5.
Vehicle Control: Fuzzy Driver

Fuzzy Logic is a computational intelligence technique that aims to reproduce human actions that can be expressed in linguistic form.

In this paper, a Fuzzy Controller is designed to emulate a human driver controlling a car through a known trajectory. The implementation of such controller makes use of the Fuzzy Toolbox of MatLab®. It is tested in Simulink®, applied to the vehicle model previously described in section 2.2.

5.1. Presentation and Description

The first challenge when designing a fuzzy controller is to understand the several phases involved in a human control of a vehicle: path recognition, decision and muscular response. A model of the procedure is shown in Figure 5.1 and detailed below.

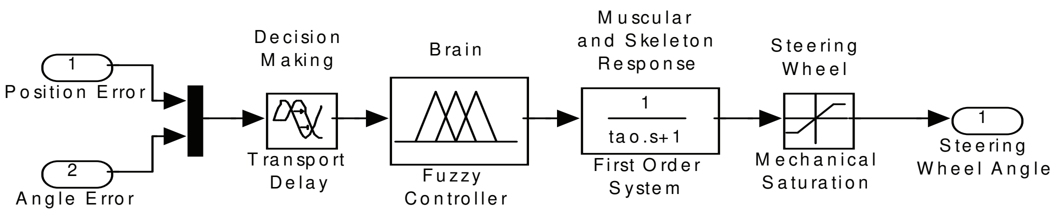

Figure 5.1 – Simulink Block Diagram: Detailed Fuzzy Driver.

Initially, the human body collects relevant information from the environment, which in this case is simplified by the car position and orientation errors related to the desired path. These errors, as explained in Chapter 3, represent the driver's eyes. Actually, a driver collects information not only through his eyes, but also by feeling the car's accelerations or by hearing the engine response to his actions. These perceptions go beyond the task of controlling the car and are not in the scope of this paper.

Second, the human brain decides what action to take, regarding the information collected and the driver's previous knowledge of the car behavior. The more experienced the driver , the quicker his decision. It is very relevant to the model to enable the calibration of the driver's proficiency. The variable that controls this “speed of thought” is γ, which is the gain of a Transport Delay block in Figure 5.1.

The decision itself is modeled here by the Fuzzy Inference System, which, from the mentioned inputs and a set of rules, defines the desired Steering Wheel Angle, δ. The brain tells the muscles what the desired Steering Wheel Angle should be. The action taken makes the steering wheel suddenly assume the chosen angle. As seen in Figure 5.1, a First Order System is used to model the muscular movement, and its time constant τ defines how fast the driver´s reactions are.

To complete the modeling, a saturation block is placed just before the output to represent the steering wheel mechanical limitation. This block could also be placed inside the vehicle model together with the entire Steering System model.

Some of the mechanical limitations are intrinsic to the driver, since it is impossible for human arms to turn the steering wheel freely. In the case of a racing car – especially considering the speeds achieved – it is never safe to let the steering wheel turn more than once. Thus, the limits are symmetrical and defined by the variable α_{Max} (Mechanical Saturation block in Figure 5.1).

As mentioned before, the Fuzzy Inference System (FIS) mimes the human strategy and maps a given input to an output. The FIS is used here for modeling the driver’s decision ability, based on the inputs and on a predefined set of rules.

All the properties and methods that define the designed Mamdani-type FIS are explained in this section. The structure of the developed FIS, called FIStraj, can be seen in Figure 5.2. The number of fuzzy sets is shown in Figure 5.2.

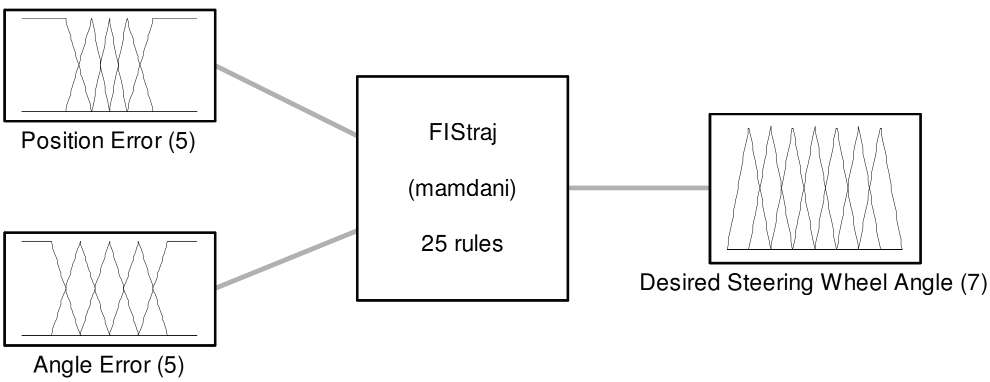

Figure 5.2 – Designed FIS Structure.

Each fuzzy set is defined by a Membership Function (MF). Figure 5.3 shows the Position Error MFs. Note that the Position Error is parameterized by l_w – which represents the lane width of any track – and that the closest MFs to the target point have shorter supports in order to achieve better convergence.

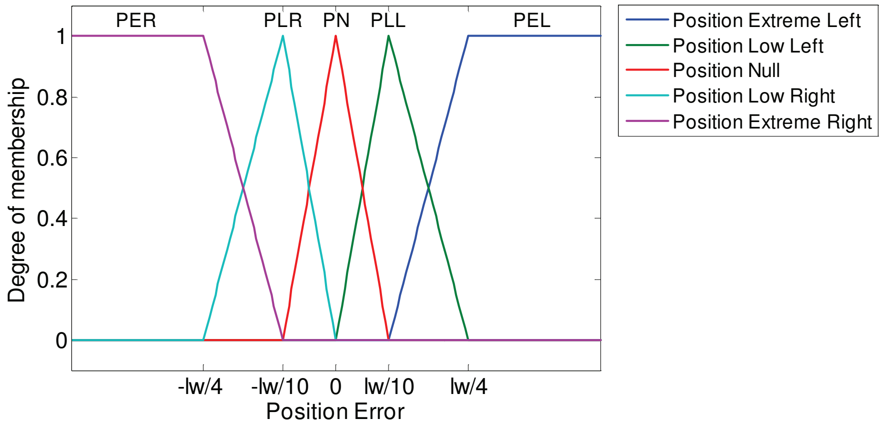

Figure 5.3 – Membership Functions: Position Error.

Figure 5.4 and Figure 5.5 show the MFs for Angle Error and Steering Wheel Angle respectively.

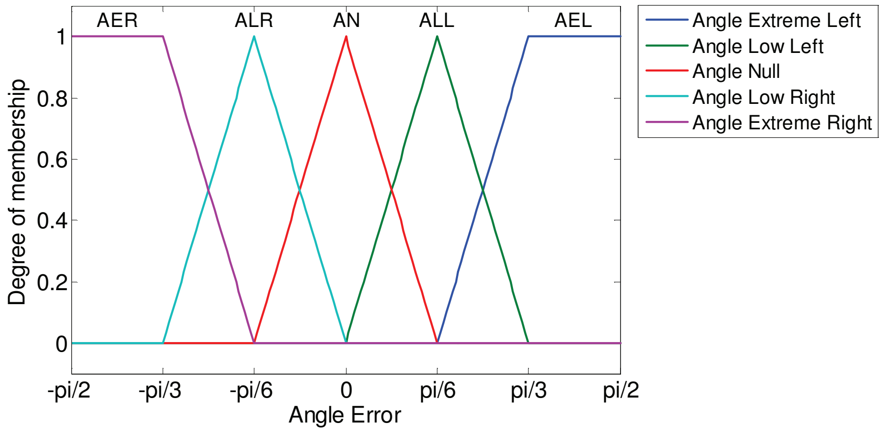

Figure 5.4 – Membership Functions: Angle Error.

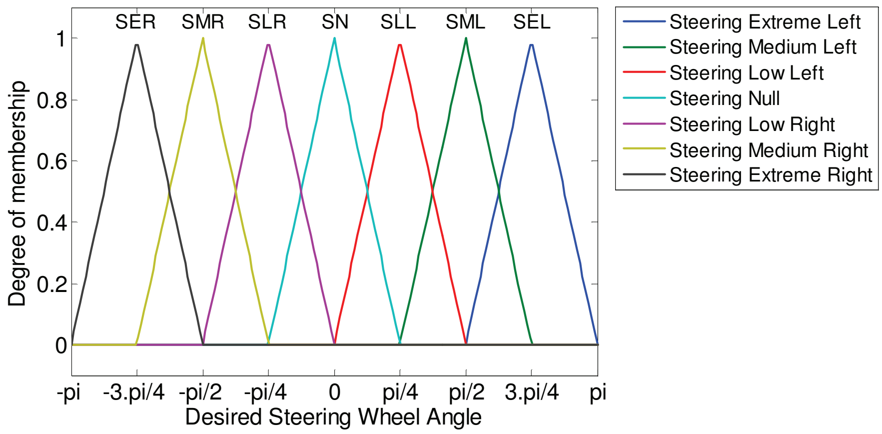

Figure 5.5 – Membership Functions: Desired Steering Wheel Angle.

The next step in the implementation is the definition of the Fuzzy Rules. They can be set by an expert or generated from numerical data.

The rules obtained from experienced drivers are represented in a matrix form as shown in Table 1. The colors correspond to each fuzzy set defined in Figure 5.3, Figure 5.4 and Figure 5.5.

Table 5.1 – Matrix Structure with the Fuzzy Rules.

Position Error / Angle Error	**Extreme Left**	**Low Left**	**Null**	**Low Right**	**Extreme Right**
Extreme Left	Steering Extreme Right	Steering Extreme Right	Steering Medium Right	Steering Low Right	Steering Null
Low Left	Steering Extreme Right	Steering Medium Right	Steering Low Right	Steering Null	Steering Low Left
Null	Steering Medium Right	Steering Low Right	Steering Null	Steering Low Left	Steering Medium Left
Low Right	Steering Low Right	Steering Null	Steering Low Left	Steering Medium Left	Steering Extreme Left
Extreme Right	Steering Null	Steering Low Left	Steering Medium Left	Steering Extreme Left	Steering Extreme Left

Finally, to complete the FIS definition, Table 5.2 shows the operators used for conjunction, disjunction, aggregation and implication, as well as the defuzzification method.

Table 5.2 – Relation of Methods Used in FIS

Operation	CONJUNCTION	DISJUNCTION	IMPLICATION	AGGREGATION	DEFFUZIFICATION
Method	min	max	min	max	centroid

For a better understanding of the implemented Fuzzy Inference System, a simple example is solved step by step. First the position and orientation of the car on the defined track are analyzed. In Chapter 3, two different methods for error analysis have been detailed. Figure 5.6 illustrates the car condition for this example. It also shows how the error values, in red, can be determined by the Present-based Error method.

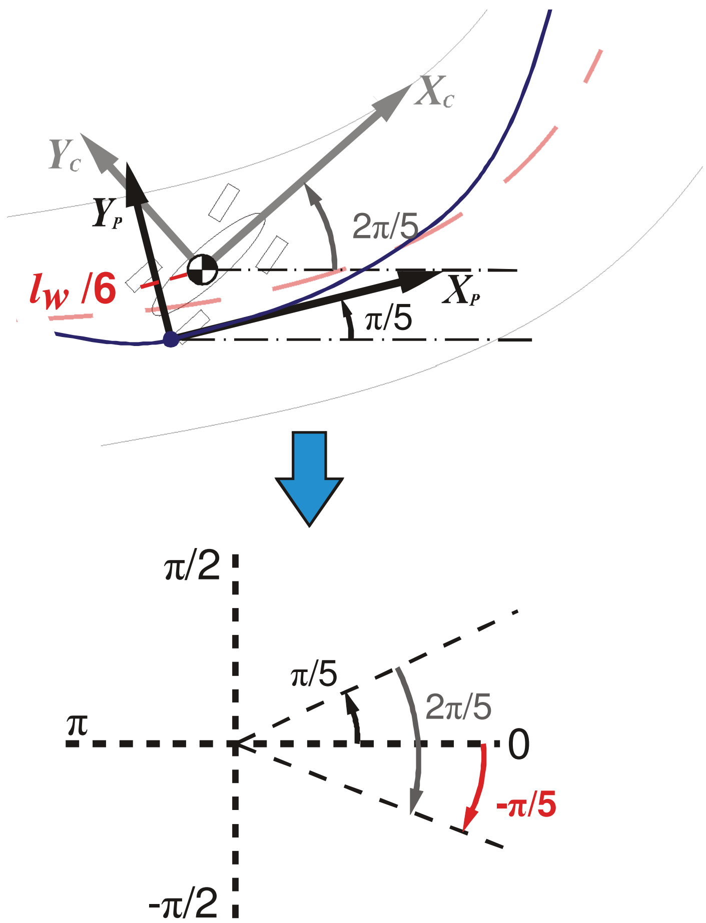

Figure 5.6 – FIS Example: Analysis of Position and Orientation of the Vehicle

The fuzzy inputs are the Position and Angle Error values, $l_w/6$ and $-\pi/5$ respectively. Figure 5.7 shows the Membership Functions for two of the activated rules.

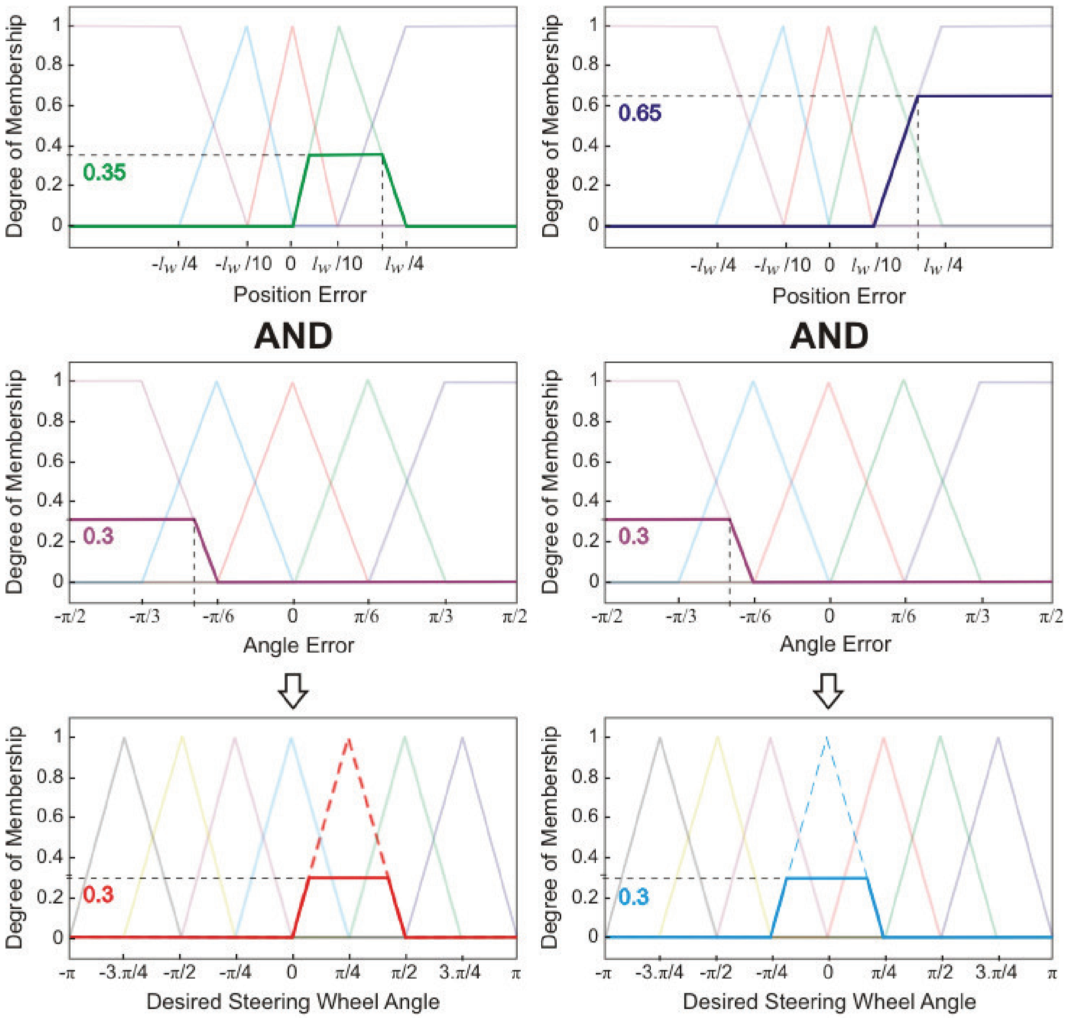

Figure 5.7 - FIS Procedure Example: 1st and 2nd Activated Rules.

The output MF is determined by the Fuzzy Rules shown in Table 5.1. The conjunction (AND) operator, in this case the minimum, defines a cutoff level. The output set final shape is generated by the application of the implication operator – also the minimum. Figure 5.8 shows the same procedure for another two activated rules.

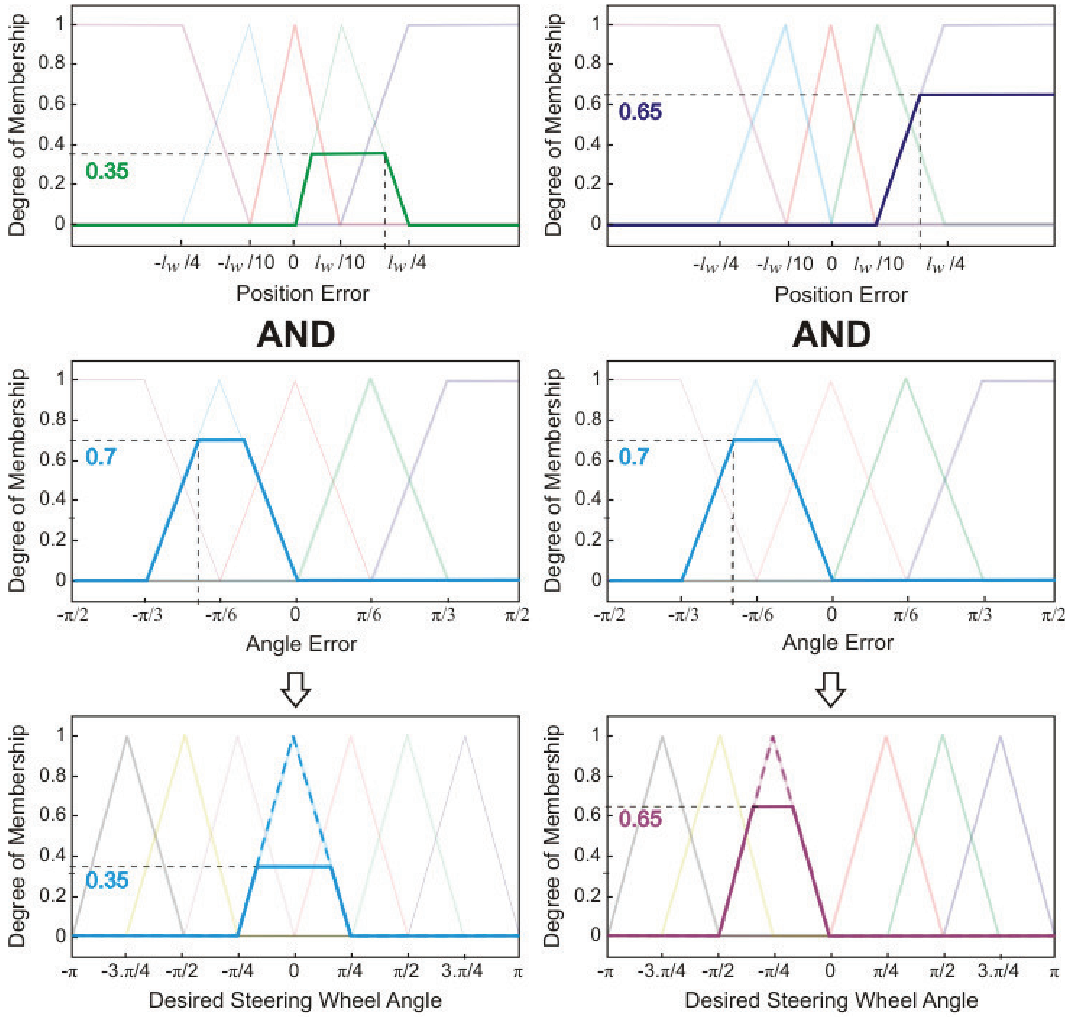

Figure 5.8 - FIS Procedure Example: 3rd and 4th Activated Rules.

The output fuzzy set is obtained by the aggregation (maximum operator) of all the output fuzzy sets. Figure 5.9 shows this operation and also the defuzzification – centroid – which finally determines the desired Steering Wheel Angle of -π/8 radians. This is illustrated by the steering wheel position shown in Figure 5.10.

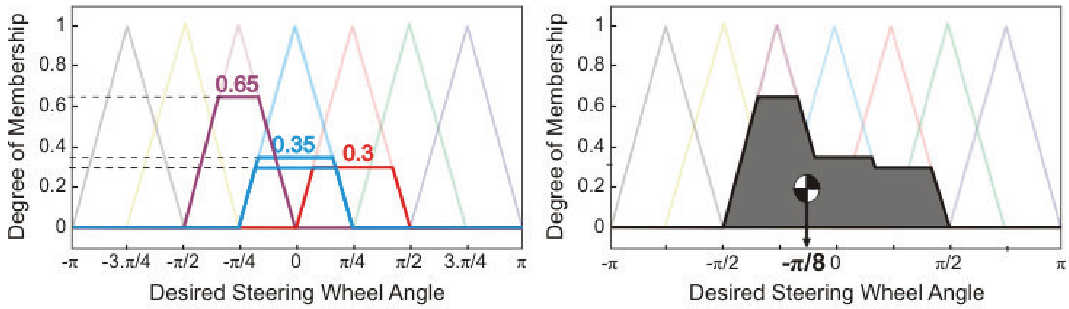

Figure 5.9 - FIS Example: Crisp Output Determination.

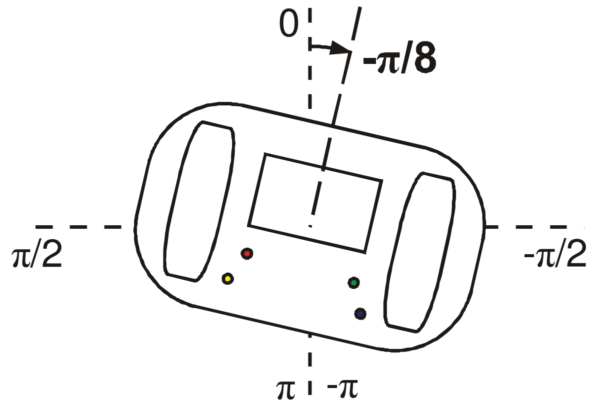

Figure 5.10 - FIS Example: Desired Steering Wheel Angle

5.2. Validation Tests

Testing separately the small parts of a developed model is very important for minimizing debugging in a complete and much more complex model. It is a worthwhile effort not only to assure the proper functionality of the model, but also to evaluate and treat some singularity conditions that the model may present.

Following the presented methodology, the FIS tests were implemented modularly in the Simulink® environment. Figure 5.11 shows the Fuzzy Driver block inserted in the testing scenario.

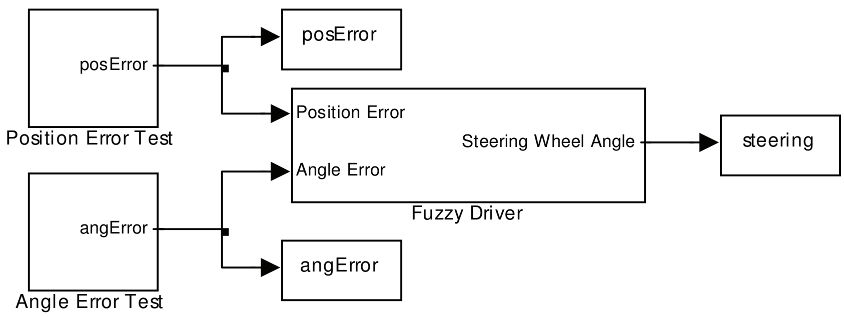

Figure 5.11 - Simulink Block Diagram Used in the FIS Tests.

In order to validate the developed FIS, a sinusoidal function is applied to the two inputs, as shown in Figure 5.12. The result is also shown in the same figure.

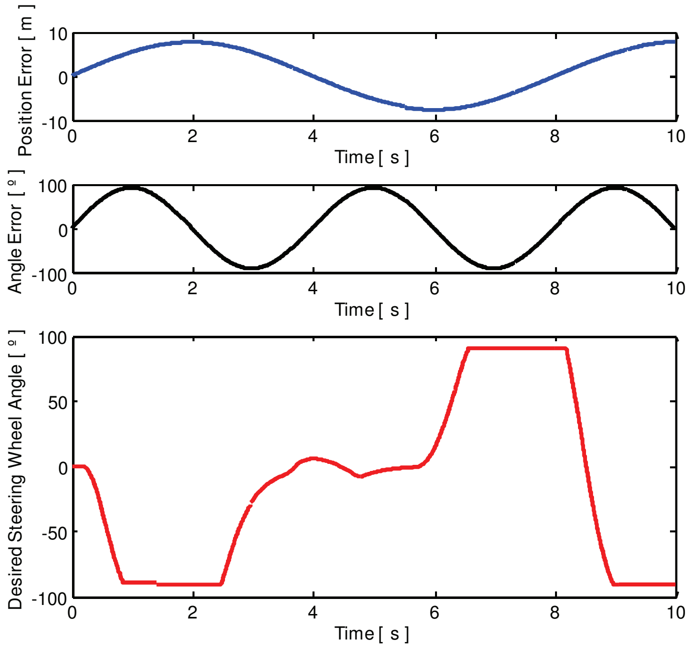

Figure 5.12 – FIS 1st Validation Test: Inputs and Output.

In the first two seconds of the simulation, and also on the last four, the vehicle is far from the desired path and facing the opposite direction. Such situation is corrected by an aggressive turn on the steering wheel. Another relevant aspect is how the saturation limits affect the obtained Steering Wheel Angle.

From the third second of the simulation and during the next three, the output displays a small variation around zero. That behavior is also expected, because if the car is away from the desired trajectory but already moving towards it, the Position Error will automatically decay with time.

To assess the effect of the transport delay and the first order transfer function, which should model the driver's efficiency, γ and τ are changed for the same inputs. Figure 5.13 shows the Drivers Comparison performed in the second test.

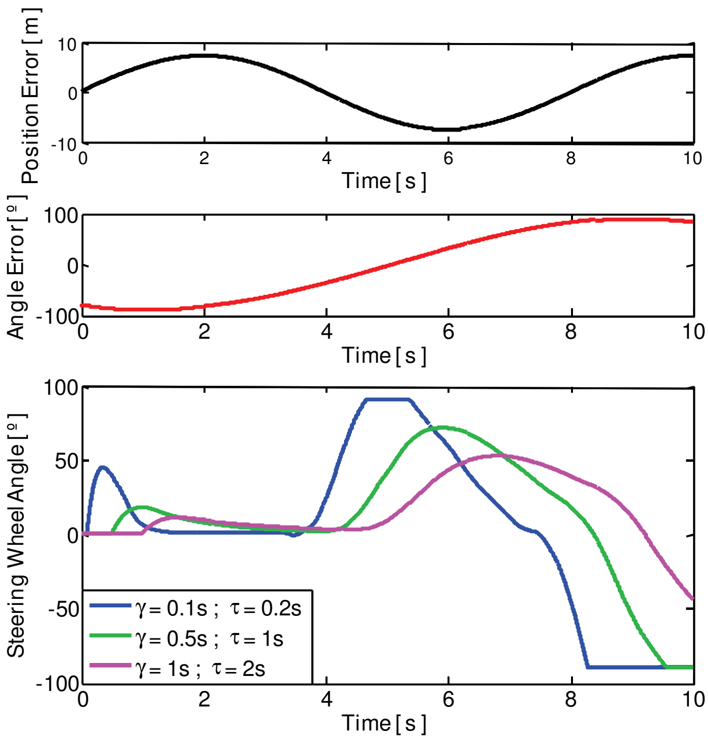

Figure 5.13 - FIS 2nd Validation Test: Driver Comparison.

As the legend shows, the blue line represents the Steering Wheel Angle for the faster driver and the pink line shows the direction controls for the slower one. The later starting point of the pink driver is due to the higher transport delay. As for lower amplitude, when the control manages to achieve that amplitude, it has already been affected by other input values that can pull the steering wheel in an opposite direction.

With a perfect calibration, this controller is able to represent several kinds of human driving styles thus enabling different studies.