Fuzzy Logic Approach to Autonomous Car Parking Using MATLAB

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Abstract.- This paper discusses a system that parks automatically an automobile given certain conditions and making decisions based in fuzzy logic. It proposes three models in cascade in order to achieve a "Decision-Action" approach, so that the car in question doesn't need an operator.

1. Overview

Car parking has been always a simple problem for a mid skilled driver to master. Usually just using sight to measure, pressing the gas pedal and turning the wheel is all that is needed. As such it could be said that an automatic system designed for this task wouldn't be difficult, but this is definitely not the case. The main problem lies within the fact that the human brain can extrapolate many more considerations when facing a problem as this, thus making as few as three variables mentioned above, the source of a lot of data.

Usually, a classic approach system designed to do such a task could be very complicated, since obtaining a model for it is difficult and also time consuming. Considering this, fuzzy logic is a much better approach to the problem, because it gives enough flexibility and capability for the design of the system

The objective is to create a system that is capable of parking a car in a horizontal line, in which car spacing can be of any size, thus making the system capable of determining what to do in each case.

2. Introduction

For a car to park on a site, many considerations have to be made. The first and foremost is the space available to park in relation to the size of the car, because this is what determines how is the parking going to be executed, or if it can even be done. Another important matter is the relative distances to the sidewalk, and other obstacles (like other cars), since these distances are the reference to the correct initial position for parking.

The problem then will be based on the aforementioned constraints, and the final execution should be able to park within any parking space, or car size (Figure 1).

Since a human driver usually doesn't have an exact measure for any of the mentioned variables, but uses approximations based on experience, fuzzy logic can then help to make a linguistic model that closely resembles the behavior of an actual human doing the same action.

For this model, only a few variables will be considered: Relative position (distance) to possible obstacles (another car, a wall), distance to the sidewalk, wheel position and speed. From these, car position and inclination will be extrapolated. The fuzzy approach will then be based on expert knowledge.

Since each part of the parking process is different, many cascaded models will be used. For instance, one model will be responsible to decide if parking is feasible or not, another model will execute a frontal parking, etc. The parking case is in-line parking, no parallel parking is modeled.

This model will assume that the driver already placed the car as close to the parking log as they could without having tried to park it. Figure 2 shows the appropriate position that the model will take as a beginning point:

3. Fuzzy model

The usual parking procedure could be generalized by the available parking space. In function of the space available tree action can be decided:

1. - Space is large; driver can make a forward parking.
2. - Space is enough; driver can make a backward parking.
3. - Space is not enough; driver cannot park in this spot.

The first evaluated variable is then available parking space. In order to do any parking procedure, it is important to locate the car in the appropriate spot. In the case of forward parking, the position is related to the car behind the spot. Backward parking has this position related to the car in front. Since the procedure needs the initial position to be correct for any case, then the first model could also correct this. The first model will then, not only decide if parking can be made, but also accommodate the car in the necessary position, so the following variables were used in order to achieve this:

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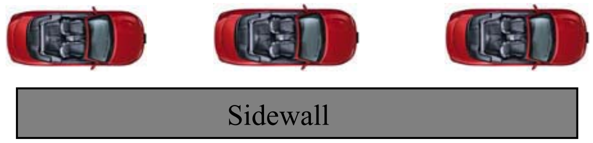

Figure1. Parking case

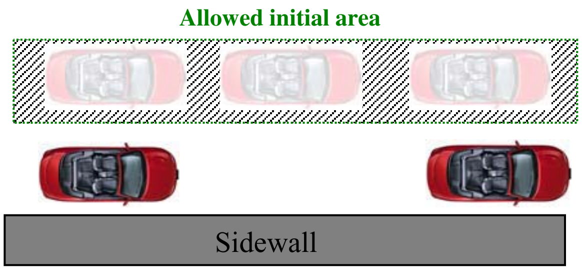

Figure 2. Allowed initial positions

1. - Relative position to car behind.
2. - Relative position to car in front.
3. - Space available between cars.

The output variables, since this model also decides what the next procedure will be, involve the parking procedure for the other models to activate their function, and commute the models by the case involved. The variables list is then:

1. - Direction of car.
2. - Speed of car.
3. - Parking procedure.

These variables are them separated as fuzzy sets. These sets were taken based on the knowledge of a group of common drivers. These can be observed on figures 3 to 7 for the input variables and 8 to 11 for the output variables. One more variable was added as a control flag in order to cascade the fuzzy control systems correctly, and announces the end of the decision and positioning procedure. This variable along with the procedure variable are used to maintain this first controller quiet when another controller is doing its procedure.

Once these variables were set up the cases were reviewed in terms of these, and then obtained the necessary rules. Since our objective was to maintain the system as simple as possible, some cases were trimmed down in order to avoid rule inconsistency. The chosen rules are the following:

R1: If (PR2 is Atrasado) and (S1-2 is Insuficiente) and (Terminado is NO) then (Volante is Centro)(Direccion is Adelante)(Decision is NO)(Terminado is NO)

R2: If (PR2 is Adelantado) and (S1-2 is Insuficiente) and (Terminado is NO) then (Volante is Centro)(Direccion is Atras)(Decision is NO)(Terminado is Si)

R3: If (PR2 is Atrasado) and (S1-2 is Suficiente) and (Terminado is NO) then (Volante is Centro)(Direccion is Adelante)(Decision is Cola)(Terminado is NO)

R4: If (PR2 is Posicion) and (S1-2 is Suficiente) and (Terminado is NO) then (Volante is Centro)(Direccion is Alto)(Decision is Cola)(Terminado is Si)

R5: If (PR2 is Adelantado) and (S1-2 is Suficiente) and (Terminado is NO) then (Volante is Centro)(Direccion is Atras)(Decision is Cola)(Terminado is NO)

R6: If (PR2 is Atrasado) and (S1-2 is Amplio) and (Terminado is NO) then (Volante is Centro)(Direccion is Adelante)(Decision is frente)(Terminado is NO)

R7: If (PR2 is Posicion) and (S1-2 is Amplio) and (Terminado is NO) then (Volante is Centro)(Direccion is Alto)(Decision is Frente)(Terminado is Si)

R8: If (PR2 is Adelantado) and (S1-2 is Amplio) and (Terminado is NO) then (Volante is Centro)(Direccion is Atras)(Decision is frente)(Terminado is No)

R9: If (PR2 is Posicion) and (S1-2 is Insuficiente) and (Terminado is NO) then (Volante is Centro)(Direccion is Alto)(Decision is NO)(Terminado is Si)

R10: If (Terminado is SI) and (Decision is NO) then (Volante is Centro)(Direccion is Alto)(Decision is NO)(Terminado is Si)

R11: If (Terminado is SI) and (Decision is Frente) then (Volante is Centro)(Direccion is Alto)(Decision is Frente)(Terminado is Si)

R12: If (Terminado is SI) and (Decision is Cola) then (Volante is Centro)(Direccion is Alto)(Decision is Cola)(Terminado is Si)

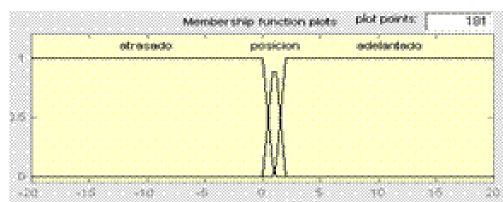

Figure 3 Fuzzy Sets for input "Relative position with car behind

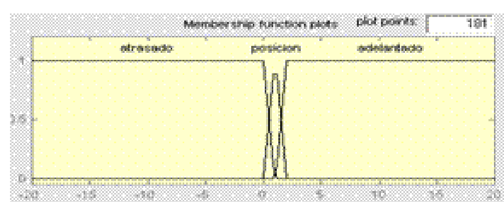

Figure 4 Fuzzy Sets for input "Relative position con car in front"

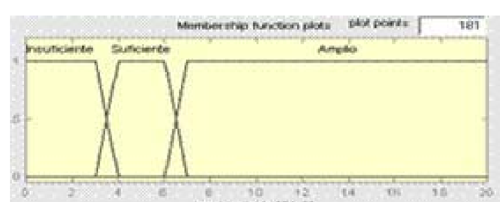

Figure 5 Fuzzy Sets for input "Distance between cars"

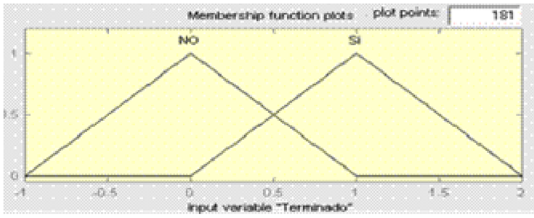

Figure 6 Fuzzy Sets for input “Terminado” or “finished” (placed as a control flag”

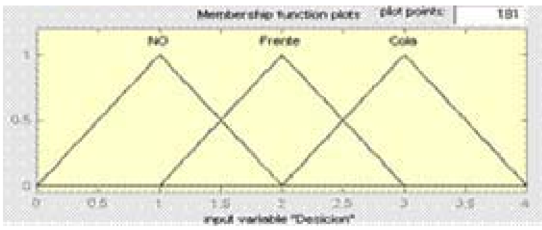

Figure 7 Fuzzy Sets for input “Decision”

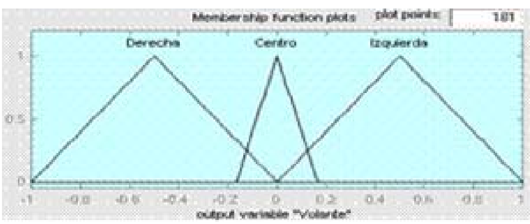

Figure 8:Fuzzy Sets for output “Volante” or “Car Direction”

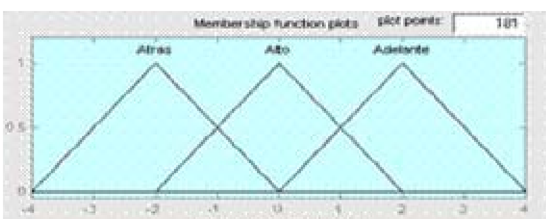

Figure 9 Fuzzy Sets for output “Direccion” or “Car Speed”

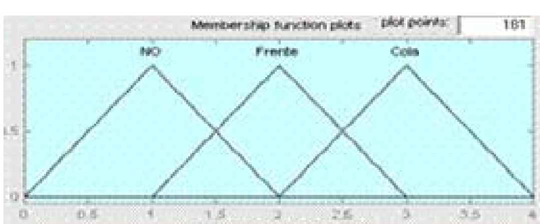

Figure10 Fuzzy Sets for output “Decision”

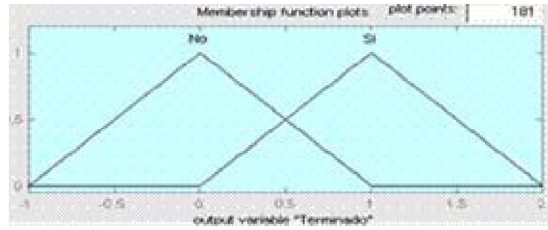

Figure 11 Fuzzy Sets for output “Terminado” or “Finished”

These rules might not be enough to cover all cases, but proved to be enough to handle the most common situations. In order to avoid interference from this procedure with the operation of other procedures, once position and decision operations are done, outputs are put on neutral position so they don’t add up on the response of the other systems.

3.2. Frontal parking procedure

The front parking procedure will only be done when space between cars is wide enough. This procedure will then take the car and place it beside the sidewalk from the initial position which is besides the car1 (As seen in figure 1).

For this procedure to work, some considerations can be done in order to save input variables and avoid rule inconsistency. The first of them is to adjust the fuzzy sets for both, inputs and outputs, in order to make cases that need another variable improbable to appear. The second would be to make rules as precise to its result so that there is a lower possibility that non considered case could come up. With this in mind, we avoided inputs such as distance to car1 or distance to car2 and adjusted the distance between cars so that the distance for a frontal parking procedure was more than enough. Same was done for the *Volante* variable, to make the car's turns more pronounced. This change led to another change in variable PR1, in which the right position to begin parking was moved 1 meter up front. The last change is that the distance to the sidewalk had four clusters instead of the usual three of the other variables; this was done because a gating point was needed for another part of this procedure. So the system ends up having the following four inputs:

1. - Distance to the sidewalk (DB)
2. - Decision (taken from Decision system)
3. - Activation (taken from Decision System)
4. – Inclination

For the outputs the system has the same two outputs (minus the two control outputs) of the Decision and position system:

1. - Volante (Car direction)
2. - Direccion (Car Speed)

All these arrangements helped avoid some variables in the system, which then ended up as shown in figures 8 to11.

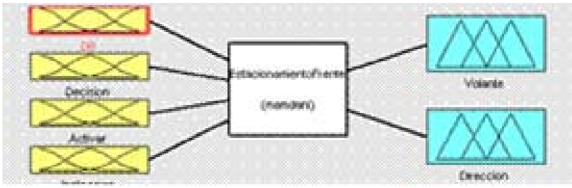

Figure 12 Fuzzy System for Frontal Parking

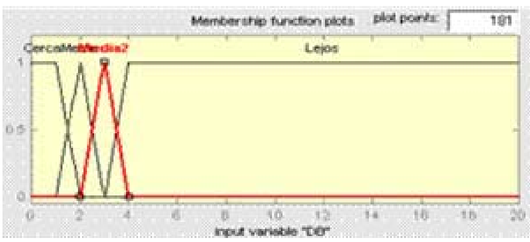

Figure 13 Fuzzy Sets for input “DB”

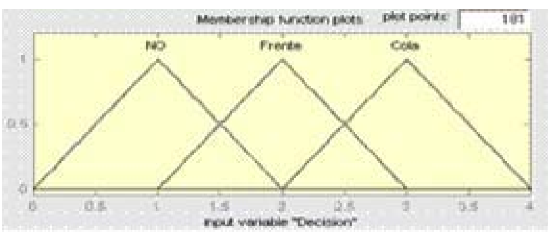

Figure 14 Fuzzy Sets for input “Decision”

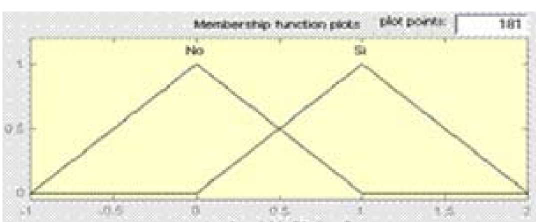

Figure 15 Fuzzy Sets for input “Activation”

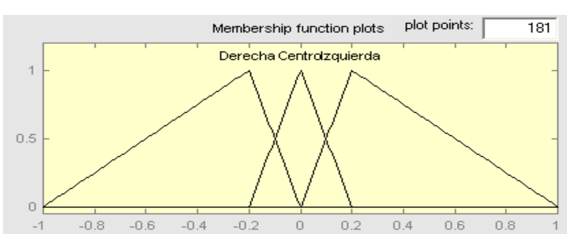

Figure 16 Fuzzy Sets for input “Inclination”

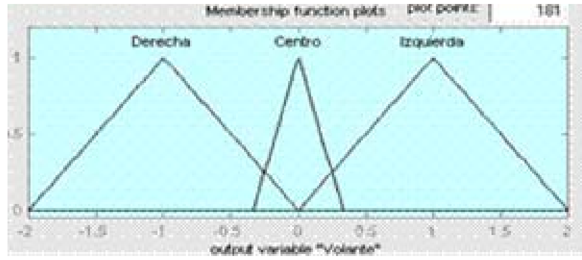

Figure17 Fuzzy Sets for output “Volante” or “Car Direction”

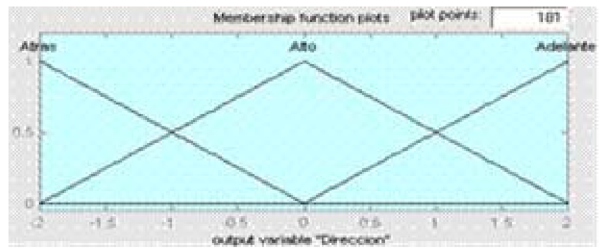

Figure18 Fuzzy Sets for output “Direccion” or “Car Speed”

The corresponding rules for this system are as follows:

R1: If (Decision is not Frente) or (Activar is No) then (Volante is Centro)(Direccion is Alto)
R2: if (DB is Lejos) and (Decision is Frente) and (Activar is Si) then (Volante is Derecha)(Direccion is adelante)
R3: If (DB is Media2) and (Decision is Frente) and (Activar is Si) then (Volante is Derecha)(Direccion is Adelante)
R4: If (DB is Medio) and (Decision is Frente) and (Activar is Si) then (Volante is Izquierda)(Direccion is Adelante)
R5: If (DB is Cerca) and (Direccion is Frente) and (Activar is Si) and (Inclinacion is not Centro) then (Volante is Izquierda)(Direccion is Adelante)
R6: If (DB is Cerca) and Direccion is Frente) and (Activar is si) and (Inclinacion is Centro) then (Volante is Centro)(Direccion is Alto)

Using the same consideration as with the *Decision and Position* model, this system will not add up anything to the output unless the activation signal is on and the decision signal is on Frontal position. This model doesn't take into consideration some variables, as it was stated before, that could be important to some, but since they depend on objects that might not be there, rule inconsistency raises when these are considered, and thus making consistent rules difficult.

3.3. Backwards parking procedure

For backwards parking to happen, the distance between the cars must be small, but it must be enough to fit the car in the final position. The beginning position is besides the frontal car, so the Decision and Position system had to be capable of this function. Once in that position this system will activate the same way the frontal parking system did, with an activation signal and the decision signal. Some sets were also changed, like the steepness of the car direction variable since in this case a more step curve is needed in order to park correctly. The rest of the variables were kept the same. In this system, the input variables used are the same that were used in the frontal parking procedure system. This was made based on an approach of one of the drivers which is based on the following:

1.- Once the car is in position, turn the wheel all the way to the right and go backwards.
2.- Once the distance to the sidewalk is about half, or the car's front is aligned with the back of the front car, turn wheel all the way to the left and go backwards.
3.- Once the distance to the sidewalk is close, the car will be aligned and acceptably parked.

While this approach seems to be no guarantee that it would work with any type of car, it is a very easy approach to implement. With this in consideration, the input and output variables are exactly the same as the frontal parking procedure (in figures 13 to 18), but with different rules. These are as follows:

R1: If (Decision is not Cola) or (Activar is No) then (Volante is Centro)(Direccion is Alto)
R2: If (DB is Lejos) and (Decision is Cola) and (Activar is Si) then (Volante is Derecha) (Direccion is atrás)
R3: If (DB is Media2) and (Decision is Cola) and (Activar is Si) then (Volante is Derecha)(Direccion is atrás)
R4: If (DB is Medio) and (Decision is Cola) and (Activar is Si) then (Volante is Izquierda)(Direccion is atrás)
R5: If (DB is Cerca) and (Decision is Cola) and (Activar is Si) and (Inclinacion is not Centro) then (volante is Izquierda)(Direccion is atrás)
R6: If (Db is Cerca) and (Decision is Cola) and Activar is Si) and (Inclinacion is Centro) then (Volante is Centro) (Direccion is Alto)
R7: If (DB is Medio) and (Decision is Cola) and (Activar is Si) and (Inclinacion is Centro) then (Volante is Centro)(Direccion is Alto)

Again, these rules don't consider extraordinary cases, but do a good job handling most of the common ones. A small adjust to the distance sets helps with this approach.

4. Simulation setup

For simulation, MATLAB was used. This software package makes this implementation very easy to test and debug. So, a simulink model was setup as appears in figure 19.

From the figure we can see that variables are extrapolated from the output of a small kinematics model of the truck, which takes tire direction and speed as an input and outputs truck position and inclination. The fuzzy models are cascaded and their outputs switched based on the decision system value. The position of the truck is then mapped on a graph, in order to have a visual representation of the results. +

The simulation is set to run for 40 seconds, which is a convenient time to let the system park. More time is not necessary and less time might not be enough. The cases that are going to be tested are when the distance between the cars is not enough, when the distance between the cars is enough, and when the distance between the cars is ample.

The position of the obstacle cars is at one meter from the sidewalk and at coordinate (0) in the horizontal plane. For the second obstacle car, this horizontal position will change to demonstrate the cases.

5. Simulations results

The simulation was then setup for the first case (space is not enough). The graph of the result is as shown in figure 20 with 1 meter of separation.

The result is quite satisfactory because it is intended that if space is not enough, the car will just align with the second obstacle car and check if there is space in front of it.

The result for the second case (Space is enough) can be seen in figure 21. The horizontal position of the front car is then 5 meters so that the separation is 5 meters. With such a space the car can comfortably enter backwards but cannot enter frontally.

As seen in the results, the parking procedure works, but it hasn't been tested with another type of vehicle.

As for the last test, the distance of the front car is set to 8 meters. The rest of the parameters are the same. The result can be seen in figure 22.

As the results show, the parking distance for a frontal parking is about 6 meters. This is a short distance for a frontal parking and thus, comfortably entered the parking slot.

As the results show, the parking distance for a frontal parking is about 6 meters. This is a short distance for a frontal parking and thus, comfortably entered the parking slot.

6. Concludind remarks

This system is capable of making usual parking procedures reliably. But, also, any extraordinary event that involves with any of the procedures could make this system prone to failure, like a long distance to the sidewalk, a long or ample car, ample obstacles, etc. Since this system is unable to track other objects, any object not considered here could be overrun by the car. More sensors and more rules could make this system more reliable, but also more prone to other problems which have been discussed here.

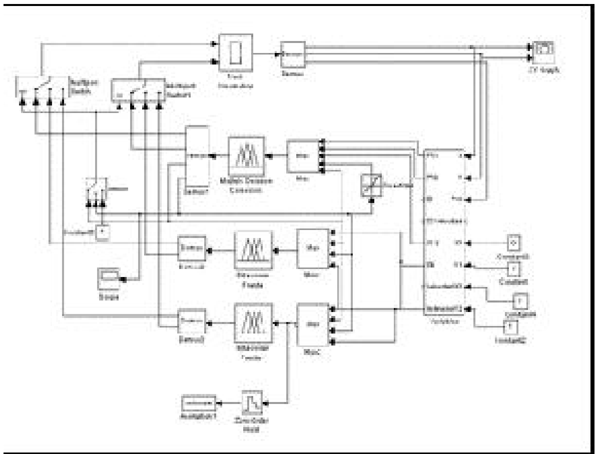

Figure 19 Simulink Model

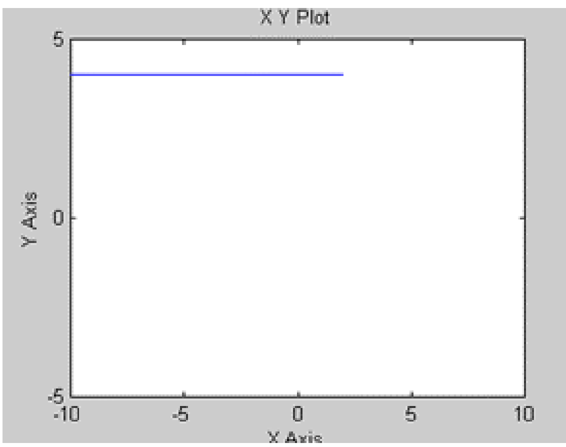

Figure 20 Test Result for “not enough space” case.

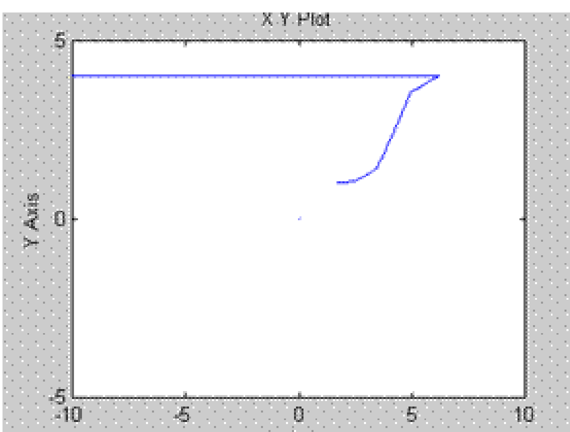

Figure 21 Backwards parking procedure

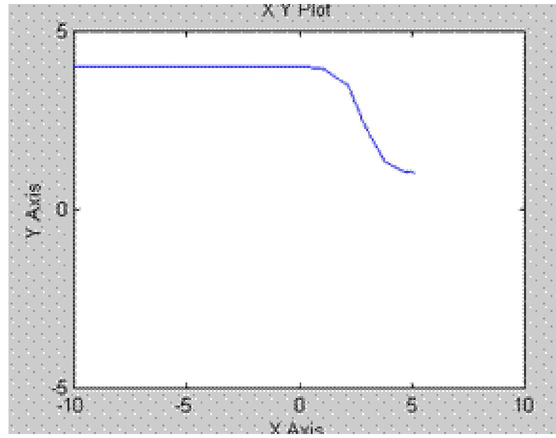

Figure 22 Test Result for “Ample Space” case

REFERENCES

[1] M. Sugeno, T. Yasukawa. “A Fuzzy-Logic-Based Approach to Qualitative Modeling”, *Transactions on Fuzzy Systems* Vol. 1 No. 1 February 2003.

[2] R. Alejos-Palomares, G. Espinosa Flores-Verdad."Systems and Devices Fuzzy Behavioral Modeling". *First International Workshop on Design of Mixed-Mode Integrated Circuits and Applications*. Cancun, Mexico 1997.

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