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Proposed Simple and Efficient Control Algorithm Design Approach

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Abstract

The present work proposes a simple and efficient control algorithm design approach for controlling a wide variety of systems, for achieving an important design compromise; acceptable stability, and medium fastness of response. The proposed approach is based on selecting control algorithm gains based on system under control parameters. Linear expressions for calculating controller gain are derived, as well as, a control algorithm that can be applied on microcontroller as control unit. The proposed controllers design approach was tested for first, second and higher order systems using MATLAB/Simulink software.

Keywords: Mechatronics, Control algorithm design, Modeling, Simulation..

INTRODUCTION

One of the most important decisions in the modern Mechatronics systems design process are selection, design and integration of two directly related to each other subsystems; Control unit and control algorithm. Both are selected and designed based on particular Mechatronics system purposes, destination, desired performance, precision, efficiency, costs, functionality and complexity.

The terms control system design can be referred, but not limited, to any of the following; a) The process of selecting feedback gains (poles and zeros) that meet design specifications in a closed-loop control system, b) Developing a knowledge base, Inference mechanisms and communication interfaces for intelligent control or, c) writing corresponding control program/algorithm e.g. for PLC, CNC or Microcontroller to control the process [1, 2].

The scope of this paper is limited to continuous PID control algorithm design. In this scope, most control algorithm design methods are iterative, combining parameter selection with analysis, simulation, and insight into the dynamics of the plant. Beside worldwide known and applied controllers design method including Ziegler and Nichols known as the “process reaction curve” method [2], and that of Cohen and Coon [3], different control algorithm design approaches have been proposed, available and can be found in different texts including [4-16], each method has its advantages, and limitations, where in [5] R. Matousek, presented multi-criterion optimization of PID controller by means of soft computing optimization method HC12. In [8] Saeed Tavakoli presented using dimensional analysis and numerical optimization techniques, an optimal method for tuning PID controllers for FOPDT system. In [12] K. J. Astrom Introduced an improved PID tuning approach using traditional Ziegler-Nichols tuning method with the help of simulation aspects and new built in function. In [13] L. Ntogramatzidis, presented a unified approach, enable the parameters of PID, PI and PD controllers (with corresponding approximations of the derivative action when needed) to be computed in finite terms given appropriate specifications expressed in terms of steady-state performance, phase/gain margins and gain crossover frequency. In [14] M. Saranya proposed an IMC tuned PID controller method for the DC motor for robust operation. (Fernando G. Martons, 2005) proposed a procedure for tuning PID controllers with Simulink and MATLAB... In [15] Juan Shi presented some derivation of IMC controllers and tuning procedures when they are applied to SOPDT processes for achieving set-point response and disturbance rejection tradeoff. In [16] Farhan A. Salem, proposed a new and simple controllers efficient model-based design method, based on relation controller's parameters and system's parameters. Many tuning formulas for PID controllers have been obtained for FOPDT processes.

This paper modifies most of those works and others [17-20] and proposes simple and efficient control algorithm design approach for controlling a wide variety of systems, to accomplish a design compromise; an acceptable stability, and medium fastness of response, in terms of minimum PO percentage, 5T, TS, and ESS. One definition of acceptable stability is when the undershoot that follows the first overshoot of the response is small, or rarely observable

PROPOSED CONTROL ALGORITHM DESIGN APPROACH

Relating the control algorithm gains/parameters to controlled system parameters is an applied control algorithm design methodology; the resulted overall closed loop system response depends on the proper gains values calculation and selection. The relationship used to derive expressions for gain calculation, is given as by Eq. (1), where ζ, ωn T, K and L are controlled system parameters, this function to be reduced in terms of variables based on required controller type (P, PI, PD, PID) and process order, to result in expressions for calculating controllers' parameters to meet acceptable stability, and medium fastness of response. The methods applied for derivation proposed expressions include dimensional analysis to simplify a problem by reducing the number of variables to the smallest number of essential ones, mathematical modeling and solving step response for tracking acceptable stability and medium fastness of response in terms of minimum PO%, 5T, TS, and ESS, and finally analysis and evaluation of results based on trial and error and relating processes parameters to control unit parameters, considering effects of each parameter on overall system response, as a result, expressions listed in tables 1,2 are proposed for control algorithm gains selection/design for controlling a wide variety of first and second order systems

$$K_x = f_y(\zeta, \omega_n, T, K, L) \qquad (1)$$

To further improve resulted response, a simple control algorithm that is used in the feedback loop known as the rate feedback controller (also called Pseudo-Derivative Feedback, PDF), which is a simple yet effective control structure, a structure that provides all the control aspects of PID control, but without system zeros, and correspondingly removing negative zeros effect upon system response. Optionally, the PDF control can be switched on with PID control, to improve the resulted response of some systems with oscillatory response. To evaluate the proposed control algorithm design, two performance indices are used namely; the integral of the square of the error, ISE given by Eq.(2) and the absolute magnitude of the error, IAE given by Eq.(3) . These two indices weigh the error equally over the entire interval of time 0-≤ t ≤ T, the time T is chosen to span much of the transient response of the system, so a reasonable choice for second-order systems is the settling time Ts.

$$ISE = \int_0^T e^2(t)\,dt \qquad (2)$$

$$IAE = \int_0^T |e(t)|\,dt \qquad (3)$$

TESTING SETUP AND METHODOLOGY

As shown in Figure 1, for microcontroller based system, microcontroller is programmed with proposed control algorithm, where PID gains are assigned. This can be accomplished as follows; first by subjecting the system to step input of system working magnitude, (in our simulation 30 VDC), then by means of sensor readings, feeding causes step response to control algorithm, that will analyze response curve. Next, approximate the system response as first or second, then calculate plant's parameters; ζ, ωn, T, corresponding controller gains (KP, KI and KD) and the control signal value, that is send to drive circuit to control plant.

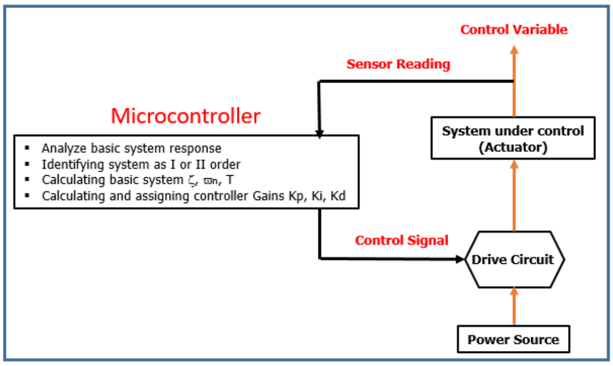


Figure 1. Block diagram representation of the proposed approach with closed loop system.

Table 1: Proposed expressions for PID parameters calculation for ***first*** order system.

Plant	PID parameters					
	K_P	**K_I**	**K_D**	**T_D**	**T_I**	**N**
PID- design For I order systems	**8*T**	**0.1*T**	T	**0.125**	**8**	**1-22**
for I order systems with small T< 0.1	**0.13*T**	**0.65/T**	**6.5*T**			

Table 2: Proposed expressions for PID parameters calculation for second order system.

Plant		PID parameters					
		K_P	**K_I**	**K_D**	**T_D**	**T_I**	**N**
ζ	ω_n	$\frac{4}{\xi\omega_n}$	$\frac{0.15\omega_n}{\xi}$	$\frac{1}{\xi\omega_n}$	0.25	4	2 ÷ 20

TESTING AND EVALUATING THE PROPOSED PID DESIGN EXPRESSIONS.

Testing results of applying derived expression for controlling different first order systems are summarized in Table 3, corresponding response curves, of original and compensated system, as well as control signal and ISE, are shown in response curves of Figures [2:6]. Testing PID expressions for second order system are summarized in Table 4, resulted response curves of Figures [7:9].

Analysis of all these response curves and others shows that applying proposed expressions results in an acceptable stability, and medium fastness of response, in terms of minimum PO%, 5T, TS, and ESS is met. Steady state error Ess, of most of the system is less than 1 %, minimum of system second order system exhibits small overshoot where the undershoot that follows the first overshoot of the response is small, or rarely observable.

Table 3: Design expressions testing results for different first order systems

PID-Controller		**T**	**K_{DC}**	**K_p**	**K_I**	**K_D**	**PO%**	Ess	**5T**	**ISE**	IAE	**PDF**
System(1)	$\frac{1}{s+1}$	1	1	8	0.1	1	0	0.08	5	3.39	1.52	off
System(2)	$\frac{1}{2s+1}$	1	2	16	0.2	2	0	0.032	1	4.96	1.48	off
System(3)	$\frac{5}{3s+1}$	3	5	24	0.3	3	0	0.0039	0.8	2.583	0.847	off
System(4)	$\frac{0.1}{0.5s+1}$	0.5	0.1	4	0.05	0.5	0		2.5	70.27	31.8	off
System(5)	$\frac{0.1}{0.1s+1}$	0.1	0.1	1.3	6.5	0.065	0	0	1.7	23.53	10.6	on

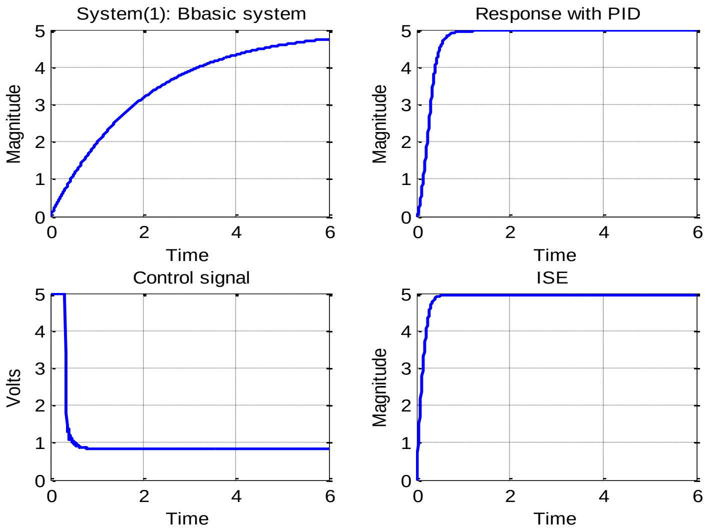


Figure 2: system (1) Response curves:

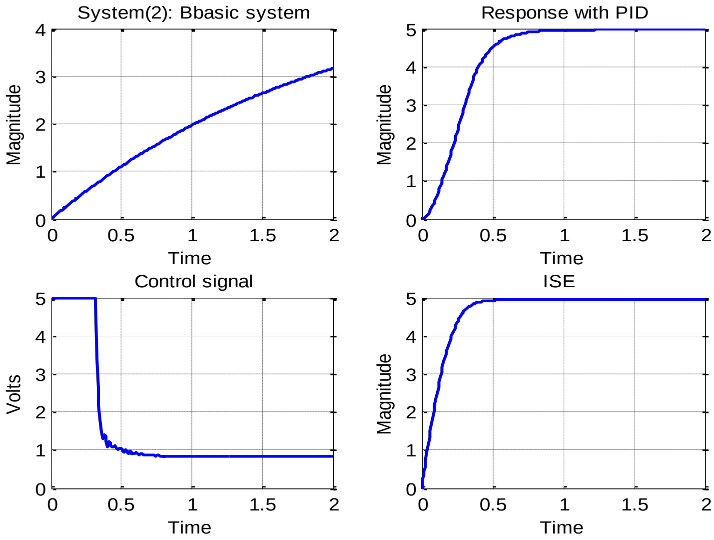


Figure 3: system (2) Response curves

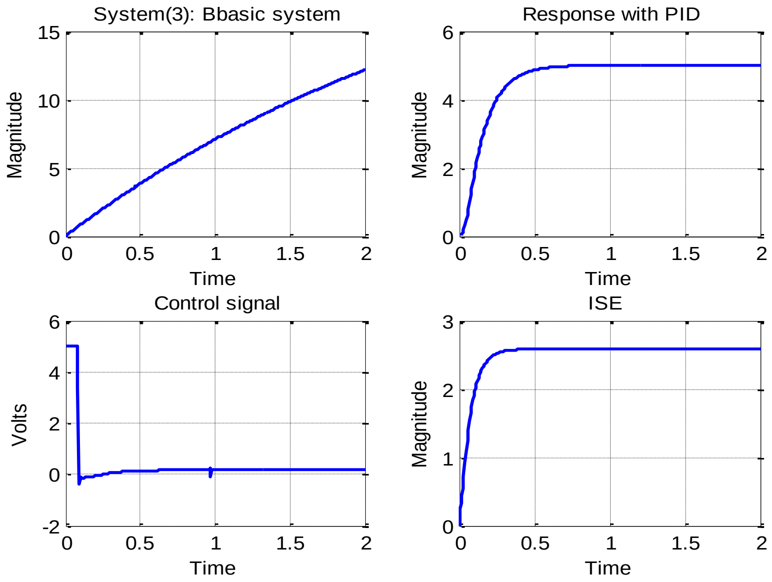


Figure 4: system (3) Response curves

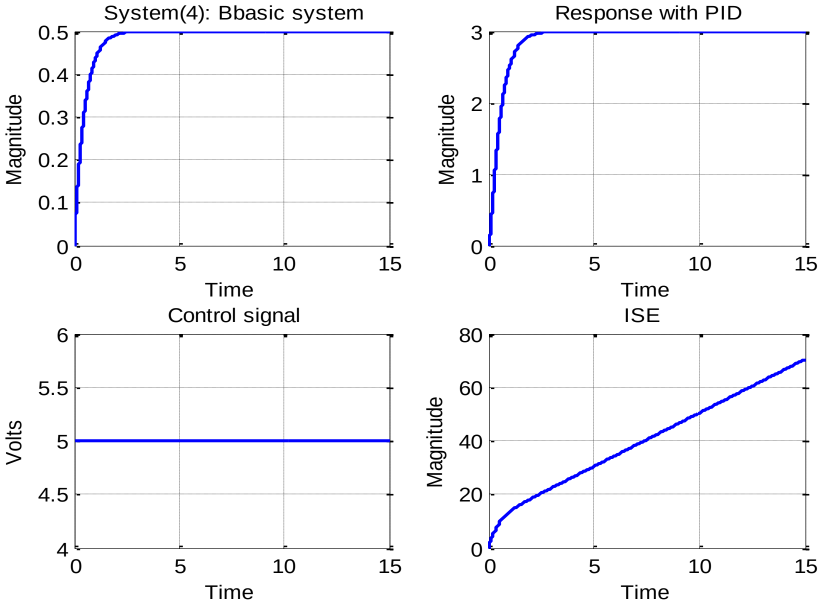


Figure 5: system (4) Response curves

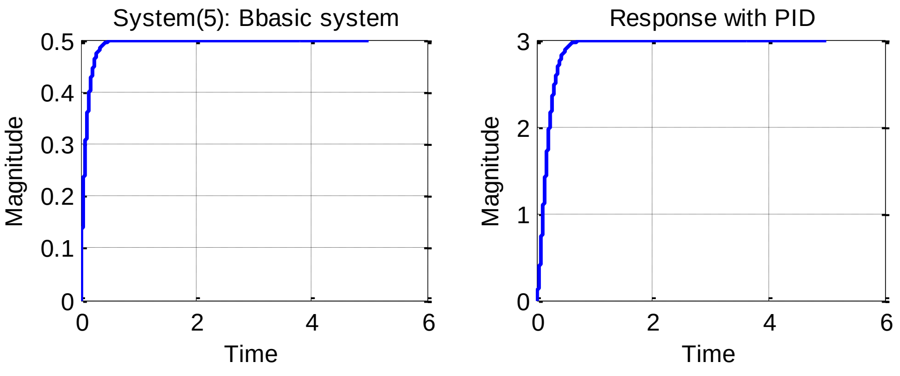


Figure 6: system (5) Response curves

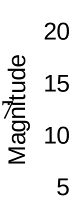


Table 4: Design expressions testing results for different second order systems

PID-Controller		ζ	ω_n	**T**	K_p	K_I	K_D	**OS%**	**Ess**	**5T**	ISE	IAE	**PDF**
system (a)	$\frac{1}{s^2+0.2s+1}$	0.1	1	10	45	1.5	10	23%	-0.030	4	10.39	3.7	off
system (b)	$\frac{1}{(s+1)(s+3)(s+5)}$	1.154	1.732	0.5	2.249	0.225	0.5	0	0.025	13	7.579	3.41	off
system (c)	$\frac{0.5}{s^2+2s+1}$	0.70	1.4142	1	4	0.3	1	13.4%	0.008	14	20.5	6.4	off

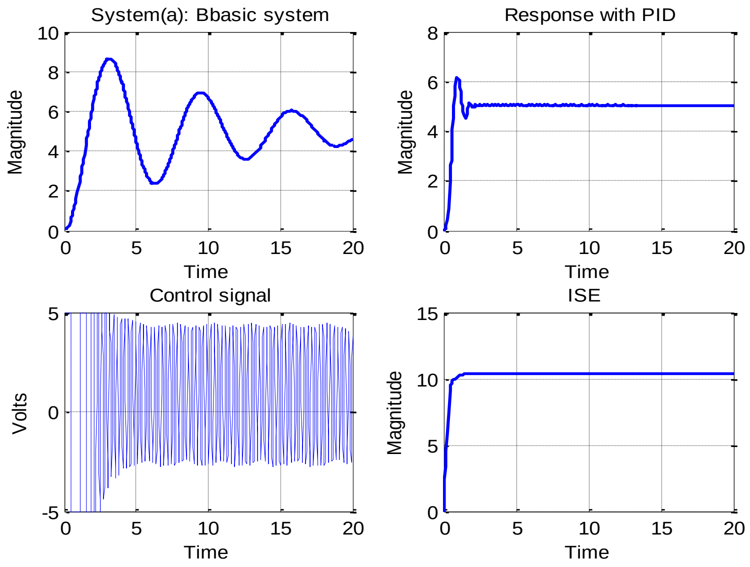


Figure 7: system (a) Response curves

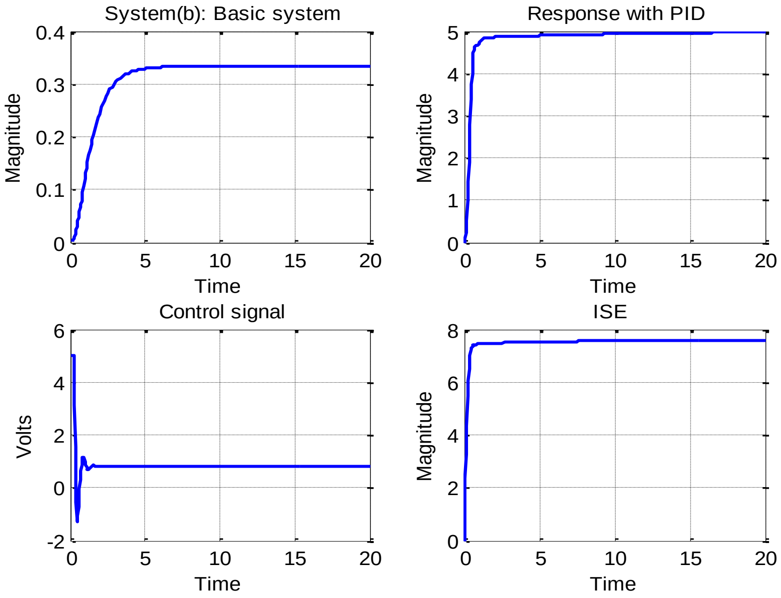


Figure 8: system (b) Response curves

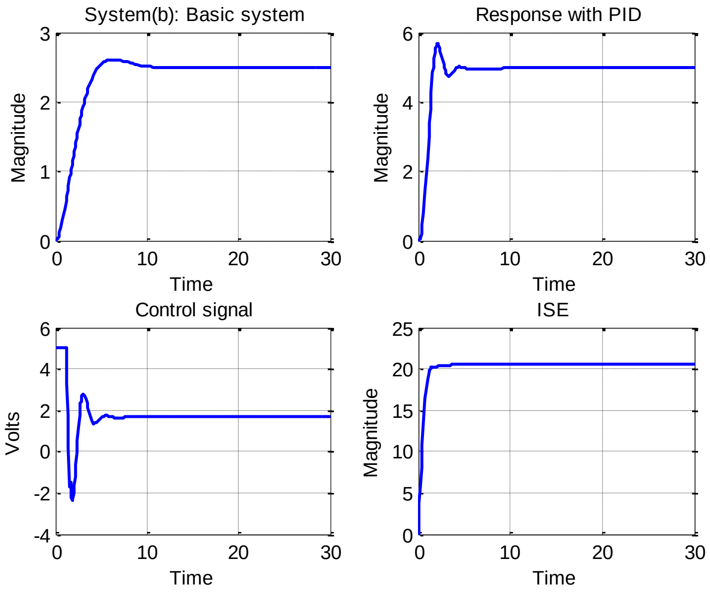


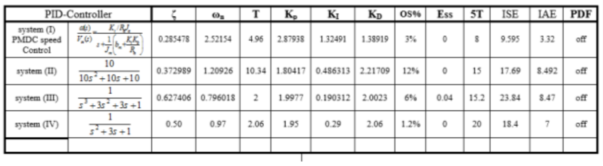
Figure 9: system (c) Response curves

5. TESTING THE PROPOSED CONTROL ALGORITHM

Simulink model, shown in Figure 10, and MATLAB *m.file* are designed and developed to test the proposed control algorithm for controlling different systems of different order, including PMDC motor speed control, second and third order system. The numerical testing results are listed in Table 5. The response curves of original and compensated systems are shown in Figures 11 - 13.

Analyzing response curves and table with numerical results shows the applicability of the proposed algorithm for controlling a wide range of first and second order system to achieve an acceptable stability, and medium fastness of response, in terms of minimum PO %, 5T, T_S, and E_{SS}.

Table 5: Control algorithm testing results for different order systems



PID-Controller		ζ	ω_n	T	K_p	K_I	K_D	OS%	Ess	5T	ISE	IAE	PDF
system (I) PMDC speed Control	$\frac{\omega(s)}{V_a(s)}=\frac{K_t/R_aJ_m}{s+\frac{1}{J_m}\left(b_m+\frac{K_tK_b}{R_a}\right)}$	0.285478	2.52154	4.96	2.87938	1.32491	1.38919	3%	0	8	9.595	3.32	off
system (II)	$\frac{10}{10s^2+10s+10}$	0.372989	1.20926	10.34	1.80417	0.486313	2.21709	12%	0	15	17.69	8.492	off
system (III)	$\frac{1}{s^3+3s^2+3s+1}$	0.627406	0.796018	2	1.9977	0.190312	2.0023	6%	0.04	15.2	23.84	8.47	off
system (IV)	$\frac{1}{s^2+3s+1}$	0.50	0.97	2.06	1.95	0.29	2.06	1.2%	0	20	18.4	7	off

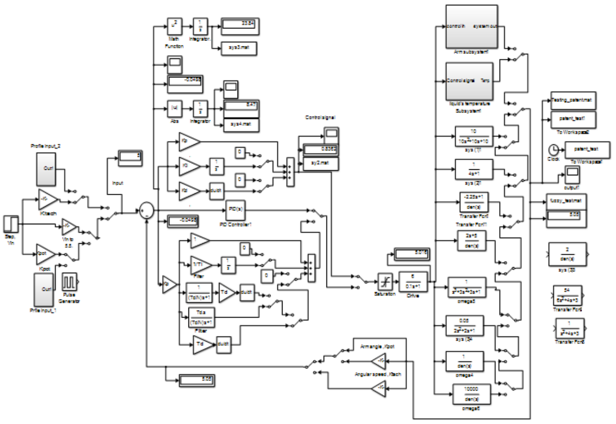


Figure 10: Simulink model for testing proposed control algorithm

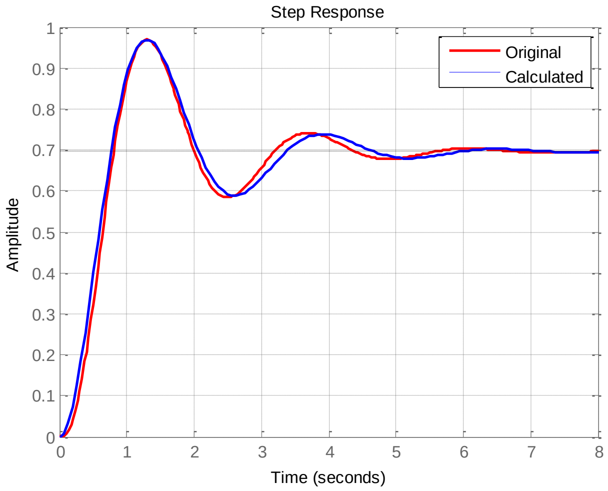


Figure 11 (a) PMDC speed control, original and calculated basic motor system response without Control

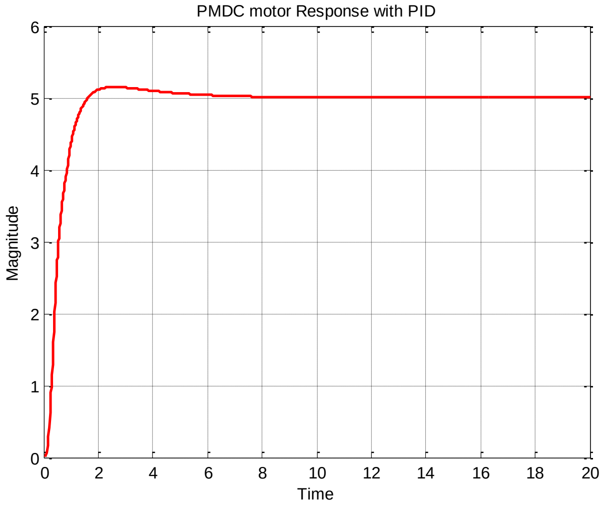


Figure 11(b): PMDC speed control, after applying PID control algorithm design

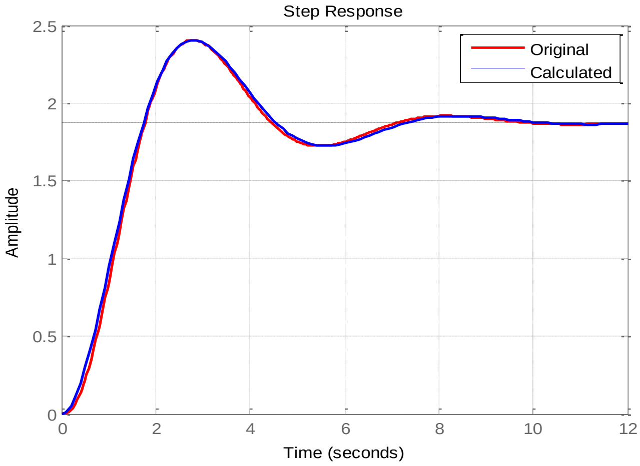


Figure 12(a): system(II), original and calculated basic system response without Control

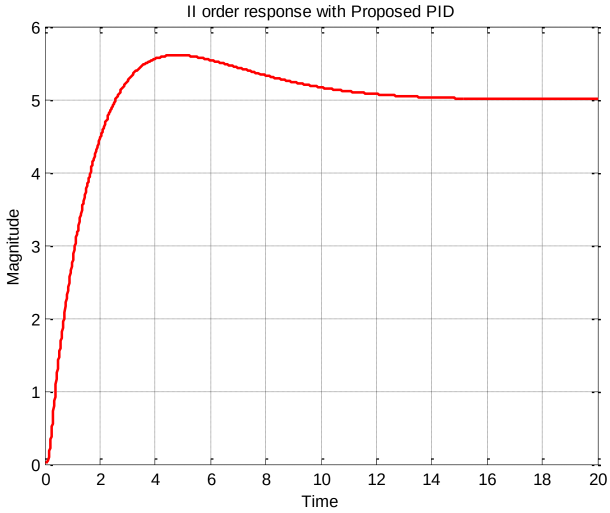


Figure 12(b): System(II) resulted response after applying PID control algorithm design

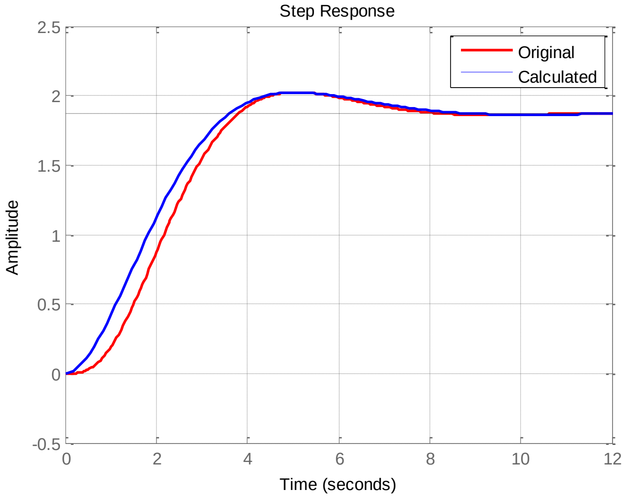


Figure 13(a): System(III), original and calculated basic system response without Control

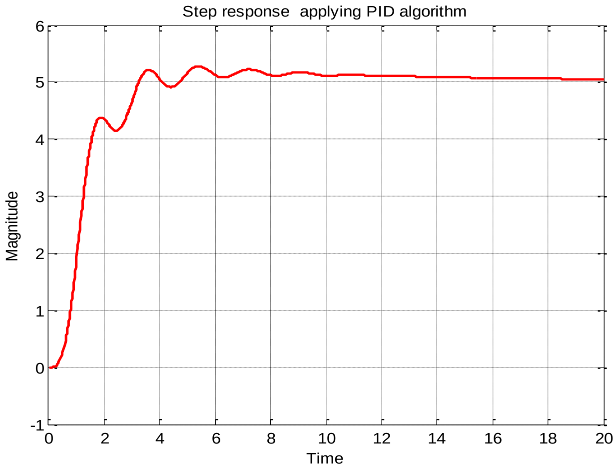


Figure 13(b): System (III) resulted response after applying PID control algorithm design

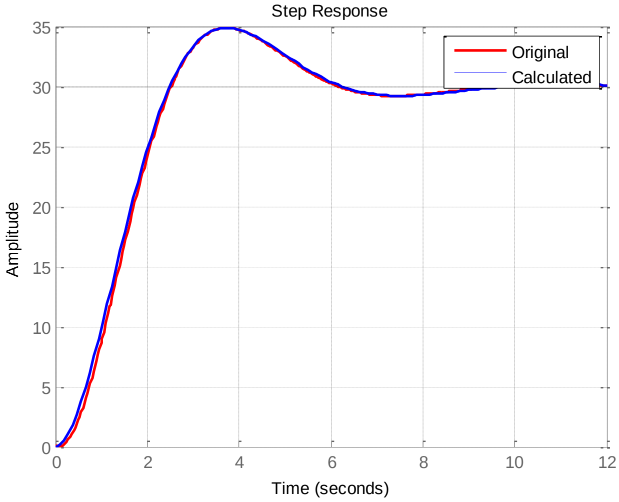


Figure 14(a): system(IV), original and calculated basic system response without Control

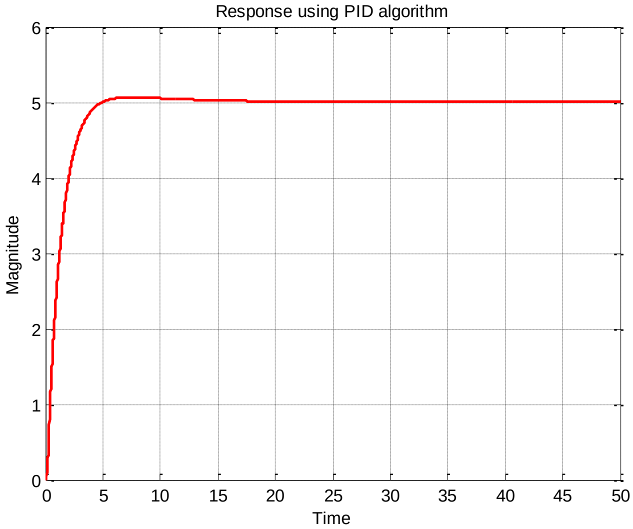


Figure 14(b): System (IV) resulted response after applying PID control algorithm design

CONCLUSION

Simple and efficient PID control algorithm design approach with expressions for calculating PID gains are proposed for controlling a wide variety of I and II order system. For higher order systems, the proposed design expressions can be considered as a mean by which designer can be as close as possible to the optimal PID gains values.

The future work aims to build physical circuit of the proposed design and test it practically, to modify written program to apply for all types of systems (FODT, SODT, first and second).

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NOMENCLATURE

ζ,	Damping ratio	-
ω_n	Undamped natural frequency	rad/s
T	Time constant	second
K	DC gain	-
L	Delay time	second
PO%, OS%	Percent overshoot	
$\mathbf{K_{DC}}$	dc gain	-
PID	Proportional plus integral plus derivative	
ISE	The integral of the square of the error,	
IAE	The absolute magnitude of the error	
Kp	Proportional controller gain	
K_I	Integral controller gain	
K_D	Derivative controller gain	
T_D	Derivative time constant	second
T_I	Integral time constant	second
Ess	Steady state error	
PDF	Pseudo-Derivative Feedback,	
PMDC	Permanent magnate Direct current Motor	