(12)Indian Patent Application

(21) Application Number: 201941009521

(22) Filing Date: 12/03/2019 (43) Publication Date: 18/09/2020

(71) Applicant(s): L&T TECHNOLOGY SERVICES LIMITED

(72) Inventor(s): Anand, G

(51) International Classifications: G05B 13/02 G05B 11/42 H04R 3/02 G01R 31/34 B62D 6/00

(54) Title: METHOD AND SYSTEM FOR PREDICTION OF FAILURE IN PID CONTROLLERS

(57) Abstract: According to an embodiment, a method and system for predicting one or more technical failures in a system with a PID controller is disclosed. The disclosed method includes forming a transition matrix using Proportional gain, Integral gain and Derivative gain and a plurality of technical parameters of the linear system and determining Proportional gain, Integral gain and Derivative gain using one or more gain determination methods for a desired steady state value of the system. The disclosed method further includes performing a parametric study on the transition matrix by varying one of the gain values at a time, computing the metrics to identify the Degree of Non-Normality for the system using identified Proportional, Integral and Derivative (PID) gains and obtaining monotonically decaying norm of the transition matrix using identified PID gains, such that the system has at least one of the faulty Proportional, Integral or Derivative gain value, if monotonically decaying norm is not obtained.

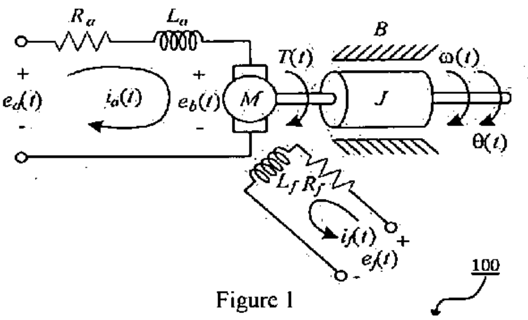


Figure 1

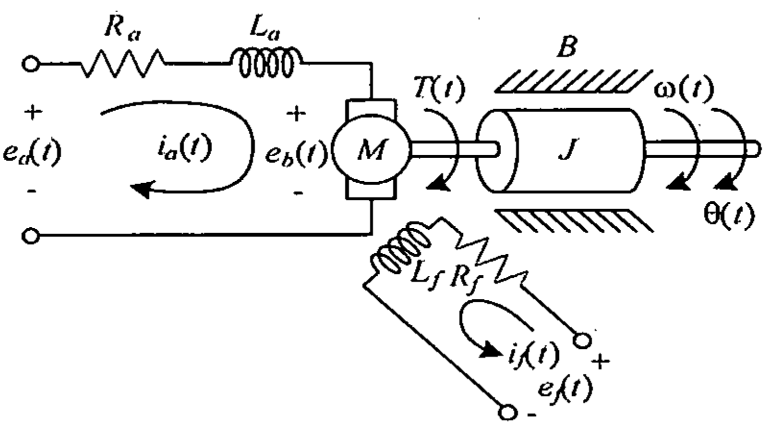
700

700318968

Abstract

Method and System for prediction of failure in PID Controllers

According to an embodiment, a method and system for predicting one or more technical failures in a system with a PID controller is disclosed. The disclosed method includes forming a transition matrix using Proportional gain, Integral gain and Derivative gain and a plurality of technical parameters of the linear system and determining Proportional gain, Integral gain and Derivative gain using one or more gain determination methods for a desired steady state value of the system. The disclosed method further includes performing a parametric study on the transition matrix by varying one of the gain values at a time, computing the metrics to identify the Degree of Non-Normality for the system using identified Proportional, Integral and Derivative (PID) gains and obtaining monotonically decaying norm of the transition matrix using identified PID gains, such that the system has at least one of the faulty Proportional, Integral or Derivative gain value, if monotonically decaying norm is not obtained.



We Claim:

1. A method for predicting one or more technical failures in a system with a PID controller, the method comprising:

   forming a transition matrix using a Proportional gain, an Integral gain, a Derivative gain and a plurality of technical parameters of the linear system; and

   determining Proportional gain, Integral gain and Derivative gain using one or more gain determination methods for a desired steady state value of the system.

2. The method as claimed in claim 1, further comprising performing a parametric study on the transition matrix by varying one of the gain values at a time, computing the metrics to identify the Degree of Non-Normality for the system using identified Proportional, Integral and Derivative (PID) gains and obtaining monotonically decaying norm of the transition matrix using identified PID gains, such that the system has at least one of the faulty Proportional, Integral or Derivative gain value, if monotonically decaying norm is not obtained.

3. The method as claimed in claim 2, wherein the Degree of non-normality may be evaluated as: DONN = $\frac{||A^T A - AA^T||}{||A||^2}$

Dated this 12th day of March 2019

Mohammed Faisal (INPA No: 1941)
Head, IPR Dept.
L&T Technology Services Limited
DLF 3rd Block, 2nd Floor,
Manapakkam, Chennai, TN, 600089

700318981

FIELD OF INVENTION

This invention relates to proportional-integral-derivative ("PID") controllers in general, and particularly to a method and system for the prediction of the failure of the PID Controllers.

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 Proportional (P), Integral (I) and Derivative (D) gains that are used to design the controller. In general, a mathematical model (possibly nonlinear) describing the system with control is linearized about a steady state and the gains are determined for this mathematical model. Many approaches, both tuning and optimization methodologies exist to arrive at a set of gain values to accomplish the desired characteristics of the system. Even though many methods exist for determining the gain values, it is also accepted that when implemented in the actual hardware, either the performance of the controller does not match the predictions or in some cases result in the physical failure of the hardware. In such scenarios, there does not seem to be a method or measures which would guide a control engineer to find the reason for the inefficacy of the control or the failure of the hardware. Any method or a set of guidelines which would assist an engineer in troubleshooting the problem is greatly desired.

SUMMARY OF THE INVENTION

According to an embodiment, a method and system for predicting one or more technical failures in a system with a PID controller is disclosed. The disclosed method includes forming a transition matrix using Proportional gain, Integral gain and Derivative gain and a plurality of technical parameters of the linear system and determining Proportional gain, Integral gain and Derivative gain using one or more gain determination methods for a desired steady state value of the system. The disclosed method further includes performing a parametric study on the transition matrix by varying one of the gain values at a time, computing the metrics to identify the Degree of Non-Normality for the system using identified Proportional, Integral and Derivative (PID) gains and obtaining monotonically decaying norm of the transition matrix using identified PID gains, such that the system has at least one of the faulty Proportional, Integral or Derivative gain value, if monotonically decaying norm is not obtained.

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 illustrate a schematic diagram of the exemplary DC Motor; and
Figure 2 illustrates an exemplary flow diagram of a method for prediction of one or more technical failure in a system with 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.

In general, an exemplary linear dynamical system with control with zero initial conditions can be written in a state space form as:

$$\frac{dX(t)}{dt} = AX(t) + Bu(t); X(0) = 0$$

where **X** (state) and **u** (control) are vectors of length n, **A** is the (constant) system matrix of size n by n and **B** is the (constant) control matrix of size n by n and 't' is time. A real matrix is said to be normal if it is equal to its transpose. When they are not equal, the matrix is said to be non-normal. This property is crucial in the transient behaviour of a linear dynamical system. An exemplary solution of the system described aforesaid equation may be written as:

$$X(t) = \exp(tA)\int_0^t \exp(-\tau A)Bu(\tau)d\tau$$

where exp is the exponential function.

By taking norm on both the sides of the equation and using the triangle inequality, the above equation may be revised as

$$||X(t)|| \leq ||\exp(tA)|| \, ||\int_0^t \exp(-\tau A)Bu(\tau)d\tau||$$

If the matrix **A** is normal, the disturbance will monotonically decay, but if the matrix **A** is non-normal, there will be a significant transient growth of the norm of the matrix exponential term ||exp(t**A**)|| known as transition matrix. And this transient growth will be amplified further by the gain values used through the control term **Bu**(t). In other words, the quantity ||exp(t**A**)|| plays a vital role in describing the transient dynamics of the system.

To further predict failure or to validate safety, "Degree of non-normality" (DONN) needs to be evaluated. According to an embodiment, Degree of non-normality may be evaluated as:

$$\text{DONN} = \frac{||A^T A - AA^T||}{||A||^2}$$

According to exemplary embodiments of the invention, failure in this invention, may be defined as the inability of the chosen gains to perform as expected or which results in the physical failure of the hardware due to the employed control.

Figure 1 illustrate a schematic diagram of the exemplary DC Motor system. The mathematical model of the DC motor system with a PID control may be given by:

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

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

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

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

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

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

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 the proportional gain, K_i is the integral gain, K_d

is the 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.

According to an embodiment, the motor may be assumed to be excited (and controlled) through an armature circuit. When this system is cast in state space form, a matrix **A** may be formed as following:

$$\mathbf{A} = \begin{pmatrix} -\frac{(K_d)}{L_a}\frac{K_t}{J} - \frac{R_a}{L_a} & -\frac{(K_b + K_p)}{L_a} + \frac{(K_d)}{L_a}\frac{B}{J} & -\frac{(K_i)}{L_a} \\ \frac{K_t}{J} & \frac{-B}{J} & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

where the state vector is given by $X = [i_a(t) \;\; \omega(t) \;\; W(t)]^T$, with $\frac{dW}{dt} = \omega(t)$. The rest of the terms form the control vector.

Computing the quantity $||\exp(t\mathbf{A})||$ as a function of different gain values may enable to demonstrate the impact of proportional, integral and derivative gain on the matrix norm $||\exp(t\mathbf{A})||$.

Figure 2 illustrates an exemplary flow diagram of a method 100 for predicting one or more technical faults in a linear system with a PID controller, according to an embodiment of the invention. The method 100 includes forming 102 a transition matrix ($||\exp(t\mathbf{A})||$) using Proportional (K_p) gain, Integral (K_i) gain and Derivative (K_d) gain and a plurality of technical parameters of the linear system. According to an embodiment of the invention, the transition matrix may be formed as illustrated in the example shown above. According to yet another embodiment, the technical parameters may include such as, but not limited to, the moment of inertia, motor viscous friction constant, electromotive force constant, motor torque constant, bias voltage, target speed, proportion gain, integral gain, the derivative gain etc.

The method 100 may further includes determining 104 Proportional (K_p) gain, Integral (K_i) gain and Derivative (K_d) gain using one or more gain determination method for a desired steady state value of the system. The method is now illustrated with exemplary data of a DC motor as provided in Table 1 below

Table 1

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

For the sake of illustration, a two-norm of the metrics is used. According to exemplary embodiments of the invention, first the proportional controller may be tuned followed by integral controller and derivative controller respectively. According to yet another embodiment, the integral controller or derivative controller may be used first, followed by other controllers, depending on the technical system considered.

The method 100 may further include performing 106 a parametric study on the transition matrix (||exp(tA)||) by varying one of the gain values at a time. For a no-control case, the matrix **A** may reduce to a 2by2 system. Using the aforesaid exemplary data, the non-normal growth for this case (the peak value of ||exp(tA)||) is 1.06 at t = 0.02. The exemplary experimental data illustrates that the effect of increasing the proportional gain (K_p) increases the transient growth of transition matrix (||exp(tA)||) at initial phase. Exemplarily, increasing (K_p) from 10 to 100, (assuming K_i=0 and K_d =0) increases the transient growth from 1.003 to 2.11. The effect of increasing the integral gain (K_i) is also to increase the growth of ||exp(tA)|| at initial phase but its effect on the transient growth (and hence the non-normality) is somewhat less pronounced as compared to that of proportional gain (K_p). Exemplarily, increasing integral gain (K_i) from 5 to 50 (with K_p = 50 and K_d=0) increases the maximum value of ||exp(tA)|| from 1.81 to 2.63. The effect of increasing the derivative gain (K_d) is to decrease the growth of ||exp(tA)||. Exemplarily, derivative gain (K_d) (assuming K_p=50 and K_i=0) is increased from 0 to 5, the maximum value of ||exp(tA)|| decreases from 1.8 to around 1.

The method further includes, computing 108 the metrics to identify the Degree of Non-Normality for the system using identified PID gains. Using the aforesaid exemplary data, the metric Degree of Non-Normality DONN for no control case is 0.593. As the value of proportional gain (K_p) is increased from 0 to 100 (assuming other gains to be zero), the peak value of ||exp(tA)|| may increases from 1.06 to 2.11. The corresponding degree of non-normality may increase from 0.593 to 0.989. As illustrated, there is about a 110% increase in the maximum value (relative to the no control case) when proportional gain (K_p) is increased to 100. And the corresponding degree of non-normality increased by 67% relative to the no control case. The corresponding degree of non-normality for integral gain (K_i) increases from 0.966 to 0.985. The degree of non-normality for derivative gain (K_d) decreases from 0.965 to 0.1886.

The method further includes, obtaining 110 monotonically decaying norm of the transition matrix using identified PID gains, such that the system has at least one of the faulty P, I or D gain value, if monotonically decaying norm is not obtained. In the illustrative example considered to achieve the monotonic decaying response, derivative gain is necessary. And the decay of ||exp(tA)|| to zero becomes gradual with increase in for derivative gain (K_d). So, a very high value of derivative gain (K_d) would delay the system to reach its steady state. But a sufficiently small value of derivative gain (K_d) may achieve the monotonic decaying ("safe") response but the system will only be a bit slow to reach its steady state.

In general, a system with high non-normality will be very sensitive to external disturbances. According to embodiments of the invention, reducing the non-normality is equivalent to making the system safer. Paradoxically, you need non-normality (i.e. P and I controllers for the above example) to reach the desired steady state, because one cannot achieve a desired steady state with D controller alone (in the example presented above).

L&T Technology Services Limited
201941009521

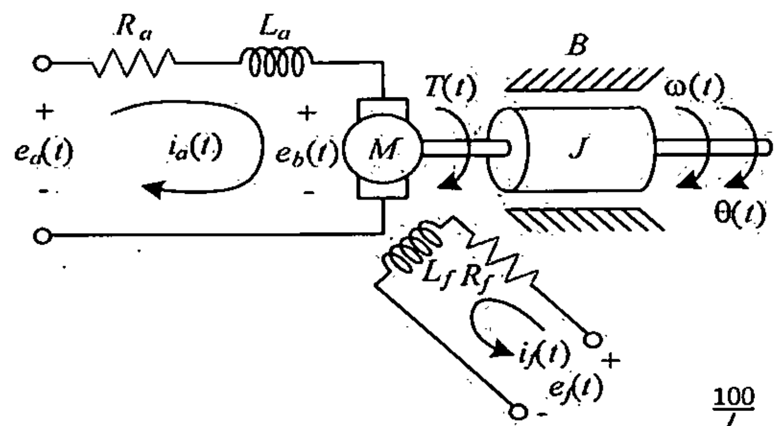


Figure 1

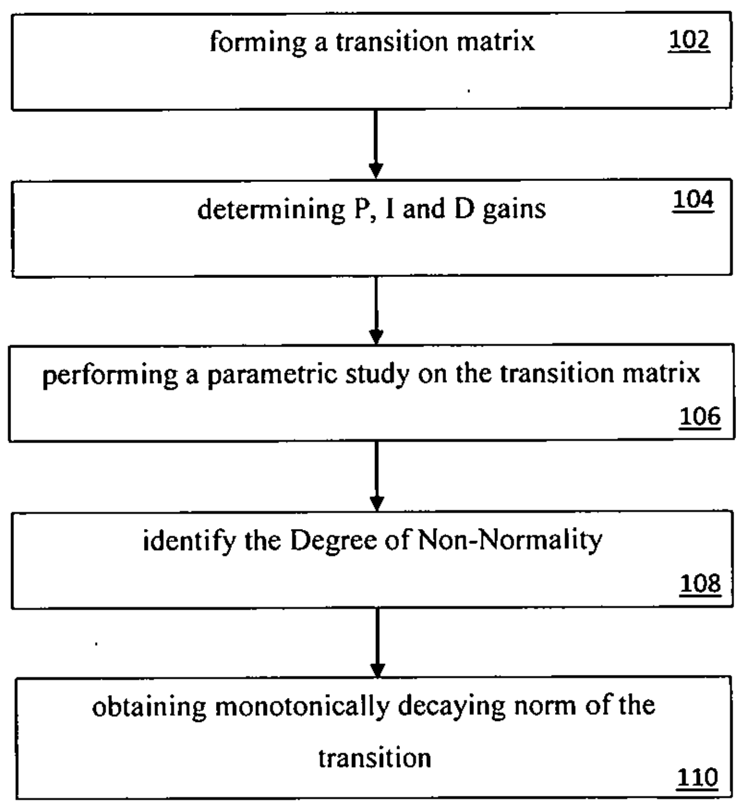


Figure 2

Mohammed Faisal (INPA No: 1941)
Head, IPR Dept.
L&T Technology Services Limited
DLF 3rd Block, 2nd Floor,
Manapakkam, Chennai – 600089