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(54) Title: A SYSTEM AND METHOD FOR AUTOMATIC TUNING FOR PID CONTROLLERS

(57) Abstract: According to embodiments of the invention, a method for identifying values for the Proportional(P) gain, Integral(I) gain and Differential(D) gain of a PID controller is disclosed. The disclosed method includes selecting a range of value for P gain between a minimum value Kpmin and a maximum value Kpmax such that a steady state output of a mathematical model of a physical system having PID controller is reasonably close to a target output; assigning a range of value for the I gain between a minimum value KImin and a maximum value KImax and for the D gain between a minimum value KDmin and a maximum value KDmax substantially same as range of value for P gain. The method further includes finding a minimum value of at least one objective function within a range from Kp min to Kp max, KI min to KI max, Kd min to Kd max by performing a numerical simulation, wherein the minimum value determines the target output or the respective values for Proportional(P) gain, Integral(I) gain and Differential(D) gain.

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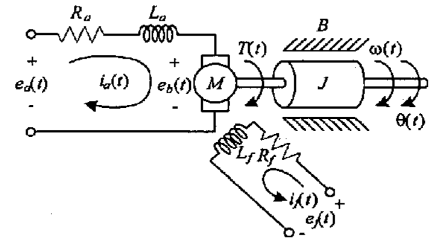

Figure 1

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Abstract

A system and method for automatic tuning for PID controllers

According to embodiments of the invention, a method for identifying values for the Proportional(P) gain, Integral(I) gain and Differential(D) gain of a PID controller is disclosed. The disclosed method includes selecting a range of value for P gain between a minimum value K_{Pmin} and a maximum value K_{Pmax} such that a steady state output of a mathematical model of a physical system having PID controller is reasonably close to a target output; assigning a range of value for the I gain between a minimum value K_{Imin} and a maximum value K_{Imax} and for the D gain between a minimum value K_{Dmin} and a maximum value K_{Dmax} substantially same as range of value for P gain. The method further includes finding a minimum value of at least one objective function within a range from K_P min to K_P max, K_I min to K_I max, K_D min to K_D max by performing a numerical simulation, wherein the minimum value determines the target output or the respective values for Proportional(P) gain, Integral(I) gain and Differential(D) gain.

FIELD OF INVENTION

This invention relates to proportional-integral-derivative ("PID") controllers, and in particular, to a method and system for automatically setting the optimal gain values associated with the proportional, integral, and derivative terms of the controller, that is, for "tuning" the controller.

BACKGROUND

A proportional–integral–derivative controller (PID controller) is a feedback control loop mechanism widely used in industrial control systems and in a variety of other applications requiring continuously modulated control. Typically, a user may have desired characteristics in mind for the controller, such as a phase margin, or a closed-loop response speed etc. Conventional applications may require that the user relate these desired controller characteristics to particular values for P, I and D gains that are used to design the controller. Relating desired characteristics to values of P, I, and D may prove difficult for the user because the relation of gains for P, I and D to the desired characteristics can be complex, nonlinear, and non-intuitive. Though many theories exist, yet determination of the gains is still considered to be a very troublesome work which is, typically, accomplished by skilled specialists. This is accomplished through many trials and errors by skilled specialists with many years of experience. In PID control, determination of parameters for proportional, integral and differential gains to improve a characteristic of the system is most important.

Several tools, methods, and theories are available for tuning PID controller gains. However, in practice, most of the known methods require a lot of engineering effort to get satisfactory results. Therefore, auto-tuning or a self-tuning PID controller were developed and there are several automatic gain tuners available in the market. In some automatic gain tuners, the controller PID gains are derived analytically based on a low-order model of the process. In other methods, the tuning is based on the optimization of some performance measure of the controller as related to the characteristics of the frequency and/or time response of the process. Persons skilled in the art will recognize that current auto-tuning techniques require frequent adjustment of the PID gains, are unreliable, and are not particularly effective. Yet, the tuning of PID gains remains a subject of great practical interest.

Hence, there remains a need for an improved method and system for automatically setting the gain values associated with the PID controllers.

SUMMARY OF THE INVENTION

According to embodiments of the invention, a method for identifying values for the Proportional(P) gain, Integral(I) gain and Differential(D) gain of a PID controller is disclosed. The disclosed method includes selecting a range of value for P gain between a minimum value K_{Pmin} and a maximum value K_{Pmax} such that a steady state output of a mathematical model of a physical system having PID controller is reasonably close to a target output; assigning a range of value for the I gain between a minimum value K_{Imin} and a maximum value K_{Imax} and for the D gain between a minimum value K_{Dmin} and a maximum value K_{Dmax} substantially same as range of value for P gain. The method further includes finding a minimum value of at least one objective function within a range from K_P min to K_P max, K_I min to K_I max, K_D min to K_D max by performing a numerical simulation, wherein the minimum value determines the target output or the respective values for Proportional(P) gain, Integral(I) gain and Differential(D) gain.

BRIEF DESCRIPTION OF DRAWINGS

Other objects, features, and advantages of the invention will be apparent from the following description when read with reference to the accompanying drawings:

Figure 1 illustrates a schematic diagram of the exemplary DC Motor; and
Figure 2 illustrates an exemplary flow diagram of a method of identifying values for the Proportional(P) gain, Integral(I) gain and Differential(D) gain of a PID controller according to an embodiment of the invention.

DETAILED DESCRIPTION OF DRAWINGS

In the drawings and specification there has been set forth preferred embodiments of the invention, and although specific terms are employed, these are used in a generic and descriptive sense only and not for purposes of limitation. Changes in the form and the proportion of parts, as well as in the substitution of equivalents, are contemplated as circumstances may suggest or render expedient without departing from the spirit or scope of the invention.

Proposed invention is illustrated with reference to an exemplary DC motor. Figure 1 illustrates a schematic circuit diagram of the exemplary DC Motor. As illustrated the circuit consists of an inductor L_a and a resistor R_a. A mathematical model governing the DC Motor with a PID feedback Control is

$$L_a.\frac{d(i_a(t))}{dt} = e_a(t) - R_a.\, i_a(t) - e_b(t)$$

$$J.\frac{d(\omega(t))}{dt} = T_m(t) - B\,\omega(t) - T_L(t) - T_f(t)$$

$$e_a(t) = e_{ref} + K_p.e_r(t) + K_i \int_0^t e_r(t')dt' + K_d \frac{d(e_r(t))}{dt}$$

$$e_r(t) = u - \omega(t)$$

$$e_b = K_b\omega(t)$$

$$T_m(t) = K_t\,.\, i_a(t)$$

where J is the moment of inertia of a rotor, $i_a(t)$ is a current, B is a motor viscous friction constant, K_b is a electromotive force constant, T_L is a load torque, T_f is a friction torque, e_b is a back electromotive force, K_t is a motor torque constant, e_{ref} is a bias voltage, u is a target speed, ω is a angular speed of the rotor, K_p is a proportional gain, K_i is a integral gain, K_d is a derivative gain and e_r is the difference between the target and the angular speeds of the rotor. The friction torque T_f and the load torque T_L are assumed to be zero in this work. Also, the motor is assumed to be excited (and controlled) through an armature circuit.

According to embodiments of the invention, objective functions may include Integrated Squared error(ISE), Integrated Absolute error(IAE), Integrated Time Squared error (ITSE), Mean Squared error (MSE), Integrated Time Absolute error (ITAE) etc. The following exemplary objective functions are used for the purpose of gains determination:

Integrated Squared error (ISE) = $\int_0^T (u - \omega(t))^2 dt$

Integrated Absolute error (IAE) = $\int_0^T |\, u - \omega(t)|\, dt$

Integrated Time Squared error (ITSE) = $\int_0^T t(u - \omega(t))^2 dt$

Mean Squared Error (MSE) = $\frac{1}{T}\int_0^T t(u - \omega(t))^2 dt$

Integrated Time Absolute Error (ITAE) = $\int_0^T t\, |u - \omega(t)|\, dt$

where T is the time period of the control horizon.

Figure 2 illustrates an exemplary method 100 of identifying values for the Proportional(P) gain, Integral(I) gain and Differential(D) gain of the PID controller according to an embodiment of the invention. The disclosed method 100 includes selecting 102 a range of value for P gain between $K_{P\,min}$ and $K_{P\,max}$ such that a steady state output of the mathematical model (exemplary method illustrated above) of the physical system having PID controller is reasonably close to a target output. According to an embodiment, the range of the P gain is selected by trial and error method. Usually, this step does not take much time, since running the mathematical model for P alone controller should be accomplished within a few minutes. The method 100 includes the step of assigning 104 a range of value for the I gain between $K_{I\,min}$ and $K_{I\,max}$ and the D gain between K_D min and K_D max substantially same as the range for P gain. The method 100 further includes the step of finding 106 a minimum value of at least one objective functions within a range K_P min to K_P max, K_I min to K_I max, K_D min toK_D max by performing numeric simulation wherein values of P gain, I gain, and D gain corresponds to the minimum value of identified corresponding objective integrals. According to an embodiment $K_{P\,min}$, $K_{I\,min}$, $K_{D\,min}$ may be zero.

The invention will now be illustrated with two exemplary sets of data of DC motors, named DS1 and DS2 for PID gains determination. The data for DS1 and DS2 are presented in Table 1 below

Table 1

Inputs	***DS1***	***DS2***
Bias voltage - e_{ref}(V)	240	10
Resistance - R_a(ohms)	11.2	7.56
Inductance - L_a(H)	0.1215	0.055
Back EMF Constant - K_b (volts/rad/s)	1.28	3.475
Rotor Inertia - J (kg m^2)	0.02215	0.068
Target speed - u (rad/s)	157.07963	10
Motor Torque constant - K_t (Nm/A)	1.28	3.475
Viscous Friction coefficient(Nms/rad)	0.002953	0.03475

The results of DS1 and DS2 are presented in table 2 and table 3 given below (for a ramped voltage input e_a(t)) respectively:

Table 2

Objective function	K_p at min. pos.	K_p, K_i at min. pos	K_p, K_d at min. pos.	K_p, K_i, K_d at min pos
ISE	200	50,9	50,0	50,9,0
IAE	200	50,30	50,0	50,30,0
ITSE	200	50,30	50,0	50,30,0
ITAE	200	2.5,30	50,0.5	2.5,30,0
MSE	200	50,30	50,0	50,30,0

(Time – 0-30 s; K_p – 0:0.5:200 (for P controller); K_p – 0:0.5:50, K_i – 0:0.5:30, K_d – 0:0.5:30)

Table 3

Objective function	K_p at min. pos.	K_p, K_i at min. pos.	K_p, K_d at min. pos.	K_p, K_i, K_d at min pos
ISE	200	50,30	50,0	50,30,0
IAE	200	50,30	50,0	20,30,0
ITSE	200	50,30	50,0	50,30,0
ITAE	200	19,30	50,0	50,30,2.5
MSE	200	50,30	50,0	50,30,0

(Time – 0-30 s; K_p – 0:0.5:200 (for P controller); K_p – 0:0.5:50, K_i – 0:0.5:30, K_d – 0:0.5:30)

The exemplary simulations are run with a h (time step for the numerical simulation) value of 0.025 seconds for P controller (second column in Tables 2 and 3). And for PI, PD and PID controllers a h value of 0.05 seconds may be chosen. For P alone controller, both *DS1* and *DS2* gave the minimum as the end point of K_p, i.e., 200. Several ranges of K_p were tried and all of them yielded the end point as the minimum. The PI, PD and PID respectively form the third, fourth and fifth columns of Tables 2 and 3. Predominantly the maximum value of K_p is one of the contributors to the minimum. For PI controller (Table 2), except for ITAE minimum, all of them have the extreme end points of K_p and K_i. Other intervals were also considered and the behaviour was pretty much the same, i.e., mostly end points dominate the minima. Another obvious thing that can be noticed is the derivative gain K_d has contributed very little to the optimal gains. According to embodiments of the invention, for a linear system with P alone control, the maximum end point should be the optimal point. For a DC motor (and possibly for other similar linear systems) end points of K_p and/or K_i should be expected as the optimal gain values.

Typically, an optimization methodology is used to determine the optimal gains. Such an optimization methodology can give local minimum as well. There is no way by which one can determine if the obtained value is local/global unless the exact solution is known, which, in general, is not the case. The proposed methodology does not suffer from such a limitation. Within the parameter range considered, the proposed method will obtain the global minimum. Also, for an optimization approach, getting local/global minimum is, in general, dependent on whether the objective function is convex or not. The proposed approach can handle both convex and non-convex objective functions, non-differentiable objective functions, step input or ramped input of any kind still obtaining the global minimum This method can serve as a benchmark for validating other optimization approaches for optimal gains determination.

We claim:

1. A method for identifying values for the Proportional(P) gain, Integral(I) gain and Differential(D) gain of a PID controller comprises:

   selecting a range of value for P gain between a minimum value K_{Pmin} and a maximum value K_{Pmax} such that a steady state output of a mathematical model of a physical system having PID controller is reasonably close to a target output;

   assigning a range of value for the I gain between a minimum value K_{Imin} and a maximum value K_{Imax} and for the D gain between a minimum value K_{Dmin} and a maximum value K_{Dmax} substantially same as range of value for P gain; and

   finding a minimum value of at least one objective function within a range from K_P min to K_P max, K_I min to K_I max, K_D min to K_D max by performing a numerical simulation, wherein the minimum value determines the target output or the respective values for Proportional(P) gain, Integral(I) gain and Differential(D) gain.

2. The method as claimed in claim 1, wherein $K_{P\,min}$, $K_{I\,min}$, $K_{D\,min}$ are zero.

3. The method as claimed in claim 1, wherein the physical system is a DC motor.

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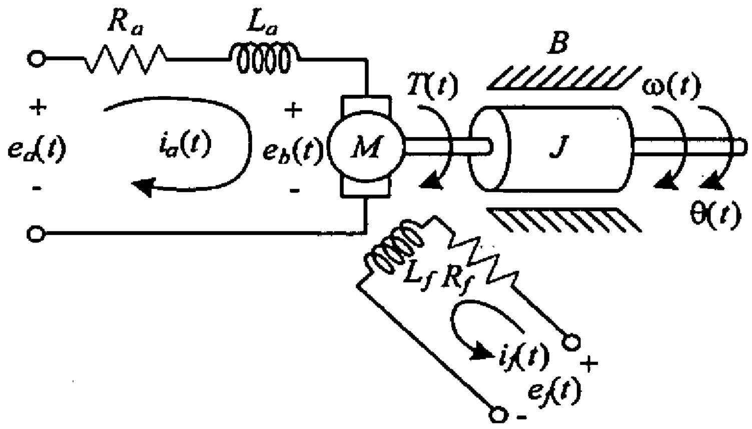

Figure 1

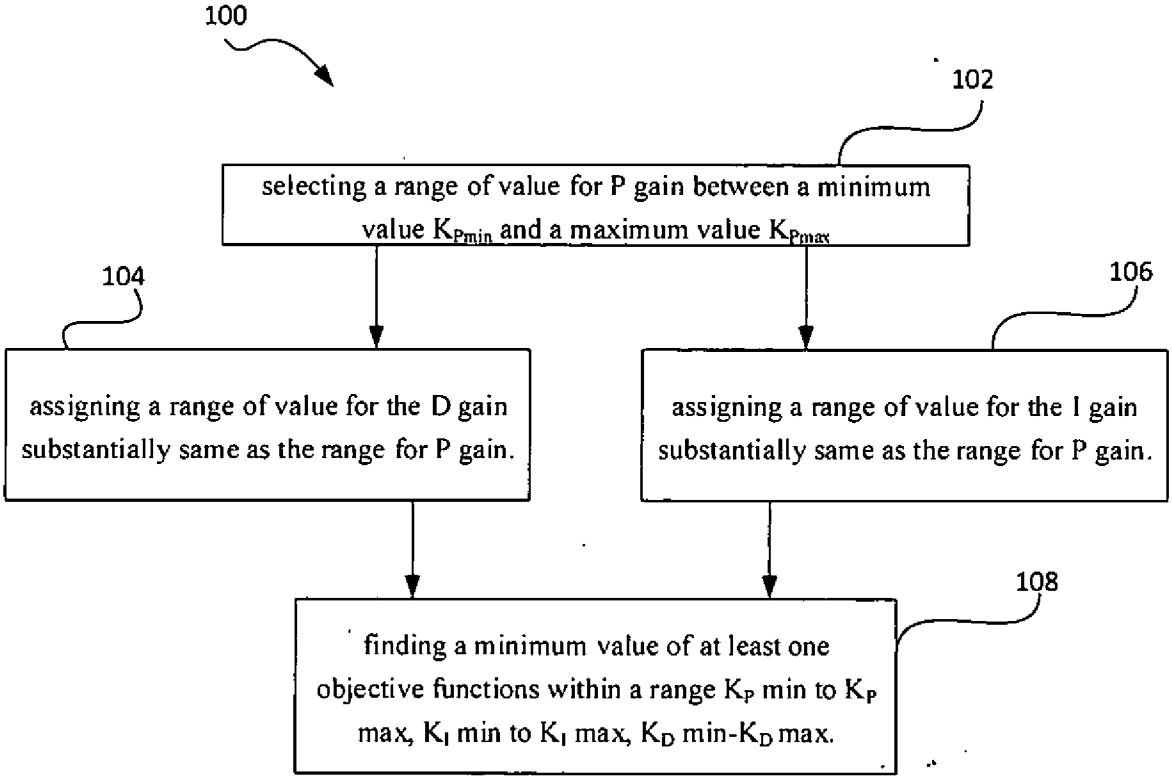

Figure 2

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