations, ME 342 (Dynamics and Control II) course's subjects were used. They were also used during selection and tuning of the PID controller representing the non human controller for this project.

In this project, all the information mentioned above obtained from relevant course subjects were used combined. Therefore, it was a good practice of the theory in a real case simulation and engineering analysis scenario.

3 Literature Research

The literature research for this project was based on two different areas: Human modeling, and Non-human steering control.

3.1 Human Modeling

Modeling human behavior correctly is one of the key factors if the human is going to be compared with a computer. Therefore, it is important to investigate current methodologies in the articles that are in the literature.

The first article that is going to be investigated for human modeling is **"A Driver Steering Model With Personalized Desired Path Generation"**. This article is written by Scott Schnelle, Junmin Wang, Haijun Su, and Richard Jagacinski, and published in *IEEE Transactions on Systems, Man, and Cybernetics: Systems* journal in 2017, January [3]. This paper offers a model for drivers where it considers driver's current position and desired path based on road geometry. The key difference of this paper from the previous works is that, it proposes its unique model with compensatory and anticipatory subsystems, which will lead to determine driver model parameters for each driver. One of the key parts of this paper is that the parameters that are used for the model of the human driver in the simulation world were actually obtained from human subjects tests in a simulation. Therefore, the automobile can save the preferred path by the different drivers.

Obtaining these results that are cross-validated with several techniques are quite useful for researches in the automotive engineering as well as in the automotive industry. One of the key pros of this work is that, providing individual driving habits of the drivers to the vehicle, the driver assistance system can adapt itself optimally when the driver of that vehicle changes. Therefore, in case of car crash due to unexpected or expected events on the traffic, because of each individual's driving habit differs, the adapted driver assistance system can help the driver by using the specific driver information that was mentioned before. Furthermore, the obtained driving habits for each individual drivers can help them to increase their driving efficiency by giving periodical report of error and this can be useful for not only training the auto-racing drivers but also individuals that wants to increase their driving performances.

The other advantage of this work is that, it can provide a statistical data for automotive research area. Since the proposed model can save the driving habits, these saved driver models can be later used in different research applications. Other than just creating randomized errors, provided real-life based data would increase the accuracy of the experiments in the research field, especially in the simulation environments.

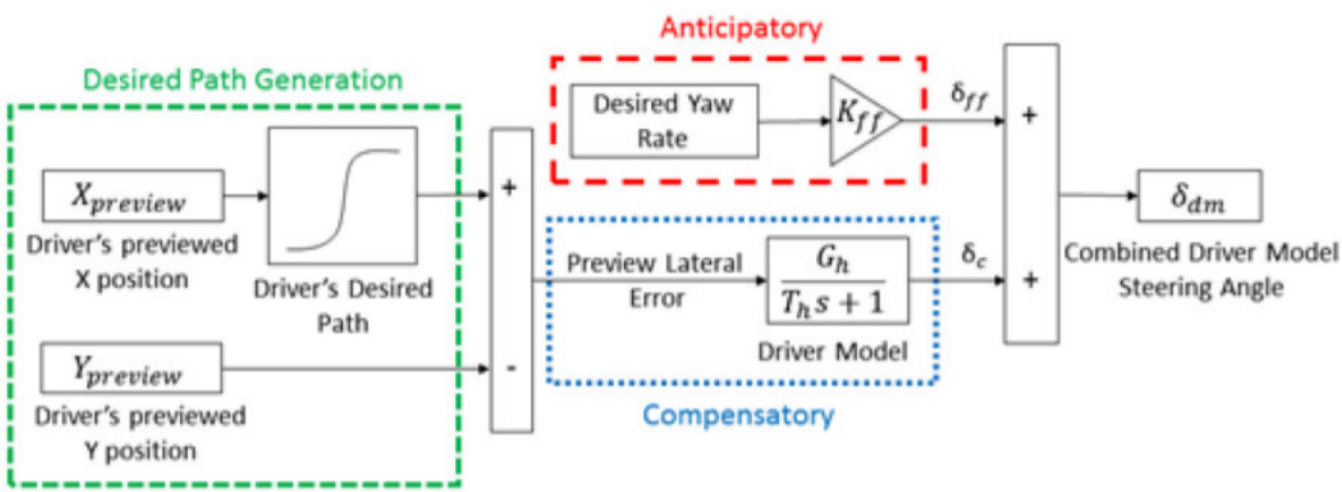

Figure 1: Schnell's proposed model structure of combined directional control driver [3]

This is the most important figure for this paper, since the main proposal of the paper is this model, where there is a compensatory and anticipatory transfer functions both contributing driver steering angle model. It is important to notice that, unlike Schnell's paper, the driver model that is designed for this project does only have compensatory transfer function where it has a derivative term as an addition to the what is given in the figure above. Moreover, the reaction time specifically was not designed as in this model but it was based on pade's approximation.

The second paper in the driver modeling is **"Effects of Age and Task Load on Drivers'**

Response Accuracy and Reaction Time When Responding to Traffic Lights" written by Emilie Salvia, Claire Petit, Stéphane Champely, René Chomette, Franck Di Rienzo, Christian Collet. This paper was published in the *Frontiers in Aging Neuroscience* journal , the 5th most cited open-access journal in Neurosciences, in 2016 [4]. This paper gives a wide range information of the relation between age and reaction times with error likelihoods in different types of tasks. In this paper, there is no proposed new model or specific methodology, but its an experimental based paper where it gives lots of data of human behaviors in the traffic based on their ages and it clearly shows the effect of age in human behaviors in the traffic environment.

The age factor in the human modeling for the vehicles is generally not considered, since the modeling a human is already a quite complex task. Moreover, experimental data belonging to the real human drivers is something that usually lacks in the automotive research area. Therefore, with this paper, many human models can be designed with proper reaction time and failure rate regarding the age of the human as well as the task difficulty for each human can be considered during modeling them and adjustment of the error rate and reaction time can be adapted to the difficulty of that specific task.

The following figure is one of the most important figures of this paper, where it represents the relation between age and reaction time in the different task difficulties.

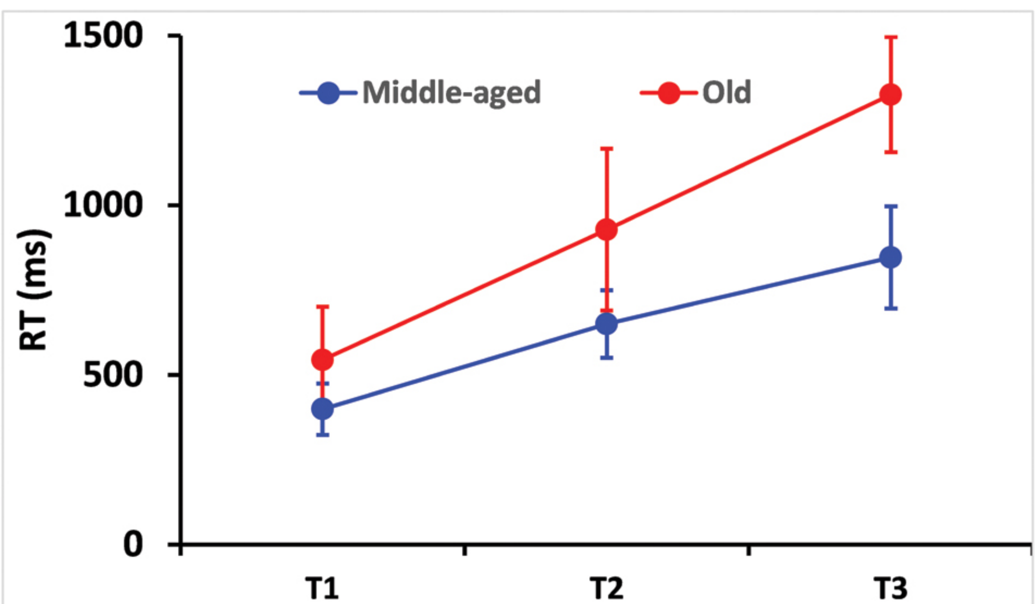

Figure 2: Reaction time in the varying test difficulty and age [4]

It can be seen that the reaction time between middle aged drivers and old drivers increases as the the difficulty of the task increases. However, in this project reports scope, the only task type was T3 (which represents the hardest task in this experiment) for the drivers, since driving in the certain route without an error would require high ability of steering.

The third paper that is going to be elaborated and explained is **"Modelling human control of steering for the design of advanced driver assistance systems"**. This paper was written by Franck Mars and Philippe Chevre, it was published in the *Annual Reviews in Control* journal, in October, 2017 [5]. This paper offers a general review of scientific studies that can be basis for the researches in the advanced driving assistance systems.

One of the most unique part of Mars's paper is that the visual-motor process of humans are explicitly investigated in the steering control. In Mars's paper, similar to the Schnell's paper, there are anticipation and compensation blocks in the control diagram. However, unlike Schnell's proposed control diagram, the motor control unit of the human nerve system was also modeled in the block diagram of Mars's.

Since this paper is only review of many methodology that was offered before in the recent past, there are no originally proposed methodology or idea in this paper. But it is important to mention that the given block diagram in the section of "A cybernetic driver model of steering control" is an important model of showing an approach to model human drivers' visual-motor process in the mathematical environment accurately.

It is important to notice that, in this mentioned block diagram, similar to the Schnell's paper, time delay was implemented in the model rather than using Pade's approximation. Moreover, this model is more complex comparing to the PD controller based human driver since each process is considered separately in the human side. Since this project reports main scope is investigating more simpler cases for humans in steering maneuvers and comparing them with a non-human controller, rather than adding an anticipation part, a simple derivative term in the PD-controller was considered to be a way of representing the anticipation of human driver. The model can be seen in the figure below.

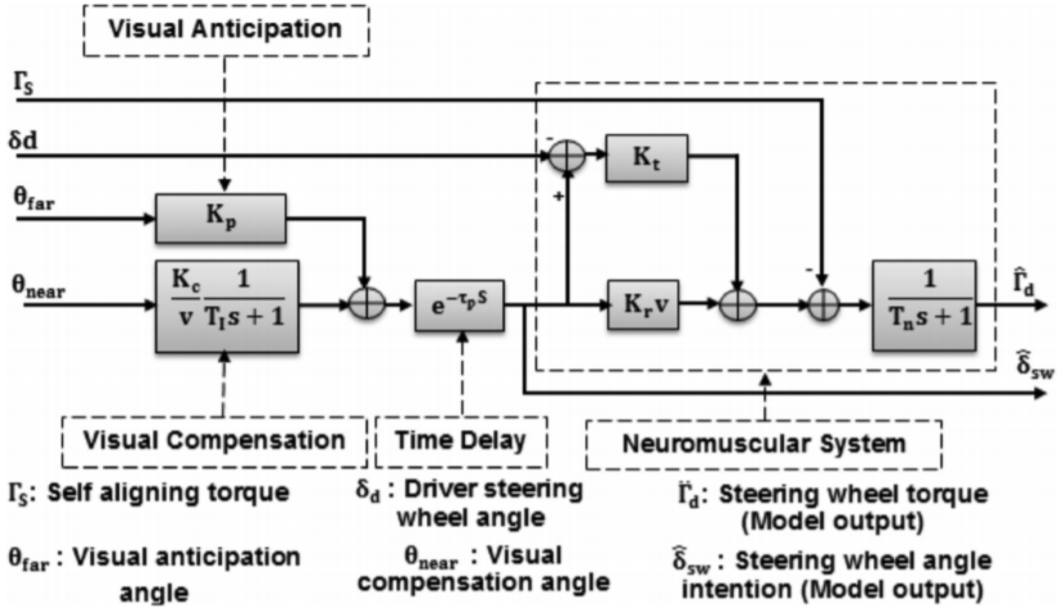

Figure 3: Cybernetic Driver Model [5]

3.2 Non-human Steering Control

As it was mentioned before in the Introduction section, humans have more likelihood of doing errors or having delays compared to machines. Possible errors that can be done in the lateral maneuver action for the vehicles can sometimes lead to severe consequences; thus, taking human out of the equation can sometimes be beneficial to prevent such consequences. Therefore, non-human control methods for such maneuvers should be investigated in the literature in order to create a non-human controller.

The first article that is going to be discussed in this section is "**Nested PID steering control for lane keeping in autonomous vehicles"**. This article was written by Riccardo Marino, Stefano Scalzi, and Mariana Netto in September, 2011. This article was published in the *Control Engineering Practice* journal [6]. In this article, a nested control methodology for controlling vehicle yaw rate and lateral vehicle position by changing steering angle is proposed. The lateral position of the vehicle is used to find the desired yaw rate for the vehicle and current yaw rate is used to find the difference from the desired one, then the second controller decides the steering angle based on this given difference. The uniqueness of this article is that, it provides experiments and full robustness analysis different than what is proposed in the literature.

The following results have been provided in this paper which shows the difference between a human driver versus a controller. It is important to notice that, in the given path following error versus time graph, the error amount that human driver does is much higher than the controller.

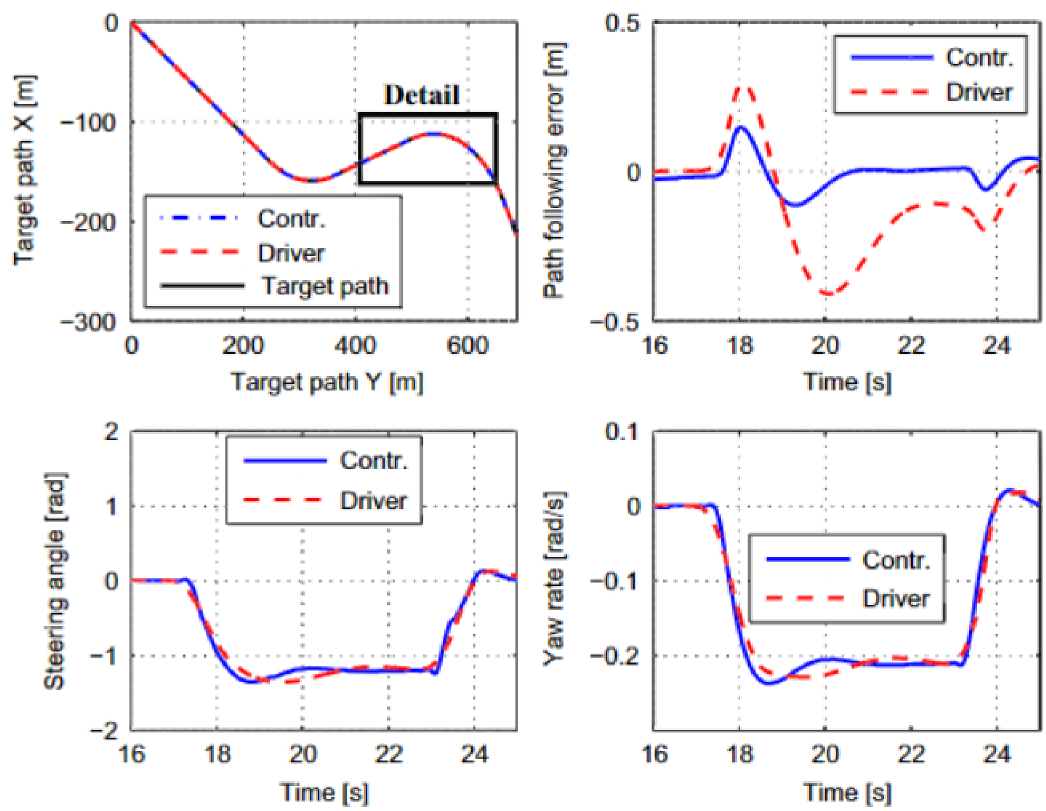

Figure 4: Standard path following maneuver simulated in CarSim with constant lateral speed 30 m/s [6]

In Marino's paper, no human model is proposed for experimentation but instead, the simulation program CarSim is used. Therefore, this is one of the points where Marino's paper differs from this project report. Furthermore, since the main goal of the Marino's paper is to propose a methodology to control lateral maneuver for the vehicles, yaw rate was in the consideration in order to increase the accuracy; however yaw rate is not considered in this project report since the main purpose differs from Marino's paper.

4 Project Work

4.1 Vehicle Dynamics Equations

In order to obtain the lateral vehicle dynamics transfer functions, first state space equations are written such that MATLAB's "ss2tf" function can be used and transfer function can be obtained. Since this project reports main purpose is to show the difference between human controllers and non-human controller, a simple bicycle model with 2-dof model is used to write lateral vehicle dynamics. The following state space equations are written in the format of $\dot{x} = Ax + Bu$:

$$\frac{d}{dt}\begin{bmatrix} y \\ \dot{y} \\ \psi - \psi_d \\ r \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & -\frac{C_{\alpha f}+C_{\alpha r}}{mu_0} & \frac{C_{\alpha f}+C_{\alpha r}}{m} & \frac{-aC_{\alpha f}+bC_{\alpha r}}{mu_0} \\ 0 & 0 & 0 & 1 \\ 0 & \frac{-aC_{\alpha f}+bC_{\alpha r}}{I_z u_0} & \frac{aC_{\alpha f}-bC_{\alpha r}}{I_z} & -\frac{a^2C_{\alpha f}-b^2C_{\alpha r}}{I_z} \end{bmatrix} \begin{bmatrix} y \\ \dot{y} \\ \psi - \psi_d \\ r \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{C_{\alpha f}}{m} \\ 0 \\ \frac{aC_{\alpha f}}{I_z} \end{bmatrix} \delta_f \qquad (1)$$

Also, the following C and D matrices are written for the output equation in the form of $y = Cx + Du$:

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \end{bmatrix}, D = 0 \qquad (2)$$

For this project, the features of the specific car model "Mercedes CLS 63 AMG" are used. In the table below, values that belongs to the CLS 63 AMG model and predetermined values are inserted in the equations below can be seen.

Mass (m)	2220 kg
Length Between Front and Rear Wheels (L)	2.86 m
Length Between Front Wheels and Center of Mass (a)	1.45 m
Length Between Rear Wheels and Center of Mass (b)	1.41 m
I_z	1549.034 $kg.m^2$
Longitudinal Speed (constant) u_0	50 km/h
$C_{\alpha f}$	6.0483e+4 N/rad
$C_{\alpha r}$	4.9759e+4 N/rad

Table 1: Parameters for state-space equations

After inserting the values to the given equations above and using the "ss2tf" tool of the MATLAB the following transfer function for the vehicle is obtained. The related MATLAB script can be found in the **Appendix**.

$$\frac{Y(s)}{\delta(s)} = \frac{1000s^3 + 0.0224s^2 + 0.2541s + 2.5030}{s^5 + 14.027s^4 + 45.586s^3} \tag{3}$$

4.2 Human Modeling

In this project, human models are based on PD-controller. Furthermore, they have been added a delay function provided by Pade's approximation and a certain amount of error. The error is provided via white noise, and it is fully random. For all human types, the constant values in the part of PD controller are the same. The differing value is the reaction time. In the diagram below, a human model that is created in the Simulink environment can be seen.

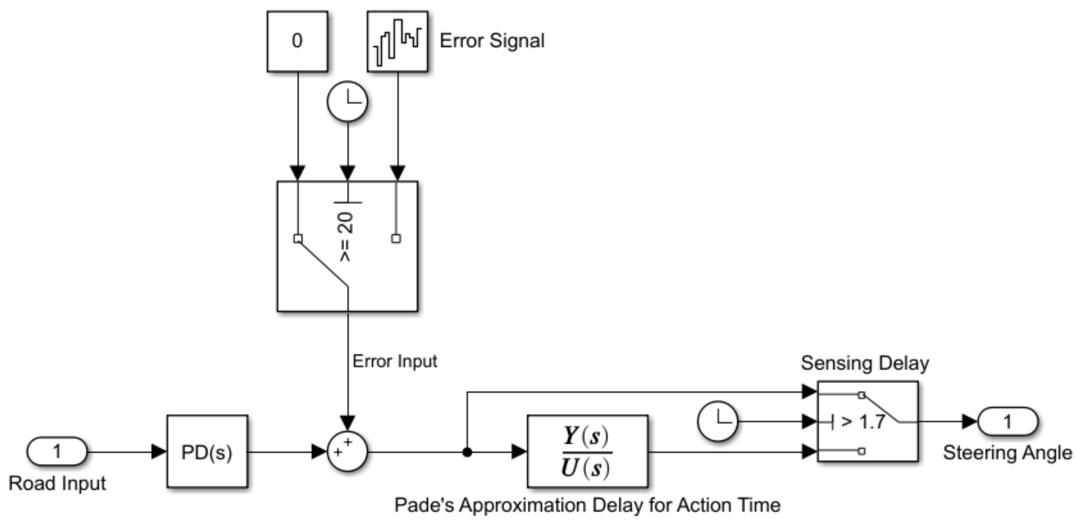

Figure 5: Human Controller Model in Simulink

The error amount is in the order of 1/1000s, which continuously given in the "S" maneuver. Pade's approximation is used to represent physical action delay. For the human type-1, after the first initial input at time t=1s, controller continuously acts late by 0.1 seconds during 0.7 seconds time interval. For the human type-2, this 0.1 second late action continues by 1.2 seconds, and for the human type-3 this late action continues by 1.5 seconds. These time intervals can be related to different reasons. For instance, it can be caused by age, situation type (expected, unexpected, surprise) etc.

4.3 Control System

The following control diagram including controllers and vehicle model with proper road input is created in the Simulink environment.

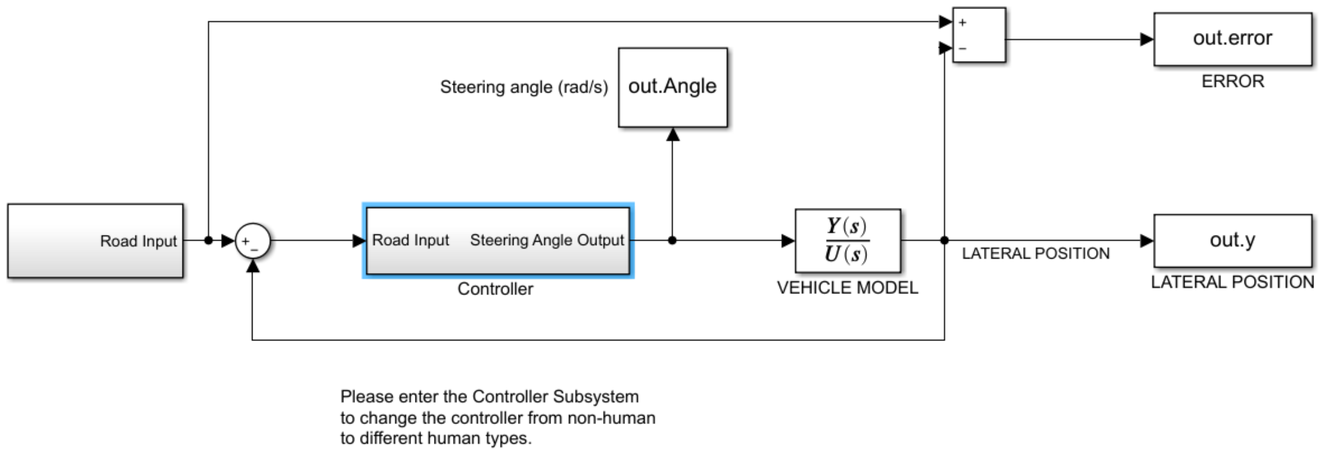

Figure 6: Control Block Diagram of the Project in Simulink

The different type of controllers are in the Controller block. To define the "S" maneuver, road input block is created accordingly. The following figure represents the given road input. Each blocks internal structure and pure road input are given as figures in the **Appendix**.

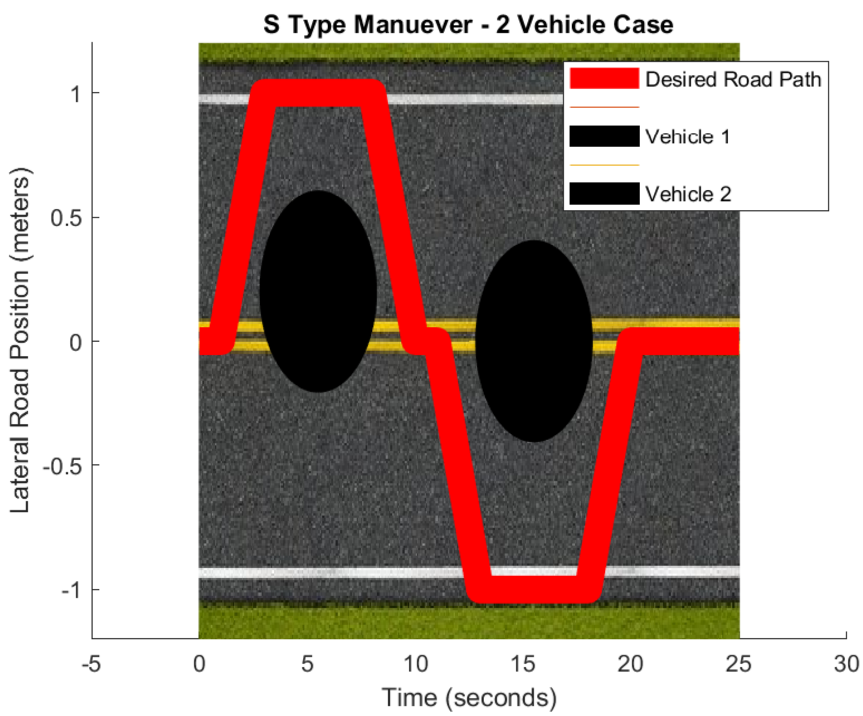

Figure 7: Desired Path Representation on the Road with 2 Vehicles

4.4 Results

The following paths for each human controllers and non human controller are plotted in the figure below. The steering angles plot and the related graph drawing MATLAB script can be found in the **Appendix**.

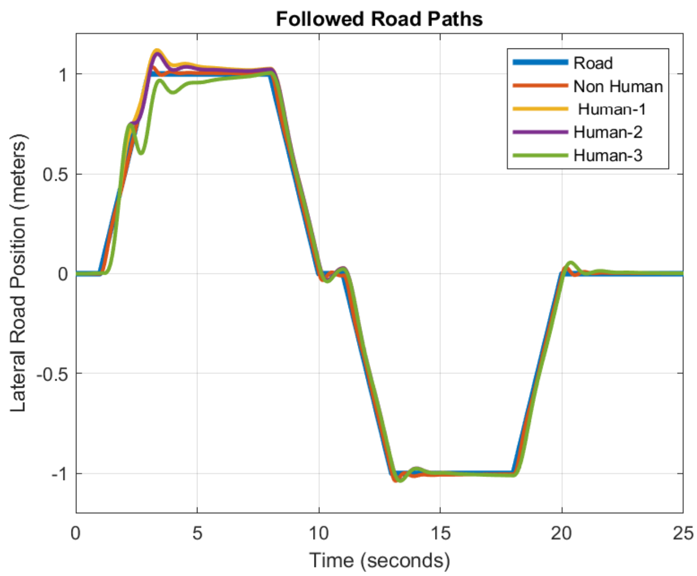

Figure 8: Paths of Each Controller

The errors of the controllers during the maneuver can be seen in the figure below.

Figure 9: Error Amounts

5 Conclusion and Future Work

In this project, the differences between human controllers and a PID controller in the lateral movement case, specifically in the "S" maneuver, is investigated. It has shown in the previous section that, as the delay time, caused by humans, increases, the error and deviation from the desired path also increases and also the non-human controller does the least amount of error. Furthermore, related total deviation amount table for each controller can be found in the **Appendix**.

Since the best working controller according to the given results, if the automotive companies can provide the desired (or optimal) with the help of the navigation and related sensors, a PID controller is capable to do such maneuvers with fewer errors than humans. But in the scenarios where this kind of information can not provided to the vehicle, the second best option that a vehicle can do for its driver is to increase the drivers attention as much as possible to decrease the delay time or the distraction time interval, since it is shown that if the distraction time interval expands, the error amount also increases. The other option is the train of the drivers with the methodology that was mentioned in the Literature Research section. So that the drivers action time decreases as well as their error randomness will also decrease. However, according to my opinion, this task is more difficult than the other two options that are mentioned above.

This work can be continued by increasing the complexity and accuracy of the human model. If the accuracy of the human model can reach at the level where it can totally represents human behaviors for different types of humans, then the obtained results can represent the reality with much higher accuracy. Furthermore, the vehicle model complexity can be increased and rather than considering 2-dof model bicycle model, a real vehicle model with higher dof with provided sophisticated equations can increase the accuracy of the simulation and the results.

6 Appendices

A Extra Graphs

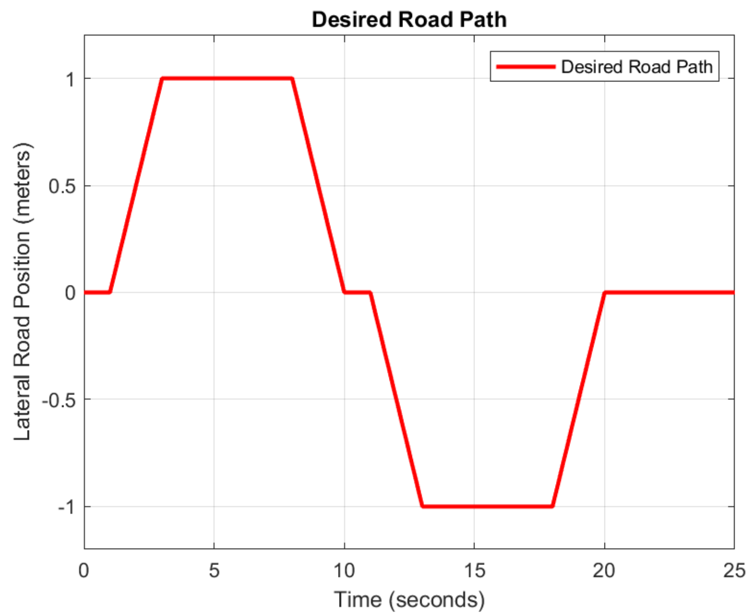

Figure 10: Pure Road Input

Figure 11: Steering Angles

B Simulink Block Structures

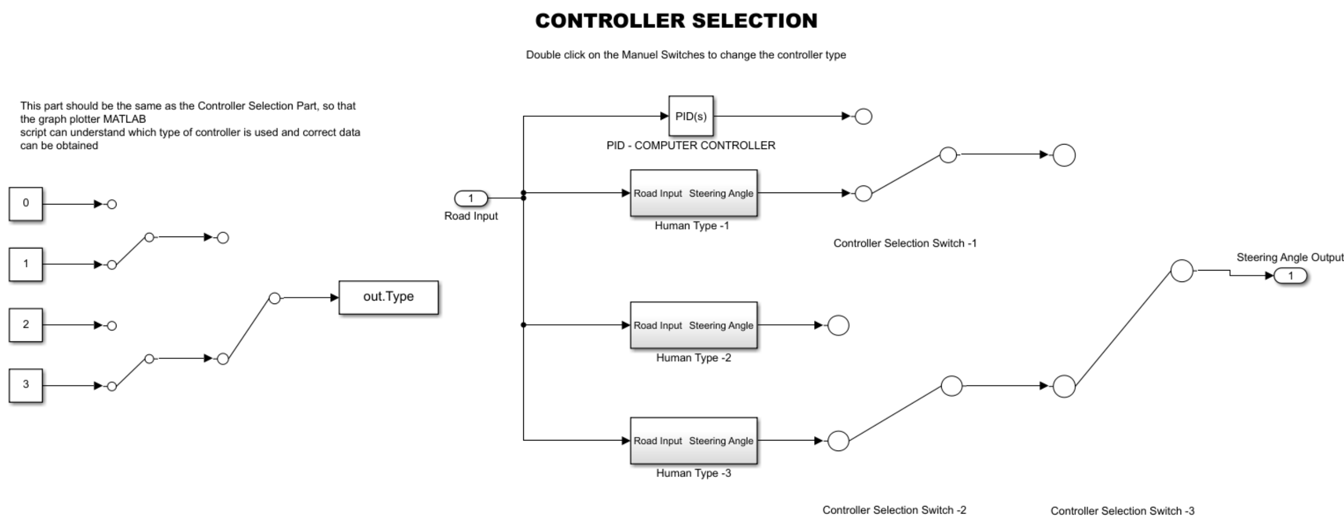

Figure 12: Controller Block

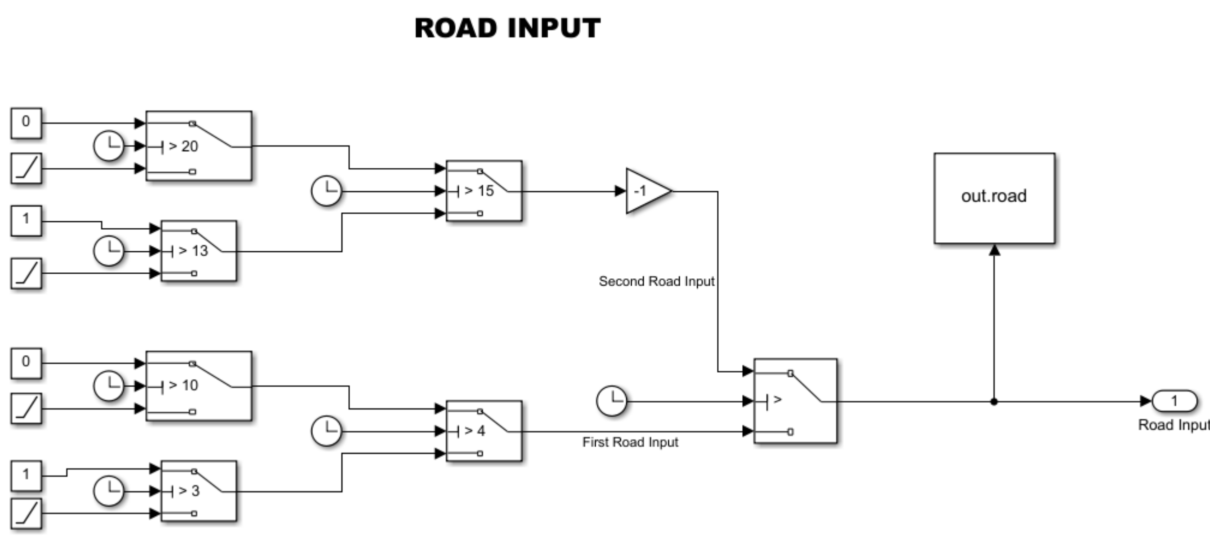

Figure 13: Road Input Block

C Total Deviation from Desired Path Table

Total Error of Non-human Controller	6.947m
Total Error of Human-1	27.295m
Total Error of Human-2	26.2179m
Total Error of Human-3	32.0245m

Table 2: Total Amount of Deviation (Error) from Desired Path

D Transfer Function Creation MATLAB Script

```
% Ahmet Selim Canakci
%31/12/2020
%Transfer Function Creation Script
%Run this script before running simulink model.

clear;
clc;
%Mercedes CLS 63 AMG Car Features
a = 1.45; % distance between front tires and the center of mass of the vehicle in meters
b=  1.41; % distance between rear tires and the center of mass of the vehicle in meters
total_length=  a+b;
total_mass = 2220; %kg
m= total_mass;
Iz = 1549.034; %kg.m^2

% Predetermined Longitudunal and Vertical Speed of the Car
u_kmh = 50; %km/h
u0 = u_kmh /3.6; %m/s
%Calculation of the Car and Caf
Car = 6.048305201853278e+04;
Caf = 4.975910662517592e+04;



%state space model
```

```
Yb=-(Caf+Car); Yr=(Car*b/u0)-(Caf*a/u0); Yd= Caf;
Nb=b*Car-a*Caf; Nd= a*Caf;
Nr=-(a^2/u0)*Caf - (b^2/u0)*Car;
A=[0 1 u0 0;
0 Yb/m/u0 0 Yr/m-u0;
0 0 0 1;
0 Nb/Iz/u0 0 Nr/Iz];
B=[0;Yd/m;0;Nd/Iz];
C=[1 0 0 0]; D=0;
[num,Gvden]=ss2tf(A,B,C,D,1);
Gvnum=num(3:5);


%pade's approximate delay function for physical reaction(body movement
%time) = 0.2 Seconds
[exp_nump,exp_denp] = pade(0.2,3); %A 3rd order transfer function is produced
```

E Graph Plotter MATLAB Script

```
% Ahmet Selim Canakci
%31/12/2020
%Graph Plot Script
%In order to work this script correctly, all four cases
%(non-human,human1,human2,human3)should be run in the Simulink model and
%run this script after each run of the Simulink model. Otherwise it won
%create necessary variables and won't show the graphs
close all;

c1 = circle(5.5,0.2,2.7);
c2 = circle(15.5,-0.,2.7);
x1 = c1(1,:);
y1 = c1(2,:);
x2 = c2(1,:);
y2 = c2(2,:);
road = out.road.Data;
y = out.y.Data;
```

```
time = out.tout;
type = out.Type.Data;
yl= [-1.2, 1.2];

if(type(1)==0)
non_human = y;
non_human_time = out.tout;
non_human_error = out.error.Data;
non_human_angle= out.Angle.Data;
elseif (type(1)==1)
human_1 = y;
human_1_time = out.tout;
human_1_error = out.error.Data;
human_1_angle = out.Angle.Data;
elseif (type(1)==2)
human_2 = y;
human_2_time = out.tout;
human_2_error = out.error.Data;
human_2_angle = out.Angle.Data;
else
human_3 = y;
human_3_time = out.tout;
human_3_error = out.error.Data;
human_3_angle = out.Angle.Data;
end

%Road Path Graph
if(exist('non_human','var')&& exist('human_1','var')&& exist('human_2','var')&& exist('h
road_plot = figure();
p=plot(time,road,'r');
p.LineWidth = 2;
ylim(yl);
grid on;
xlabel("Time (seconds)");
ylabel("Lateral Road Position (meters)");
title("Desired Road Path")
```

```
legend("Desired Road Path");
end

%Road Path Graph
if(exist('non_human','var')&& exist('human_1','var')&& exist('human_2','var')&& exist('h
road_plot_real = figure();
img = imread('img.jpg');
image('CData',img,'XData',[0 25],'YData',[-1.5 1.5]);
hold on
p=plot(time,road,'r');
p.LineWidth = 12;
hold on
p2=plot(x1,y1);
p2.LineWidth=0.1;
fill(x1,y1,'k');
hold on
p3=plot(x2,y2);
p3.LineWidth=0.1;
fill(x2,y2,'k');
ylim(yl);
xlabel("Time (seconds)");
ylabel("Lateral Road Position (meters)");
title("S Type Manuever - 2 Vehicle Case")
legend("Desired Road Path","","Vehicle 1","","Vehicle 2");
end

if(exist('non_human','var')&& exist('human_1','var')&& exist('human_2','var')&& exist('h
drivers= figure();
r = plot(time,road);
r.LineWidth = 3;
hold on
nh = plot(non_human_time,non_human);
nh.LineWidth = 2;
hold on
h1 = plot(human_1_time,human_1);
h1.LineWidth = 2;
```

```
hold on
h2 = plot(human_2_time,human_2);
h2.LineWidth = 2;
hold on
h3 = plot(human_3_time,human_3);
h3.LineWidth = 2;
ylim(yl);
xlabel("Time (seconds)");
ylabel("Lateral Road Position (meters)");
title("Followed Road Paths")
grid on
legend ("Road","Non Human"," Human-1" , "Human-2" , "Human-3");
end

if(exist('non_human','var')&& exist('human_1','var')&& exist('human_2','var')&& exist('h
error= figure();
nh = plot(non_human_time,non_human_error);
nh.LineWidth = 2;
hold on
h1 = plot(human_1_time,human_1_error);
h1.LineWidth = 2;
hold on
h2 = plot(human_2_time,human_2_error);
h2.LineWidth = 2;
hold on
h3 = plot(human_3_time,human_3_error);
h3.LineWidth = 2;
ylim([-0.5 0.5]);
xlabel("Time (seconds)");
ylabel("Deviation from Desired Path (meters)");
title("Error Amount for the Drivers")
grid on
legend ("Non Human"," Human-1" , "Human-2" , "Human-3");


angle= figure();
```

```
nh = plot(non_human_time,non_human_angle);
nh.LineWidth = 2;
hold on
h1 = plot(human_1_time,human_1_angle);
h1.LineWidth = 2;
hold on
h2 = plot(human_2_time,human_2_angle);
h2.LineWidth = 2;
hold on
h3 = plot(human_3_time,human_3_angle);
h3.LineWidth = 2;
ylim([-0.5 0.5]);
xlabel("Time (seconds)");
ylabel("Steering Angles (rad)");
title("Steering Angles in the Maneuver")
grid on
legend ("Non Human"," Human-1" , "Human-2" , "Human-3");



total_non_human_e= sum(abs(non_human_error));
total_human_1_e = sum(abs(human_1_error));
total_human_2_e = sum(abs(human_2_error));
total_human_3_e = sum(abs(human_3_error));

end
try
saveas(road_plot,"road.png");
saveas(road_plot_real,"road2.png");
saveas(drivers,"drivers.png");
saveas(error,"error.png");
saveas(angle,"angle.png");

disp("Total Error of Non-human Controller "+total_non_human_e+"m");
disp("Total Error of Human-1 "+total_human_1_e+"m");
disp("Total Error of Human-2 "+total_human_2_e+"m");
```

```
disp("Total Error of Human-3 "+total_human_3_e+"m");
catch
end

function c = circle(x,y,r)
th = 0:pi/50:2*pi;
x_circle = r * cos(th) + x;
y_circle = 0.15*r * sin(th) + y;
c = [x_circle;y_circle];
end
```

7 References

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