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Design an Innovative Smart Control Scheme to Hybridize Conventional and Expert Controllers

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Abstract: ***The purposes of the proposed research present approaches to the design of an Innovative Smart Control Scheme (SCS) methodology mergers the proposed local controllers (conventional PID and the expert controller such as fuzzy Logic controllers (FLC)) in a smart way. This SCS switching and merging mechanism depends on FLC that monitors the process state and act as a supervisory to make hybrid control between the local controllers. A local controller is an analytical controller designed to work around specific process operation .Once the conditions change, the rule-based supervisor decreases the influence of one classical controller (PI) and gives more weight to another intelligent controller (Fuzzy Logic) that has been designed to work in the new conditions. Application of the suggested (SCS) on a simple plant which could be a resonator in proposed system, DC machine is introduced and better response of the new proposed SCS is presented. The performance of SCS will compared to the FLC and PID. MATLAB/SIMULINK program is projected for Comparison testing by applying different disturbances cases.***

Keywords: *Smart Control Scheme, Fuzzy Logic, IT1FLS, PID, Fuzzy PID Controller.*

1. Introduction

Designing nonlinear feedback-control systems is generally a cruel task. Building local controller such as the classical PID and expert controller (FLC) and combining their function using an innovative performance scheme is usually better than designing a single non-linear controller. It is well known that up until now, a conventional proportional integral-derivative (PID)-type controller is most widely used in industry due to its simple control structure, ease of design, and inexpensive cost. However, the PID type controller cannot yield a good control performance [1]. PID control is mostly used because of their simple structure and robustness for wide range of operation conditions [2]. The PID design needs specification for only three parameters such as proportional gain, integral gain, and derivative gain the problem was solved using Fuzzy for control gain scheduling whereby the PID parameters can be determined on-line based on errors and their derivative [2]. If a controlled object is highly nonlinear and uncertain. Another type of controller based on FLC is being increasingly applied to many systems with nonlinearity and uncertainty [3]. Especially, the most successful FLC applied into industrial plants are designed by control engineers. Defining membership functions of linguistic variables and formulating fuzzy rules by manual operation is time consuming work [4-6]. Fuzzy concept was presented by Zadeh in 1965 to process / manipulate data and information affected by probabilistic uncertainty/imprecision [7]. These sets were designed to mathematically represent the vagueness and uncertainty of linguistic problems; thereby obtaining formal tools to work with intrinsic imprecision in different type of problems; it is considered a generalization of the classic set theory [8].

2. Modelling and the Conventional Controller Formulation

2.1 The Nonlinear Differential Equation and Modelling

This is clearly a phenomenon that is defined by a set of the following nonlinear differential equations. Applied Newtonian mechanics method to find the differential equations for mechanical systems:

Using Newton's second law:

$$\sum T = J\,\alpha = J\,\frac{d\omega}{dt} \qquad (1)$$

The Electromagnetic torque developed by separately excited DC motor: $T = L_{af}\, i_f\, i_a$ (2)

The Viscous torque: $T_{viscous} = B_m\,\omega_r$ (3)

From Newton's Second Law, Torsional-Mechanical equation is:

$$\frac{d\omega_r}{\mathrm{dt}} = \frac{1}{\mathrm{j}}\left(T_e - T_{viscous} - T_L\right) = \frac{1}{\mathrm{J}}\left(L_{af}\, i_a i_f - B_m\omega_r - T_L\right) \quad (4)$$

The nonlinear differential equation for separately excited DC motor which is found using Kirchhoff's Voltage Law:

$$\frac{di_a}{\mathrm{dt}} = -\frac{r_a}{L_a} i_a - \frac{L_{af}}{L_a} i_f\,\omega_r + \frac{1}{L_a} u_a \qquad (5)$$

$$\frac{di_f}{\mathrm{dt}} = -\frac{r_f}{L_f} i_f + \frac{1}{L_f} u_f \qquad (6)$$

$$\frac{d\omega_r}{\mathrm{dt}} = \frac{L_{af}}{J} i_a i_f - \frac{B_m}{J}\omega_r - \frac{T_L}{J} \qquad (7)$$

The relations for the armature controlled DC motor are shown schematically in Figure 1.

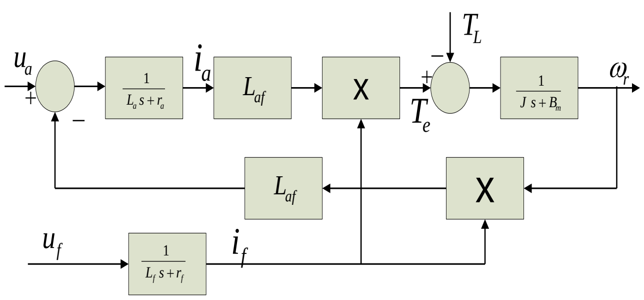

Figure 1: Block diagram of Separately Excited DC motor

2.2 The Conventional PID Formulation for the Proposed System

The reason for the popular use of the PID-type controller is that this controller can be easily designed by adjusting only three controller parameters. In addition, it control performance can be accepted in many applications [9]. Classical PID controllers are very popular in industries because they can improve both the transient response and steady state error of the system at the same time. Although great efforts have been devoted to develop PI controller, PI controllers are not robust to the parameter variation to the plants being controlled. For a compensated system with a PID controller with the configuration shown below has a parameters which are determined using the Ziegler-Nicholas first method by obtaining the delay time and the time constant and the gain from the first order plus dead time model obtained from the unit step response of the process then the PID controller can be constructed as shown in Figure 2.

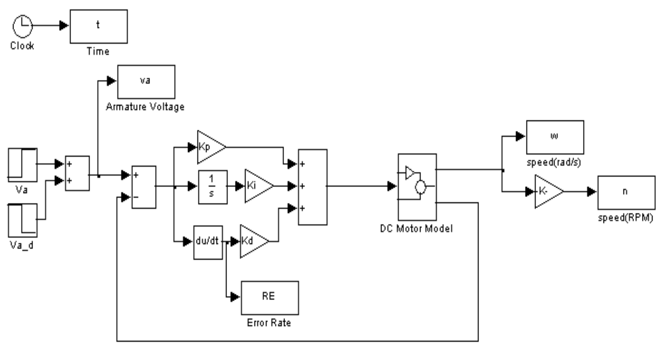

Figure 2: Simulink model with the conventional PID controller

3. Expert Controller (FLC) Formulation

After Zadeh presented the fuzzy sets, the concepts of fuzzy algorithms, fuzzy decision making, and fuzzy ordering had been proposed. In 1973, Zadeh published another paper which established the foundation for fuzzy control. In that paper he introduced the concept of linguistic variables and proposed the IF-THEN rules to formulate human knowledge [10, 11]. The term fuzzy logic has been used in two different senses [12]. In a narrow sense, fuzzy logic refers to a logic system that generalizes classical two-valued logic for reasoning under uncertainty. In a broad sense, fuzzy logic refers to all of the theories and technologies that employ fuzzy sets, which are classes with non-sharp boundaries [13].

The task of modeling complex real-world processes for control-system design is difficult. Even if a relatively accurate model of dynamic system can be developed, it is often too complex to use in controller development as much simpler (e.g. linear) process model is required by most of the conventional control-design techniques. In practice, heuristics are used to modify the original design based on a simplified process model once the algorithm is implemented and confronted with reality [14].

The effects from inaccurate parameters and models are reduced because a FLC does not require a system model .However building a FLC from the ground-up may not provide good results or sometime even a worse result than a conventional controller if there is not enough knowledge of the system. Therefore, in this research the result from a PID controller is initially borrowed as a-prior knowledge in the design process. The performance of the FLC is then improved by adjusting the rules and membership functions.

3.1 Inputs, Outputs, Universe of discourse and Rules

The inputs are the error (E) between the reference (ω_r) and the actual speed (ω_a), and the change in error (CE).The output is the change in armature voltage (CU).The universe of discourse of the change in error is based on the experiment data from the PID controller. The inputs and outputs shown below in Figure 3 by the following equations:

$$E = e_{(K)} = \omega_r - \omega_a \quad (8)$$

$$CE = e_{(K)} - e_{(K-1)} \quad (9)$$

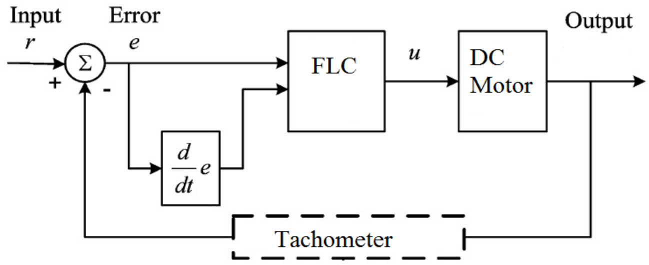

Figure 3: Block diagram of the FLC

Toward perform fuzzy computation, the inputs and outputs must be converted from numerical or (crisp) value into linguistic forms. The terms such as Small and Big are used to quantize the inputs and the output values. The linguistic terms that used to represent the inputs and output values are defined by five fuzzy variables and the rules are expressed as shown in Table 1.

Table.1 Block diagram of the FLC

E / ***CE***	**NB**	**NS**	**ZE**	**PS**	**PB**
PB	ZE	PS	PB	PB	PB
PS	NS	ZE	PS	PB	PB
ZE	NB	NS	ZE	PS	PB
NS	NB	NB	NS	ZE	ZE
NB	NB	NB	NB	NS	ZE

3.2 The Fuzzy Membership Functions for Inputs and output.

The fuzzy membership functions are used as tools to convert crisp values to linguistic terms. A fuzzy membership functions can contain several fuzzy sets depending on how many linguistic terms are used. The number for indicating how much a crisp value can be a member in each fuzzy set is called a degree of membership. One crisp value can be converted to be partly in many fuzzy sets, but the membership degree in each fuzzy set may be different. In order to define fuzzy membership function, designers can choose many different shapes based on their preference or experience. The popular shapes are triangular and trapezoidal because these are easy to represent designer's ideas and require low computation time the membership functions for (E), (CE) and (CU) shown in the following Figure 4.

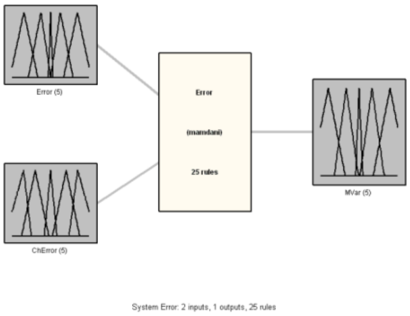

Figure 4: The Inputs and the output blocks for the FLC.

4. Design an Innovative Smart Control Scheme (SCS)

Smart Control Scheme can be well-thought-out as another methodology to obtain Takagi-Sugeno (TS) fuzzy systems TS fuzzy models .The proposed SCS leads to decrease the number of model rules, e.g., the fuzzy model for the inverted pendulum in [14] has 16 rules. In comparison, a 3-rule fuzzy model will be formed using the SCS. The Local controllers systems designed and tuned for particular operating conditions; that way, they guarantee closed-loop stability and other performance measures in the neighborhood of the specific process state. The planned SCS will monitor the process state and act as a supervisory to make hybrid (switching and blending) control between the local conventional and expert controllers. TS Fuzzy inference used in the weighting for the proposed smart control scheme.

Assume a single-input/single-output feedback-control system having one process variable (PV) and one manipulated (control) variable (CV). The task for the planned SCS is to design a control system for the dynamical process that tracks a set-point as shown in Fig.4. The smart control scheme methodology blends the conventional and expert controllers in a smart way is shown in Figure (4).

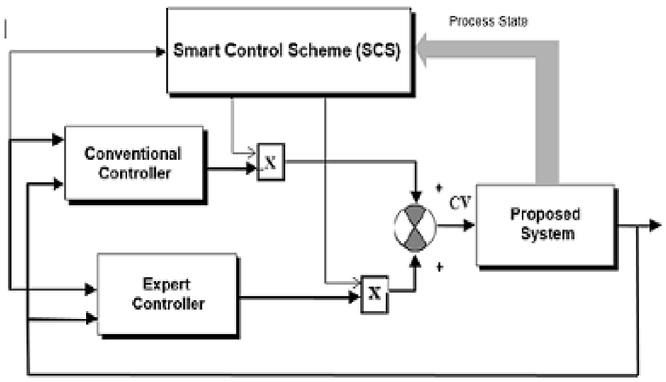

Figure 4: Smart control scheme system block diagram

4.1 Takagi-Sugeno Fuzzy Systems

In the Takagi-Sugeno (TS) fuzzy system the conclusion of the rule is not a fuzzy set but a crisp function of the inputs. For example:

$$IF(X_1 is A_1) AND (X_2 is B_1) THEN. Y = f_1(x) = C_1 \quad (10)$$

$$IF(X_1 is A_2) AND (X_2 is B_2) THEN. Y = f_2(x) = C_2 \quad (11)$$

The functions f(x) of the input vector x = [x1, x2,..] can generally be very complex but the most commonly used function is linear function described by the coefficients [c0, c1, c2, ..]. The TS fuzzy inference is very similar to the normal fuzzy inference with singletons in conclusions and CA defuzzification. But instead of the weighted average of the singletons we calculate weighted average of the functions in conclusions evaluated for the current values of inputs [15].

4.2 Inputs, Outputs, Universe of discourse and for the SCS

The inputs are the current (I), speed (ω), and the set point (SP). The outputs are the weight influence output value will generated for conventional controller f (u) and the weight influence output value for the expert controller f (u1). The universe of discourse of the speed and current are based on the experiment data from the both conventional and expert controllers. To perform fuzzy computation, the inputs and outputs must be converted from numerical or (crisp) value into linguistic forms.

4.3 The Rules and the Linguistic Forms of SCS

To perform fuzzy computation, the inputs and outputs must be converted from numerical or (crisp) value into linguistic forms. The terms such as Negative, Positive and No change are used to quantize the inputs and the output values. The linguistic terms that used to represent the inputs and output values are defined by nine fuzzy variables as shown in Table 2 and rules in Table 3.

Table 2: Fuzzy Linguistic Terms of SCS controller

Term	Definition
N	Negative
P	Positive
NC	No change
TRA	Transient
OS	Overshoot
SS	Steady state
L	Low
M	Medium
H	High

Table 3: Fuzzy Rules of SCS controller

I / ***Ω***	**N**	**NC**	**P**
TRA	***f (u)*** = OS ***f (u1)*** = OS	***f (u)*** = TRA ***f (u1)*** = TRA	***f (u)*** = TRA ***f (u1)*** = TRA
OS	***f (u)*** = OS ***f (u1)*** = OS	***f (u)*** = OS ***f (u1)*** = OS	***f (u)*** = OS ***f (u1)*** = OS
SS	***f (u)*** = OS ***f (u1)*** = OS	***f (u)*** = SS ***f (u1)*** = SS	***f (u)*** = SS ***f (u1)*** = SS

4.4 The Fuzzy Membership Functions for the SCS

Takagi-Sugeno (TS) fuzzy inference the conclusion of the rule is not a fuzzy set but a crisp function of the inputs. The TS fuzzy inference is very similar to the fuzzy inference described in the previous section with singletons in conclusions and CA Defuzzification. But instead of the weighted average of the singletons we calculate weighted average of the functions in conclusions evaluated for the current values of inputs. The membership functions for (I), (ω) and (SP) shown in the following Figure 5.

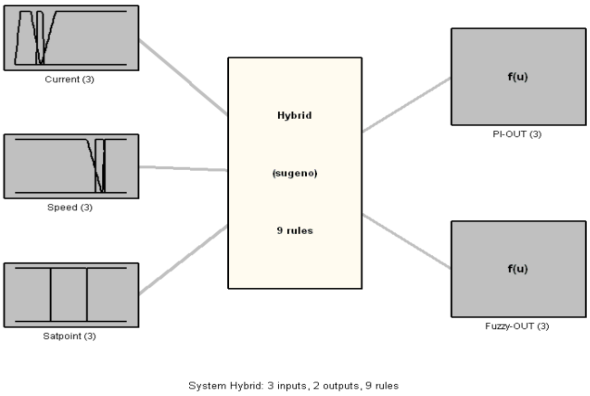

Figure 5: The Inputs and the output blocks for MATLAB Fuzzy program of hybrid system

5. Proposed System Simulation and SCS, FLC and PID controllers performance Results

In this paper shows how SCS, expert and conventional could obtain good performance that may occurs due to load changes or due to change in excitation source as well as shows how SCS could combines the advantages of the both controllers conventional and expert to shows the effects of the Controllers SCS, conventional and expert on the stability improvements, different three cases of disturbances and perturbation cases on the proposed system are studied and simulated. MATLAB/SIMULINK is the powerful program tools used for create proposed model.

5.1 First Study Case

The response of the compensated closed loop system for the SCS and expert controller individual. Simulation results are shown in Figure 6.

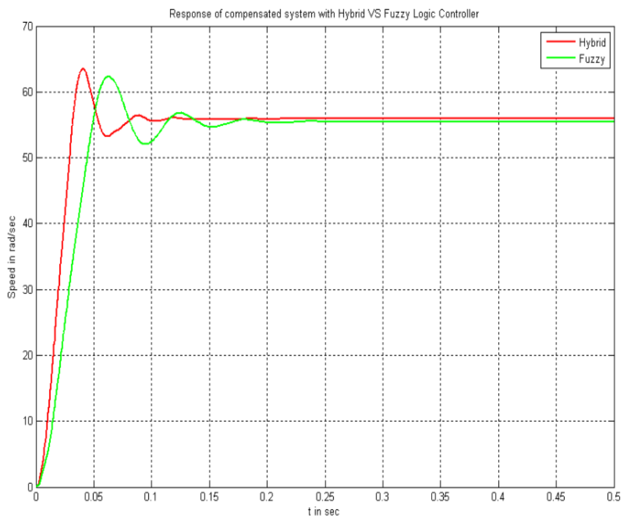

Figure 6: Response of compensated system with both SCS and FLC controllers

5.2 Second Study Case

The response of the compensated closed loop system for the SCS and Conventional controller individual. Simulation results are shown in Figure 7.

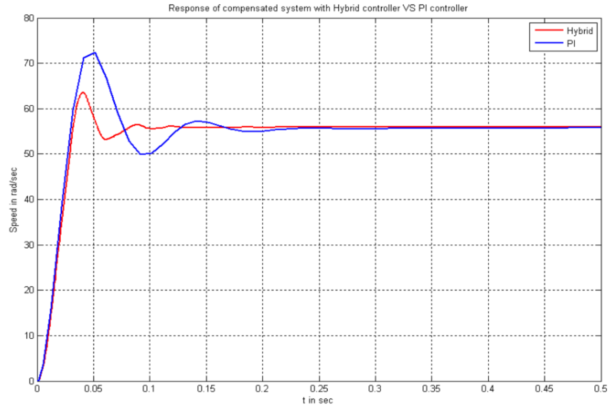

Figure 7: Response of compensated system with both SCS and PI controllers

5.3 Third Study Case

The response of the compensated closed loop system without load then the response of the proposed system. Simulation results are shown in Figure 8.

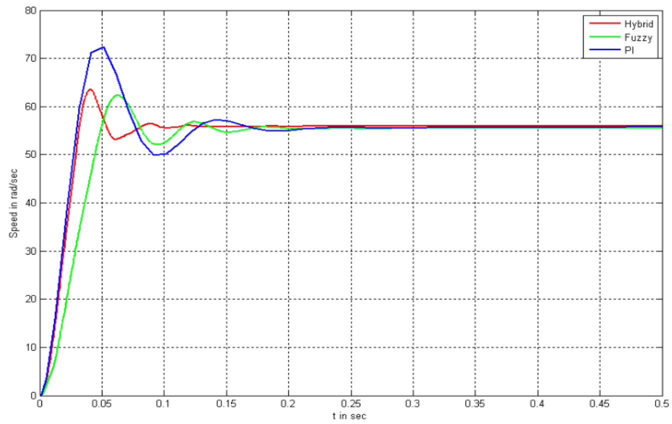

Figure 8: Response of compensated system without load.

5.4 The Fourth Study Case

The time response of the compensated closed loop controlled system for SCS, FLC and PI controller after applying a step disturbance with 75% load torque then the response of the proposed system. Simulation results are shown in Figure7.

5.5 The Fifth Study Case

The time response of the compensated closed loop controlled system for SCS, FLC and PI after applying 20% step change of input voltage of the system then the response of the proposed system. Simulation results are shown in Figure8.

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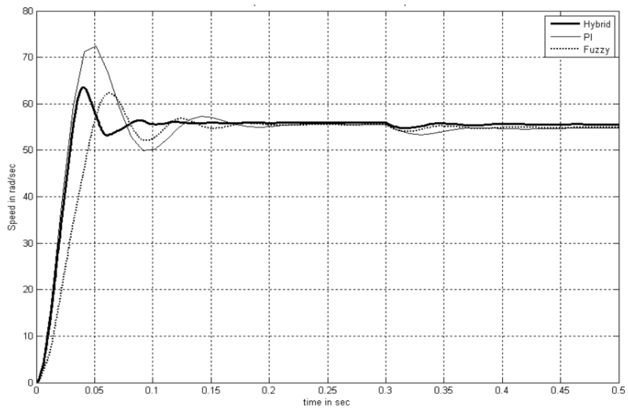

Figure 7: Response of compensated system with 75% load torque disturbance

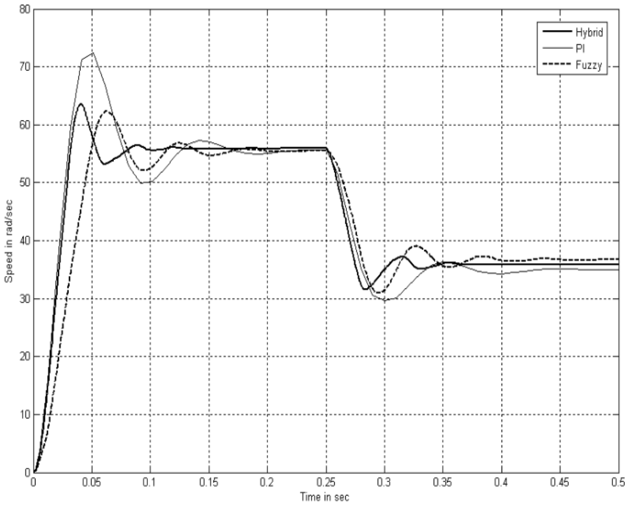

Figure 9: Response of compensated system with -20% step change

6. Results Discussion

Discussing to the above cases indicate the time response of the closed loop controlled system to compare SCS and conventional (PI) controllers. SCS results show it takes the advantages of the conventional (PI) controller fast response and no steady state error but SCS results show controllable overshoot and faster settling time than the conventional (PI) controller. In addition indicates the time response of the closed loop controlled system with both SCS and FLC. SCS results show faster response, faster settling time and no steady state error and take the advantage of the FLC controllable overshoot.

Figure 8 results shown that SCS combines the advantages of the expert (FLC) and conventional (PI) controllers and shows that the SCS is faster response, faster settling time, no steady state error and controllable overshoot. Table.2 point to the results comparison of closed loop controlled system with SCS, expert FLC and conventional PI controllers.

Table 2: Results for compensated system without load

Controller / Terms	PI	Fuzzy	Hybrid
Percent Overshoot	29%	11%	12.5%
Rise Time	0.021	0.035	0.022
Settling Time	0.1815	0.152	0.1
Steady State Error	0%	2%	0%

Discussing to the 2nd case indicates the time response of closed loop controlled system for SCS, FLC and PI controller after applying a step disturbance with 75% load torque. The response of the SCS approached better and no steady state error than PI and FLC and the SCS controller successive to make response better after a 75% increase in load torque as shown in figure7.

Discussing to the 3rd case indicates the time response of closed loop controlled system for SCS, FLC and PI controller after applying 20% step change of input voltage of the system. The response of the SCS approached better, no steady state error, faster settling time and a controllable overshoot as shown in figure 8.

7. Conclusions

In this paper SCS methodology used to hybridize conventional (PI) and expert (FLC) Controllers by switching and blending mechanism based on separately excited DC motor system. The results showed that the SCS could provide good damping performance over wide range of different operating conditions and combines the advantages of the expert over conventional like overshoot percentage although expert has best overshoot by very small percentage over SCS, good settling time and lowest small steady state error and the advantages of conventional over expert like rising time and faster damping for the terminal voltage than expert .SCS has good over damping performance , settle prior and fast time rising with steady state error than conventional and expert as shown in table 2.

Table 3: Model Parameters

R_a	3.44 Ω
L_a	0.05715 H
L_f	1.58582 H
L_{af}	0.1H
F	0.0027 N .m .s / rad
J	0.0036 Kg.m2
K_t	0.2651 N.m /A
K_b	0.28 v/v
V_a	56 v
V_f	56 v

References

[1] L. A. Zadeh, “Fuzzy sets,” Inform. Contr., vol. 8, pp. 339–353, 1965.

[2] M. Tomizuka and S. Isaka. 1993. Fuzzy Gain Scheduling of PID Controllers. IEEE Trans. Syst. Man. Cybern. 23(5): 1392–1398.

[3] H. R. Berenji, “Fuzzy logic controllers,” in An Introduction to Fuzzy Logic Application in Intelligent Systems, R. R Yager and L. A. Zadeh, Eds. Boston, MA: Kluwer, 1992, pp. 69–96.

[4] E. H. Mamdani, “Application of fuzzy algorithm for control of simple dynamic plant,” Proc. Inst. Elect. Eng., vol. 121, pp. 1585–1588, 1974.

[5] M. Braae and D. A. Rutherford, “Theoretical and linguistic aspects of the fuzzy logic controller,” Automatica, vol. 15, pp. 553–577, 1979.
[6] S. Tzafestas and N. Papanikolopoulos, “Incremental fuzzy expert PID control,” IEEE Trans. Ind. Electron., vol. 37, pp. 365–371, 1990.
[7] A. M. Harb, I. Al-Smadi, “Chaos Control Using Fuzzy Controllers”, Integration of Fuzzy Logic and Chaos Theory, Springer Berlin Heidelberg, vol. 187, pp. 127-155, 2006.
[8] M. Ozek, Z. Akapolat,” A Software Tool: Type-2 Fuzzy Logic Toolbox”, Computer Applications in Engineering Education, Wiley Periodicals, vol.16, No.2, pp. 137-146, 2007.
[9] Wei Li, Member, IEEE Design of a Hybrid Fuzzy Logic Proportional plus Conventional Integral-Derivative Controller IEEE TRANSACTIONS ON FUZZY SYSTEMS, VOL. 6, NO. 4, NOVEMBER 1998
[10] J. Mendel, Uncertain Rule-Based Fuzzy Logic Systems: Introduction and New Directions. NJ: Prentice-Hall, 2001.
[11] O. Castillo, P. Melin, Type-2 Fuzzy Logic: Theory and Applications, Studies in Fuzziness and Soft Computing, Springer-Verlag Berlin Heidelberg 2008.
[12] A. M. Harb, I. Al-Smadi, “Chaos Control Using Fuzzy Controllers”, Integration of Fuzzy Logic and Chaos Theory, Springer Berlin Heidelberg, vol. 187, pp. 127-155, 2006.
[13] Li-Xin Wang, A Course in Fuzzy Systems and Control, Prentice-Hall, Upper Saddle River, 1997.
[14] K. Tanaka and H. O. Wang ‘Fuzzy Control Systems Design and Analysis: A Linear Matrix Inequality Approach,’ John Wiley & Sons, Inc., New York, 2001.
[15] Sugeno M.: Industrial Applications of Fuzzy Control. Elsevier Science Ltd, (1985).
[16] Dave Carr, Program Manager & Jeff Shearer, Technical Consultant Nonlinear Control Decision Making Using Fuzzy Logic In Logix (2007).

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