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Design of Fuzzy Logic based Plasma Position Control in Aditya Tokamak

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Abstract

Plasma position control is a major concern in Tokamak machines. Radial position and plasma current are the input parameters that affect the plasma stabilization current which in turn affects the plasma position. As the relationship between the input and output parameters are non linear in nature, intelligent controllers are to be developed. In this paper, FIS based plasma position controller is developed. Also the optimization of linguistic variables and membership functions is performed based on the accuracy of the results. It is found that triangular membership with 9 linguistic variable provide better results for stabilization current prediction.

Keywords: Feedback Coil Current, Fis, Plasma, Plasma Current, Radial Position

1. Introduction

Aditya Tokamak commissioned in Gujarat, India is based on controlled thermonuclear image fusion to generate energy. It involves plasma generation and confinement within the torroidal chamber to produce plasma current. Plasma current is strongly dependent on the plasma confinement time. However due to unpredictable reasons, the shape, size and position of the plasma varies and eventually plasma hits the in-vessel components (limiters). It not only deteriorates the limiters, but also leads to a sudden decrease in the plasma current (current quench). Hence it is necessary to confine the plasma within the chamber such that it does not hit the limiters.

Plasma position is affected by the plasma current and the feedback coil current that produces plasma stabilization voltage. Though plasma can move in both vertical and radial positions, probability of radial displacement of plasma is much higher than that of the vertical displacement. Extensive research is carried out to control the radial position of the plasma. Initially MIMO systems were developed for confining plasma. However, in recent years, the paradigm has shifted towards studying the feasibility of soft computing techniques for plasma position control.

In this paper, Fuzzy Logic Based Plasma Position Controller (FLPPC) has been successfully developed. Impact of the choice of the membership functions, limit values is also studied and the best membership functions are identified for the proposed system. This paper is organized as follows: Existing work is described in Section II. Section III describes the proposed Fuzzy Logic Based Plasma Position Controller. Section IV provides the Results and Discussion. Section V concludes the work.

2. Related Work

Francesco Carlo Morabito et al.[1] proposed a Fuzzy Time Series (FTS) approach for preventing the inset disruption in Tokamaks. They developed two factors fuzzy time series models and proved that it was advantageous for predicting the onset disruption in JET machine. They had also developed a B algorithm to solve the anticipation problem. Fortuna L., et al.[2] proposed a fault detection

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approach to detect the faults which occurred during mechanical measurements. In this work, a neural model was cascaded on a fuzzy inference system. Garrido et al3 designed a numerical model of a tokamak by using state space analysis. They had developed a lumped parameter numerical model to design a novel Sliding Mode Controller (SMC) in a non linear system. It was found that SMC provided better accuracy than conventional PID controller. Garrido I., et al.[3] introduced a lumped parameter numerical model of the tokamak in order to design a robust sliding mode controller for the internal inductance using the transformer primary coil as actuator. Here plasma was controlled at the primary side. So it required less energy to correct the plasma profile. Yuri V., et al.[4] developed a test bed which used PCs for simulation of a MIMO plant and a controller on a real time operating system called xPC Target. They have used proportional gain controllers to suppress the vertical instability. Yuri V., et al.[5] presented the results of design and simulation of linear and impulse control systems of a plasma unstable vertical position for three plasma linear DINA-L models of the tokamak T-15. They have used a loop shaping approach to design linear controllers. They have designed a set of linear controllers for the tokamak T-15. Marco Ariola, et al.[6] introduced a linear and impulse control system for controlling the vertical position of the plasma. Initially a poloidal field coil system was developed. These poloidal field coils were linked together by 10 circuits driven by independent power supplies. FRFA controlled the vertical instability and the remaining eight circuits controlled the plasma shape and moved the plasma column in the torroidal chamber. They had also designed a Shape Controller (SC) in JET tokamak which was used to drive the current into the PF circuits. Witrant E., et al.[7] developed a resistive model of tokamak by specifying the resistivity and the non-inductive current sources. This resistive model has been solved numerically using the scientific free Scilab. The state derivatives were approximated by appropriate differentiation matrices.

3. Fuzzy Logic based Plasma Position Controller (FLPPC)

Fuzzy logic is extensively used to simulate real time systems. In general, a Fuzzy based system involves Fuzzification (where crisp inputs are converted into fuzzified values), fuzzy inference (Fuzzy rules are framed from expert knowledge base) and defuzzification (converting fuzzified values as crisp outputs)[8–13]. In the proposed Fuzzy logic based plasma controller, two input parameters namely plasma current (in kA) and radial position of the plasma (in cm) are used. Required output is the feedback coil current (in A). As the performance of the controller is strongly dependent on the input database, in this work and extensive real time database is created. 23 data shots each containing 501 input output pairs are collected. Metadata about the datasets are provided in the Table 1.

Table 1. Description of datashots

Data Shot Number	No of Input and Output pairs	Range		
		Plasma Current in kA	Radial position in cm	Feedback coil current in A
22333	501	[-0.08,95.63]	[-29.08,294.95]	[-154.64,175.24]
22334	501	[0.095,96.12]	[-28.3,4.54]	[-95.6,141.09]
22335	501	[-8.9,88.32]	[-41.78,181.42]	[-144.4,36.16]
22336	501	[-6.83,95.18]	[-35.04,39.43]	[-215.16,67.68]
22337	501	[-0.11,96.69]	[-62.03,339.28]	[-115.12,82.59]
22338	501	[0.30,95.31]	[-43.30,3.32]	[-100.48,129.88]
22339	501	[-8.30,95.13]	[-41.10,675.02]	[-122.44,107.00]
22340	501	[0.37,94.21]	[-34.86,2.67]	[-86.28,55.44]
22341	501	[-0.11,94.59]	[-33.76,41.11]	[-154.16,153.28]
22342	501	[-0.71,90.26]	[-52.85,123.17]	[-59.20,204.52]
22343	501	[-0.51,96.07]	[-65.55,43.90]	[-154.16,124.00]
22344	501	[0.23,97.58]	[-21.34,4.33]	[-168.32,187.44]
22345	501	[-2.98,83.49]	[-127.79,1047.83]	[-85.84,82.52]
22346	501	[-1.90,84.00]	[-9069.60,995.22]	[-232.24,20.94]
26489	501	[-7.02,101.82]	[-110.79,233.82]	[-380.4,11.76]
26492	501	[-6.37,90.43]	[-41.95,82.05]	[-154.24,11.76]
26493	501	[-4.25,94.50]	[-204.62,272.63]	[-466.48,11.76]
26494	501	[-6.23,91.27]	[-115.04,13.58]	[-193.28,14.20]
26495	501	[-8.58,94.43]	[-142.39,174.27]	[-410.36,16.64]
26496	501	[-3.57,91.28]	[-125.68,23.75]	[-393.28,14.20]
26497	501	[5.53,30.31]	[-58.80,18.97]	[-456.72,11.76]
26498	501	[-4.05,40.40]	[-45.64,74.55]	[-475,21.57]
26499	501	[-7.11,95.36]	[-125.90,57.00]	[-381.08,16.64]

Performance of the Fuzzy based Controller is dependent on the number of linguistic variables, choice of the membership functions and the defuzzification method. In order to study the impact of linguistics variables, three different sets of linguistic variables are created (namely 7 variables, 9 variables and 11 variables) for triangular, Trapezoidal, Gaussian and Gaussian bell shaped membership functions. In order to study the impact of the choice of the membership function, triangular membership function, trapezoidal membership function, Gaussian membership function and Gaussian bell shaped membership functions are chosen for fuzzy logic controller.

Table 2. Rules of FLPPC

Rp & Ip	VMN	MN	LN	VLN	Tiny	VLP	LP	MP	VMP
VLL	VMP	VMP	VMP	VMP	Tiny	VMP	VMP	VMP	VMP
LL	MP	MP	MP	MP	Tiny	MP	MP	MP	MP
ML	LP	LP	LP	LP	Tiny	LP	LP	LP	LP
SL	VLP	VLP	VLP	VLP	Tiny	VLP	VLP	VLP	VLP
C	Tiny	Tiny	Tiny	Tiny	Tiny	Tiny	Tiny	Tiny	Tiny
SR	VLN	VLN	VLN	VLN	VLN	Tiny	VLN	VLN	VLN
MR	LN	LN	LN	LN	LN	Tiny	LN	LN	LN
LR	MN	MN	MN	MN	MN	Tiny	MN	MN	MN
VLR	VMN	VMN	VMN	VMN	VMN	Tiny	VMN	VMN	VMN

Table 3. Comparison between actual and desired output using 7 membership functions

Input Parameters		**Output Parameter**				
		Feedback Current in A				
			For 7 Membership functions			
Radial position (Rp) incm	***Plasma current (Ip) in A***	***Desired Feedback coil current in A***	***Gbell MF***	***Triangular MF***	***Trapezoidal MF***	***Gauss MF***
-0.19451	67.5526	-41.9201	-22.3	-22.4	-30.2	-17.5
-0.23401	67.0865	-41.9201	-23.5	-22.5	-30.2	-18.5
-0.29578	66.698	-39.4801	-23.9	-22.6	-29.4	-19.2
-0.34416	66.1542	-44.3601	-25	-22.9	-29.2	-19.8
-0.27922	63.9561	-44.3601	-28	-23.5	-29.3	-22
-0.41523	64.5777	-44.3601	-27.3	-23.4	-29.1	-21.4
-0.15178	67.349	-41.9201	-22.9	-22.4	-30.2	-18
-0.21133	67.1159	-44.3601	-23.4	-22.5	-30.2	-18.5
-0.39562	66.0283	-44.3601	-25.3	-23	-29.2	-20
-0.5196	65.0183	-44.3601	-26.9	-23.2	-29.3	-21.1

Table 4. Comparison between actual and desired output using 9 membership functions

Input Parameters		**Output Parameter**				
		Feedback Current in A				
			For 9 Membership functions			
Radial position (Rp) incm	***Plasma current (Ip) in A***	***Desired Feedback coil current in A***	***Gbell MF***	***Triangular MF***	***Trapezoidal MF***	***Gauss MF***
-0.19451	67.5526	-41.9201	-47.8	-42.2	-26.4	-50.7
-0.23401	67.0865	-41.9201	-47.5	-42.3	-26.5	-50.3
-0.29578	66.698	-39.4801	-45.9	-42.4	-26.7	-49.6
-0.34416	66.1542	-44.3601	-44.7	-42.2	-27.2	-48.4
-0.27922	63.9561	-44.3601	-43.2	-42.3	-29.5	-46.6
-0.41523	64.5777	-44.3601	-43.4	-42.3	-29	-46.9
-0.15178	67.349	-41.9201	-48.6	-42.1	-26	-50.8
-0.21133	67.1159	-44.3601	-47.7	-42.2	-26.5	-50.4
-0.39562	66.0283	-44.3601	-44.6	-42.2	-27.3	-48.2
-0.5196	65.0183	-44.3601	-44	-42.4	-28.6	-47.3

Table 5. Comparison between actual and desired output using 11 membership functions

Input Parameters		Output Parameter				
		Feedback Current in A				
Radial position (Rp) incm	*Plasma current (Ip) in A*	*Desired Feedback coil current in A*	*For 11 Membership functions*			
			Gbell MF	*Triangular MF*	*Trapezoidal MF*	*Gauss MF*
-0.19451	67.5526	-41.9201	-28.5	-39.7	-30.1	-34.9
-0.23401	67.0865	-41.9201	-28.5	-36.6	-30.1	-34.9
-0.29578	66.698	-39.4801	-28.5	-36.6	-30	-34.8
-0.34416	66.1542	-44.3601	-28.5	-36.4	-29.7	-34.7
-0.27922	63.9561	-44.3601	-27.8	-35.5	-27.9	-33.5
-0.41523	64.5777	-44.3601	-28.5	-35.8	-27.9	-34
-0.15178	67.349	-41.9201	-28.5	-36.7	-30.1	-34.9
-0.21133	67.1159	-44.3601	-28.5	-36.7	-30.1	-34.9
-0.39562	66.0283	-44.3601	-28.4	-36.3	-29.6	-34.6
-0.5196	65.0183	-44.3601	-28.3	-35.9	-28.8	-34.2

Table 6. Comparison between actual and desired output using different numbers of trapezoidal membership functions

Input Parameters		Output Parameter			
		Feedback Current in A			
Radial position (Rp) incm	*Plasma current (Ip) in A*	*Desired Feedback coil current in A*	*For Trapezoidal MF*		
			7 MF	*9 MF*	*11 MF*
-0.19451	67.5526	-41.9201	-30.2	-26.4	-30.1
-0.23401	67.0865	-41.9201	-30.2	-26.5	-30.1
-0.29578	66.698	-39.4801	-29.4	-26.7	-30
-0.34416	66.1542	-44.3601	-29.2	-27.2	-29.7
-0.27922	63.9561	-44.3601	-29.3	-29.5	-27.9
-0.41523	64.5777	-44.3601	-29.1	-29	-27.9
-0.15178	67.349	-41.9201	-30.2	-26	-30.1
-0.21133	67.1159	-44.3601	-30.2	-26.5	-30.1
-0.39562	66.0283	-44.3601	-29.2	-27.3	-29.6
-0.5196	65.0183	-44.3601	-29.3	-28.6	-28.8

Table 7. Comparison between actual and desired output using different numbers of gaussian membership functions

Input Parameters		Output Parameter			
		Feedback Current in A			
Radial position (Rp) incm	*Plasma current (Ip) in A*	*Desired Feedback coil current in A*	*For Gaussian MF*		
			7 MF	*9 MF*	*11 MF*
-0.19451	67.5526	-41.9201	-17.5	-50.7	-34.9
-0.23401	67.0865	-41.9201	-18.5	-50.3	-34.9
-0.29578	66.698	-39.4801	-19.2	-49.6	-34.8
-0.34416	66.1542	-44.3601	-19.8	-48.4	-34.7
-0.27922	63.9561	-44.3601	-22	-46.6	-33.5
-0.41523	64.5777	-44.3601	-21.4	-46.9	-34
-0.15178	67.349	-41.9201	-18	-50.8	-34.9
-0.21133	67.1159	-44.3601	-18.5	-50.4	-34.9
-0.39562	66.0283	-44.3601	-20	-48.2	-34.6
-0.5196	65.0183	-44.3601	-21.1	-47.3	-34.2

Table 8. Comparison between actual and desired output using different numbers of gaussian bellshaped membership functions

Input Parameters		Output Parameter			
		Feedback Current in A			
Radial position (Rp) incm	*Plasma current (Ip) in A*	*Desired Feedback coil current in A*	*For Gaussian Bell shaped MF*		
			7 MF	*9 MF*	*11 MF*
-0.19451	67.5526	-41.9201	-22.3	-47.8	-28.5
-0.23401	67.0865	-41.9201	-23.5	-47.5	-28.5
-0.29578	66.698	-39.4801	-23.9	-45.9	-28.5
-0.34416	66.1542	-44.3601	-25	-44.7	-28.5
-0.27922	63.9561	-44.3601	-28	-43.2	-27.8
-0.41523	64.5777	-44.3601	-27.3	-43.4	-28.5
-0.15178	67.349	-41.9201	-22.9	-48.6	-28.5
-0.21133	67.1159	-44.3601	-23.4	-47.7	-28.5
-0.39562	66.0283	-44.3601	-25.3	-44.6	-28.4
-0.5196	65.0183	-44.3601	-26.9	-44	-28.3

Plasma current is assigned as Very More Negative (VMN), More Negative (MN), Less Negative (LN), Very Les Negative (VLN), Zero (Z), Very Less Positive (VLP), Less Positive (LP), More Positive (MP) and Very More Positive (VMP) which can be varied from -9 to 102. Radial position is assigned as Very Large Left (VLL), Large Left (LL), Medium Left (ML), Small Left (SL), Centre (C), Small Right (SR), Medium Right (MR), Large Right (LR) and Very Large Right (VLR) which can be varied from -9070 to 1048. Similarly the crisp output i.e, feedback coil current is also assigned into nine linguistics variables. There are Very More Negative (VMN), More Negative (MN), Less Negative (LN), Very Less Negative (VLN), Zero (Z), Very Less Positive (VLP), Less Positive (LP), More Positive (MP) and Very More Positive (VMP) which can be varied from -467 to 205. Totally 81 If-then rules have been framed. The Fuzzy Associative Memory (FAM) for 9 input variables is shown in Table 2.

Table 9. Comparison between actual and desired output using different numbers of triangular membership functions

Input Parameters		**Output Parameter** *Feedback Current in A*			
		Desired Feedback coil current in A	*For Triangular MF*		
Radial position (Rp) incm	*Plasma current (Ip) in A*		*7 MF*	*9 MF*	*11 MF*
-0.19451	67.5526	-41.9201	-22.4	-42.2	-39.7
-0.23401	67.0865	-41.9201	-22.5	-42.3	-36.6
-0.29578	66.698	-39.4801	-22.6	-42.4	-36.6
-0.34416	66.1542	-44.3601	-22.9	-42.2	-36.4
-0.27922	63.9561	-44.3601	-23.5	-42.3	-35.5
-0.41523	64.5777	-44.3601	-23.4	-42.3	-35.8
-0.15178	67.349	-41.9201	-22.4	-42.1	-36.7
-0.21133	67.1159	-44.3601	-22.5	-42.2	-36.7
-0.39562	66.0283	-44.3601	-23	-42.2	-36.3
-0.5196	65.0183	-44.3601	-23.2	-42.4	-35.9

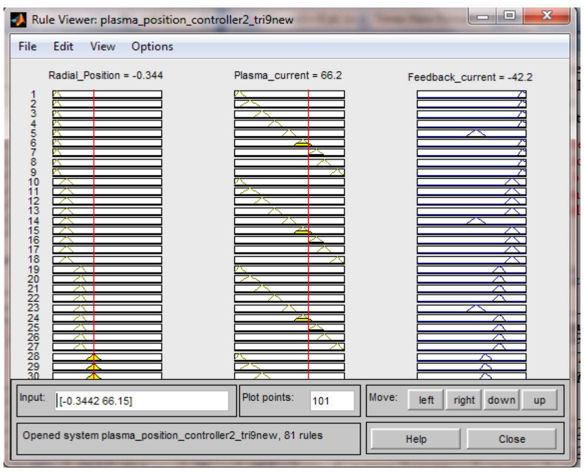

Figure 1. Output of the fuzzy based plasma position controller.

The size of the Fuzzy Associative Memory (FAM) is 9x9. Tokamak is a non linear machine so Mamdani inference method is implemented.

4. Results and Discussion

Output of the fuzzy based plasma position controller is shown in Figure 1. For the value of Plasma current of 66.1542 in kA and the Radial position of -0.34416 in cm, the desired feedback coil current is -44.3601 A. From the Figure 1, it is shown that the feedback coil current of the fuzzy logic controller is -42.2 A.

From the 3rd – 7th columns of Table 3, it is found that the actual values obtained from the fuzzy controller do not match with the desired value. Hence for the particular data set, choice of 7 linguistic variables could not provide the desired results.

From the 3rd – 7th columns of Table 4, the errors between the actual and desired values are less irrespective of membership functions with 9 linguistic variables.

Hence from the Table 3, 4 and 5, it is concluded that 9 linguistic variables provide better results when compared to that of 7 and 11 linguistic variables.

Having decided the number of linguistic variables, the next task is to identify the most suitable membership functions. From the 3rd – 7th columns of Table 4, it is found that Triangular membership gives the better results because the error between the actual and desired output is less.

In Table 6 to 9, the actual and desired values of fuzzy logic based plasma position controller was tabulated for all three different numbers of Membership Functions (MF) i.e. 7MF, 9MF and 11 MF for all four different shapes of the membership functions i.e. Trapezoidal, Gaussian, Gaussian bell shaped and Triangular membership functions.

From the Table 6 to 9, it is concluded that Triangular membership function with seven linguistic variables will be suited for the fuzzy logic based plasma position controller since the difference in actual and desired values of the feedback coil current is less for this case.

5. Conclusion

In this paper, Fuzzy based plasma position controller with different membership functions and three set of linguistic variables. It is inferred that Triangular membership function for the set of nine linguistic variables provides the better results. However the error between the actual and desired value is very high. In order to improve the performance degrees of assignment in membership functions can be modified in accordance with the input parameters. Also Classification and Regression Tree Algorithm (CART) can be used for deciding the linguistic variables. Further BPN based plasma position controller and ANFIS based plasma position controller can be used.

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