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AN APPROACH TO IMPROVE THE PERFORMANCE OF A POSITION CONTROL DC MOTOR BY USING DIGITAL CONTROL SYSTEM

By

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Abstract:

DC motors are one of the most popular motors for control in various industries. Now the advent of cheap and powerful microcontrollers have paved the way for digital controllers be designed and implemented successfully. This paper describes the popular digital controllers available for the control of DC motors with same or higher accuracy than that of digital controllers. Dead-beat, Dahlin, Digital PID and PD-type fuzzy controllers are discussed and implemented here and their results are compared in this paper with the basics of designing them. Even the practical implementation is also described here.

Keywords: DC motor, digital controller, Dead-beat, Dahlin, fuzzy, controller design.

1. Introduction

With the increasing application of the DC motor in various industries from aerospace to robotic manipulators, precision control of DC motors have become inevitable. Now since the advents of computers are already booming the industries digital controllers are an absolute necessity. This paper serves the purpose to choose the best controller according to the need. Not only have that for beginners the paper can be used to design controller specific to the system even to improvise according to need.

The paper is divided into the following section. The introduction gives a brief idea of the complete work behind the paper. The next section is literature review, reviewing the important books and chapters from which the controllers have been design and compared based on the performance.

Problem statement serves to clearly define the problem that is been discussed in the paper. This section is very much intertwined with the section of proposed solution which defines the uniqueness of the paper. However the proposed solution section is sub-divided into the design of the controllers briefly.

The simulation section uses MATLAB and Simulink to design the transfer function of the system and controller and simulate the control system performance with respect to set-point tracking and disturbance rejection. Results section discusses both the time domain and error domain performance indices are tabulated.

Conclusion section discusses on the performance of the controller for the system. Appendix section deals with the practical application of the designed controller in a microcontroller.

2. Literature Review

To begin with the analysis and synthesis of a digital control system Ibrahim [2] provides a lucrative practical and straightforward aspect of the design methodology. Starting with system modelling of various systems, the book directly introduces the readers with microcontrollers and its programming in C language with the sensors discussed in the introduction itself.

Landou and Zito [1] starts the book with continuous time system and their time domain and frequency domain response. In the later chapter the book develops robust digital control methodology with one general structure modified to various specialized model based control algorithms that works even on the presence of random disturbance. The book also provides practical and theoretical tool for system identification and practical aspects of digital control along with reduction of the controller complexity.

A wide variety of examples has been solved and demonstrated meticulously by Bishop & Dorf [3]. This book follows the conventional organization of control books similar to that of Nise [4]. Both the book dwells on common mathematical models, frequency and time domain response, but Chapter 11, 12 and 13 based on state variable approach, robust controllers and digital controller are unique and deepens the advanced concept of control systems in detail.

The book by Fadali & Visioli [8] is based entirely on digital control system. It starts with the use of digital system along with the selection of discretization and it's subsequent effects. The state space and optimal control based on digital control algorithm has been discussed along with the model of Analog to Digital Controller (ADC), Digital to Analog Controller (DAC) and Zero-Order Hold (ZOH). Stability, practical issues and non-linear control has also been discussed in subsequent chapters with attention to every minute detail.

The series of web lectures [7] complements the resources accumulated from the above mentioned sources. These lectures cover a wide area of the digital control domain with stress on examples based on power system in abundance. However these are pretty advanced lectures and demand the basic digital control understanding as prerequisite.

Mudi and Pal [10] discuss the fuzzy type PD & PI controller developed to control any type of process using inherently unstable and even non-linear processes. This controller however has three tuning parameters to be tuned based on operator experience.

3. Problem Statement

Of the various digital methods available there is no common platform to design them and judge them for specific application depending on the performance criteria. The digital control technique becoming popular, the beginners' guides to design and select a digital controller and practically implement them in microcontrollers are not available in contemporary literature or remotely accessible.

This paper discusses the different digital controller available and uses them to control the position of a DC motor which is not available till now, along with a new approach to the pole placement design without using the state space formalism.

Moreover the armature controlled DC motor position transfer function has an inherent pole at origin which makes the system limiting stable and hence unsuitable to use an integral control action. Therefore the system might offer an offset to a step input.

1. Proposed Solution

In this section various controllers are designed to act as a controller to the DC motor position control system.

Now the armature controlled DC motor position control plant can be designed as

$$G(s) = \frac{\theta(s)}{V(s)} = \frac{K_t}{s\{(sJ+f)(sL+R)+K_tK_a\}}$$

Here,

Θ is the position, *V* in the applied armature voltage, *L* and *R* is the armature inductance and resistance respectively. *J* is the moment of inertia of the rotor; *f* is the viscous force constant. K_e and K_t are the back emf and toque constant respectively.

The values of the physical parameters of the motors have been taken from data sheet of a real motor [11].

The resulting transfer function becomes

$$G(s) = \frac{350581173.5283}{s(s+41.6)(s+1.714 \times 10^6)}$$

Now we see that there is a pole at very far left hand side of the s-plane which has a very minor effect on the plant except in case of very high loop gain. Hence it is cancelled out by the dominant pole at -41.6, reducing it to

$$G(s) = \frac{2045.1035}{s(s+41.6)}$$

Here the pole at origin and -41.6 gives rise to a limiting stable system, hence only negative feedback cannot control the system.

Now this plant has an approximate gain crossover frequency of 37 radians/second or 5.8Hz. Hence choosing 1 millisecond sampling period has a much faster dynamics than that of the plant.

For this system we will use Zero-Order Hold sampling theorem since it is the most practical type of transform when a motor has to be controller physically because of the use of Zero-Order Hold Circuit. The sampled time model hence is a cascade of the system itself and the zero order hold.

$$G_0G(z) = \frac{0.0010085(z+0.9885)}{(z-1)(z-0.9593)}$$

Now the controllers are discussed one by one

A. DEAD-BEAT AND DAHLIN CONTROLLER

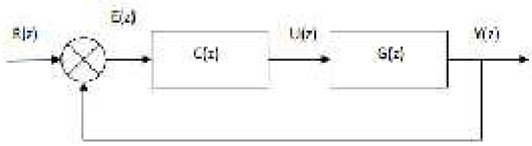

Figure i: Digital Control System

A general digital control system is shown in the figure; here the plant is actually the cascade of the zero-order hold and the plant itself. Now we can write

$$\frac{Y(z)}{R(z)} = T(z) = \frac{C(z)G(z)}{1 + C(z)G(z)}$$

We can re-arrange to get the controller transfer function as

$$C(z) = \frac{1}{G(z)}\frac{T(z)}{1 - T(z)}$$

Now we can define the total transfer function of the system and derive the necessary controller needed. However the controller designed must be causal.

In dead-beat controller we want the output to follow the input after k samples. Now k-must be chosen so that the controller is causal, since

$$T(z) = z^{-k}$$

Now k is chosen to be 2 to make the controller realizable and causal. Hence the controller transfer function becomes

$$C(z) = \frac{992.4071(z - 0.9593)}{(z+1)(z + 0.9885)}$$

On similar lines, the Dahlin controller is developed, however the response is based on exponential smooth rise

$$Y(s) = \frac{1}{s}\frac{e^{-us}}{1 + sq}$$

The z-transform equivalent becomes

$$Y(z) = \frac{z^{-k-1}(1 - e^{-T/q})}{(1 - z^{-1})(1 - e^{-T/q}z^{-1})}$$

Hence the transfer function is

$$T(z) = \frac{Y(z)}{R(z)} = \frac{z^{-k-1}(1 - e^{-T/q})}{(1 - z^{-1})(1 - e^{-T/q}z^{-1})}(1 - z^{-1})$$

for step input.

Hence the controller becomes

$$C(z) = \frac{94.4683(z - 0.9593)}{(z + 0.9885)(z + 0.09516)}$$

B. POLE PLACEMENT

Here the specifications are absolutely essential to design the controller which are defined to be

a. 20% overshoot
b. 100 milliseconds settling time

Now using this parameters the value of damping ratio ζ and natural undamped frequency ω_n are calculated according to the standard formula as

ω_n = 37.8543 and ζ = 0.4559. The pole location corresponding to these values in the z-plane is -0.9823 ± j0.033. Hence the procedure is termed as pole placement with reference to the criteria of placing the poles in z-plane.

Now let us observe the angle criterion of root locus by placing -0.9823 + j0.033 in place of z in the system design. It results in an angle of 7.6209^o. Therefore only gain in cascade is not going to make the root locus pass through the desired point; hence a controller of the form below is suggested

$$C(z) = K\frac{z - n}{z - p}$$

Now we arbitrarily place the zero at 0.6, and then apply the angle condition in the controller. It happens so that a pole located at 0.8338 makes the root locus pass through the desired poles. Now gain at that point is evaluated using the magnitude criteria of the root locus and found to be 0.38585.

Hence the controller becomes

$$C(z) = 0.38585\frac{z - 0.6}{z - 0.8338}$$

C. PD-TYPE FUZZY CONTROLLER

The fuzzy logic controller discussed here is designed is universal and can be applied to a wide range of systems. The paper from which the rule base and membership functions are adopted has both PI and PD type controllers, PD-type being the obvious choice for a first order integrating system.

4. Simulation1

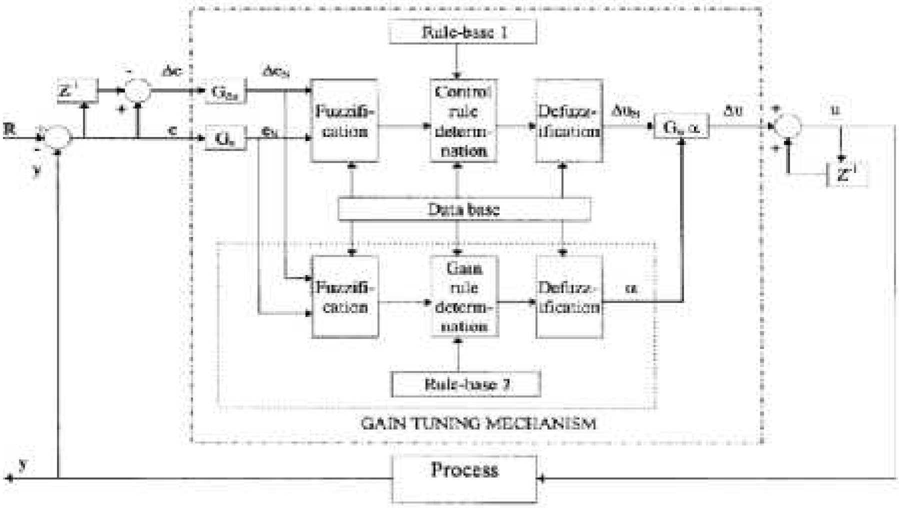

Fig ii: Structure of the controller

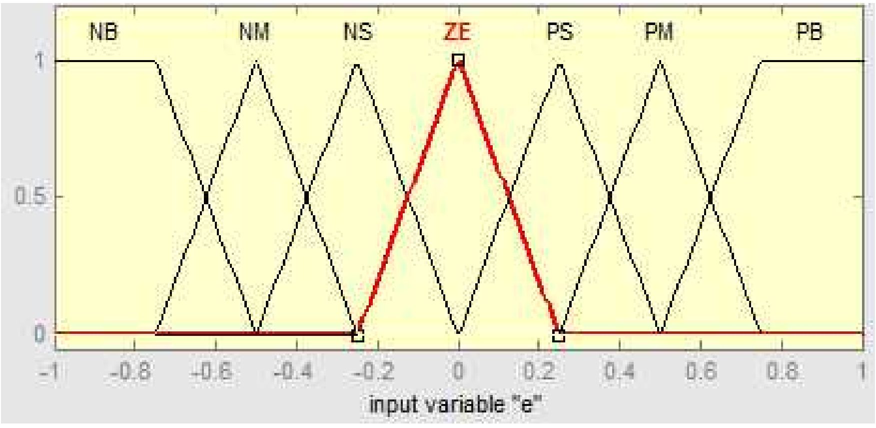

Fig iii: Membership function for inputs

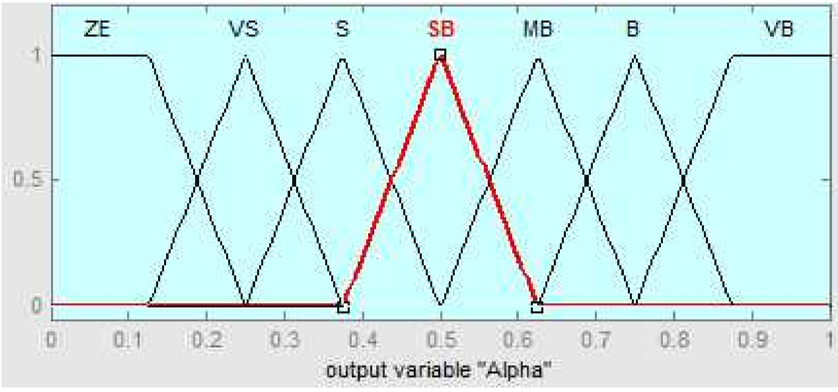

Fig iv: Membership function of scaling factor

Δe\e	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB

Table i: Calculation of output

Δe\e	NB	NM	NS	ZE	PS	PM	PB
NB	VB	VB	VB	B	SB	S	ZE
NM	VB	VB	B	B	MB	S	VS
NS	VB	MB	B	VB	VS	S	VS
ZE	S	SB	MB	ZE	MB	SB	S
PS	VS	S	VS	VB	B	MB	VB
PM	VS	S	MB	B	B	VB	VB
PB	ZE	S	SB	B	VB	VB	VB

Table ii: Calculation of scaling factor

In this controller both the input and change of input are scaled to have a value in the range of -1 to 1. The output function is not only the output but also a scaling factor multiplied with it, calculated on the same rule base.

5. Simulation2

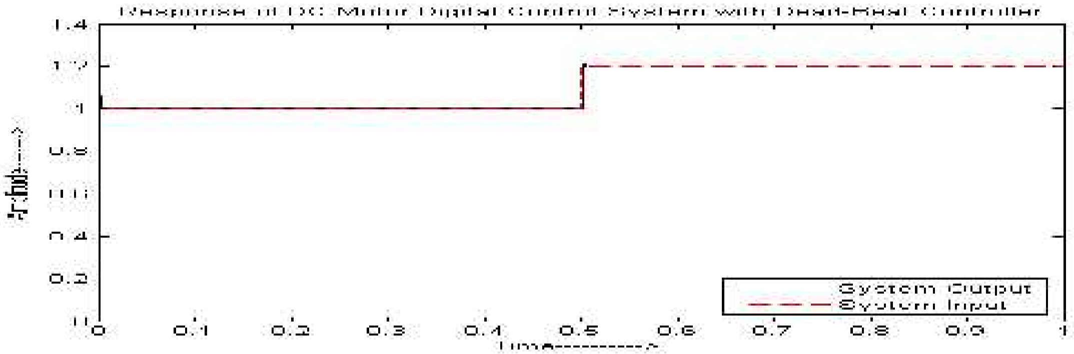

Fig v: Response of Dead-Beat Controller

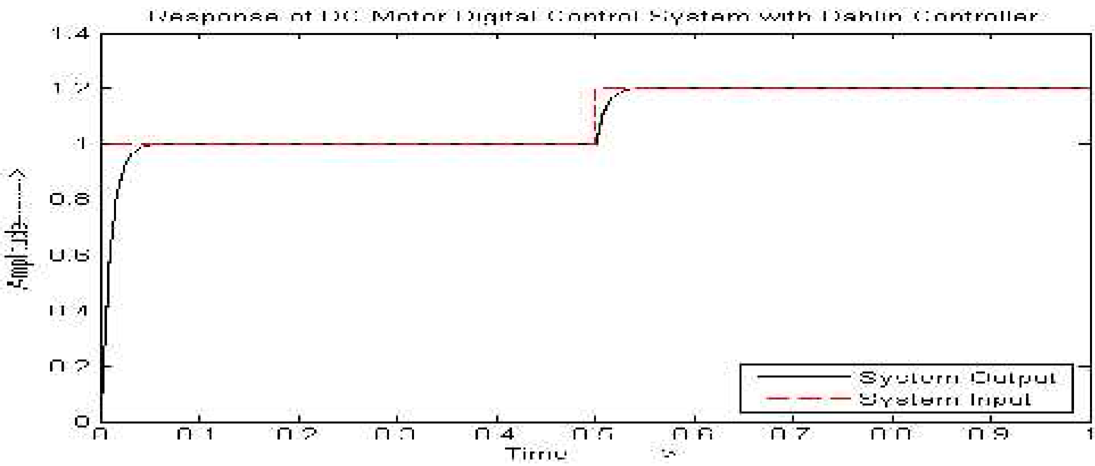

Fig vi: Response of Dahlin Controller

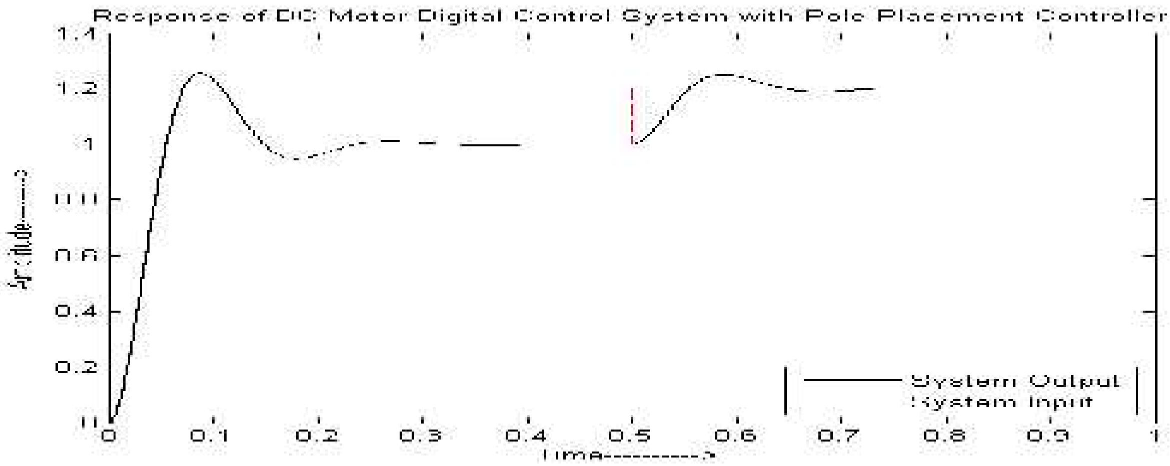

Fig vii: Response of Pole Placement controller

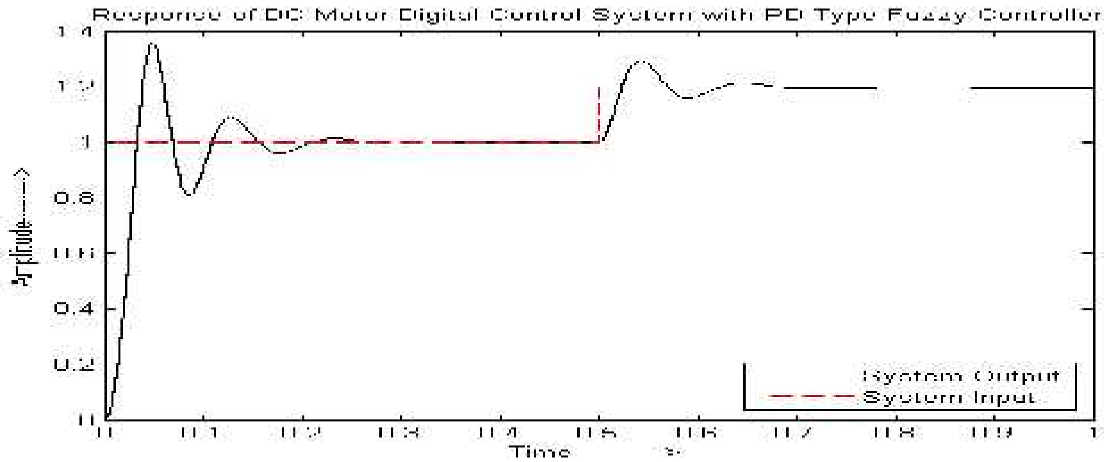

Figure viii: PD type fuzzy controller

6. Simulation Results Discussion

The time-domain analysis and performance indices based on error criterion are given below

	Rise Time t_r (seconds)	Percentage Overshoot (Percent)	Setlling Time t_s (Seconds)

Dead beat Controller	0.002	6.1	0.004
Dahlin Controller	0.038	0	0.038
Pole Placement	0.054	25.74	0.217
Fuzzy Controller	0.033	35.61	0.195

Table iii: Time domain comparison

	IAE	ITAE	ISE	ITSE
Dead beat Controller	0.0022	2.2812×10^{-4}	0.0018	4.6393×10^{-4}
Dahlin Controller	0.0133	0.0013	0.0067	1.71×10^{-4}
Pole Placement	0.0620	0.0086	0.0304	0.0013
Fuzzy Controller	0.0480	0.0064	0.0223	8.0126×10^{-4}

Figure iv: Performance Indices comparison

6. Conclusion

Here we review the various performance specification. From the time domain response we see that the dead beat controller gives the best performance with tolerable percentage overshoot and rise and sampling time in 2nd and 4th sample. Fuzzy controller even giving a good rise time it has a very high overshoot. Pole placement deviates from the ideal controller configuration due to the fact that the feedback is slightly greater than unity. But the best performance is obtained by Dahlin’s controller without any overshoot and gives the best settling time.

But Dahlin's controller has an advantage over the Dead-Beat controller, which is not just the elimination of overshoot, but the control action which is much smoother than the dead-beat controller.

7. Scope Work

Now if we observe the output of the controller itself, we see that it is practically unrealizable for this motor. Hence a few modifications are necessary.

To make the controller output a smaller voltage, the gain of the controller needs to be reduced, however to keep the total loop gain constant we find it suitable to use a mechanical gain i.e. a gear assembly to the output shaft.

Since the output of the microcontroller is uni-polar but the control signal being bipolar, we just add a certain offset in the microcontroller before processing. Then after the signal shape remains constant, we clamp down the signal to form a bi-polar signal.

Then the reduced controller z-transform function is then operate with it's inverse and the resulting difference equation is easily implemented in the microcontroller.

Most microcontrollers do not come with in-built ADC but instead Pulse Width Modulation is used with a low pass filter to use t as analog output.

References

i) Landau Ioan D. and Gianluca Zito, "Digital Control Systems Design, Identification and Implementation" Springer-Verlag London Limited 2006. ISBN-10:1846280559

ii) Ibrahim Dogan "Microcontroller Based Applied Digital Control" John Wiley & Sons Ltd. ISBN 0-470-86335-8

iii) Dorf Richard & Robert Bishop July 2014 "Modern Control Systems" 12th Edition Pearson New International. ISBN: 9781292037127

iv) Nise Norman S. December 2010 "Control Systems Engineering", 6th Edition John Wiley & Sons Ltd. ISBN : 978-0-470-54756-4

v) Control Tutorials for MATLAB and Simulink - DC Motor Position: System Modeling. Retrived on April17, 2016.

vi) National Programme on Technology Enhanced Learning (NPTEL) – Digital Control System. Retrieved on April 17, 2016 from "http://nptel.ac.in/courses/108103008" June 27, 2012 by Indrani Kar, Somnath Majhi, Department of Electrical & Electronics Engineering Indian Institute of Technology Guwahati.

vii) Fadali M. Sami & Antonio Visioli September 2012 "Digital Control Engineering Analysis and Design" 2nd Edition Academic Press. ISBN-13: 978-0123943910 9

viii) Starr Gregory P. November 2006 "Introduction to Applied Digital Control" 2nd Edition, Department of Mechanical Engineering, The University of New Mexico.

ix) Mudi Rajani K., Nikhil R. Pal, "A Robust Self-Tuning Scheme for PI and PD Type Fuzzy Controllers" IEEE Transactions On Fuzzy Systems, Vol. 7, No. 1, February 1999.

10) http://www.moog.com/literature/MCG/moc23series.pdf.