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Design Sensor-less PID Filter Controller for First Order Delays System

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Abstract

The dynamics of a first order delay system is highly nonlinear, time variant, uncertain and coupling effects. The main objectives to control of first order delay system are time response and acceleration measurements. The problem of acceleration measurements can be reduced, based on design sensor-less Proportional-Integral-Derivative (PID) filter controller in this research. Assuming unstructured uncertainties and structure uncertainties can be defined into one term and considered as an uncertainty and external disturbance, the problem of computation burden and large number of parameters can be solved to some extent. To solve the uncertainties acceleration measurements play an important role. In order to design sensor-less PID filter controller, an accurate PD surface and the derivative of PD surface plays important role. To design an accurate PD surface, stable and tuning surface slope is needed to form the structure of main PID controller. In this algorithm, the derivative of PD surface computes the second derivation of error. Regarding to this method, the challenge of system uncertainties and time response have been solved based on sensor-less acceleration linear filter controller. As this point if $S = K_1 e + \dot{e} + K_2 \sum e$ *is chosen as desired surface, if the dynamic of first order delay is derived to surface then the linearization can be realized. Because, when the system dynamic is on the surface is used the derivative of surface* $\dot{S} = K_1 \dot{e} + \ddot{e} + K_2 e$ *is equal to the zero that is a decoupled and linearized closed-loop systems dynamics. Linearization and decoupling by the above method can be obtained in spite of the quality of the first order delay dynamic model.*

Keywords: *First order delays system, position PID controller, sensor-less control algorithm, PD surface algorithm*

1. Introduction and Background

In modern usage, the word of control has many meanings, this word is usually taken to mean regulate, direct or command. The word feedback plays a vital role in the advance engineering and science. The conceptual frame work in Feed-back theory has developed only since world war II. In the twentieth century, there was a rapid growth in the application of feedback controllers in process industries. According to Ogata, to do the first significant work in three-term or PID controllers which Nicholas Minorsky worked on it by automatic controllers in 1922. In 1934, Stefen Black was invention of the feedback amplifiers to develop the negative feedback amplifier[1-3]. Negative feedback invited communications engineer Harold Black in 1928 and it occurs when the output is subtracted from the input. Automatic control has played an important role in advance science and engineering and its extreme importance in many industrial applications, i.e.,

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aerospace, mechanical engineering and robotic systems. The first significant work in automatic control was James Watt's centrifugal governor for the speed control in motor engine in eighteenth century[4-7].

There are several methods to control of first order delay system, which all of them follow two common goals, namely, hardware/software implementation and acceptable performance. In linear control theory the transfer function is linear functions which, divided into the following algorithms:

- Proportional algorithm
- Integral algorithm
- Derivative algorithm
- Proportional-Integral algorithm
- Proportional-Derivative algorithm
- Proportional-Integral-Derivative algorithm.

Control action in PID controllers can be expressed with simple model-free techniques. Given the dominance of conventional PID control in industrial control, it is significant both in theory and in practice if a controller can be found that is capable of outperforming the PID controller with comparable ease of use. Some of PID controllers are quite close to this dream. The majority of applications during the past two decades belong to the class of PID controller in industries. These controllers can be further classified into three types: the direct action (DA) type, the gain scheduling (GS) type and a combination of DA and GS types. The majority of PIDC applications belong to the DA type; here the PID controller is placed within the feedback control loop, and computes the PID coefficients through trial and error. In GS type controllers, supervisory technique is used to compute the individual PID gains. From the recent years, the majority of the research work on PID controllers focuses on the two-input PI or PD type controller. However, PID controller design is still a complex task due to the involvement of a large number of parameters in defining the coefficients and the rates of $K_p, K_v\ and\ K_i$ with each others. By expressing the coefficients in different forms, each PID structure is distinctly identified. The simple analytical procedure has developed to deduce the closed form solution for a three-input controller. This solution is used to identify the PID action of each structure type in the dissociated form [1-6]. The solution for SISO nonlinear system illustrates the effect of nonlinearity tuning. The design of a PID controller is then treated as a two-level tuning problem. The first level tunes the PID gains and the second level tunes the initial on-line tuning gains, including scale factors of PID variables [8-11]. The two type gains are deduced and explicitly have been presented by assigning a minimum time. Tuning of the characteristics of different PID structures is evaluated with respect to their functional behaviors. Proportional type control is used to responds immediately to difference of control input variables by immediately changing its influences variables, but this type of control is unable to eliminate the control input difference. PD controller is widely used in control process where the results are sensitive to exceeded of set point. This controller, like Proportional controller, has permanent variation in presence of self-limitation control. The Derivative component in this type of methodology is used to cancel outs the change process variables change in presence of quick change in controllers input. Integral term category, integrate the input signal deviation over a period of time. This part of controller is used to system stability after a long period of time. In contrast of Proportional type of controller, this type of controller used to eliminate the deviation. According to integral type of controller, it takes relatively long time [10-13]. The proportional type controller used to immediately response to the input variations. The proportional-integral (PI) controller has the advantages of both proportional and integral controller; it is rapid response to the input deviation as well as the exact control at the desired input. The combination of proportional (P) component, integral (I) component with a derivative (D) controller offered advantages in each case. This type of controller has rapid response to the input deviation, the exact control at the desired input as well as fast response to the disturbances. The PID controller takes the error between the desired joint variables and the actual joint variables. A proportional-derivative integral control system can easily be implemented. This method does not provide sufficient control for systems with time-varying parameters or highly nonlinear systems. An Important question which comes to mind is that why this proposed methodology should be used when lots of control techniques are accessible? Answering to this question is the main objective in this part. First order delay system is nonlinear and delay system. The problem of nonlinearity can be reduced in linear control technique, with the following two methods [14-15]:

- Limiting the performance of the system
- System linearization

Therefore linear type of controller, such as PD or PID cannot be having a good performance. Consequently, to have a good performance, linearization and decoupling without using many gears, online tuning control methodologies is presented and applied to linear control technique [16-18].

This paper is organized as follows:

- Second part focuses on the system modeling dynamic formulation and theory of linear control technique.
- Third part is focused on the methodology.
- Simulation result and discussion is illustrated in forth part.
- The last part focuses on the conclusion and compare between this method and the other ones.

2. Theory

Delay First Order Plant: Many industrial processes can be represented by a first order model; equation (1) shows the mathematical plant model (in *s-plane*). Discrete transfer function of this model has obtained using ZOH method, and the selected sampling period (T) is 0.1, equation (2) shows the discrete transfer functions, (in *z-plane*).

$$\boldsymbol{CS_1(s) = \frac{1}{S+1}} \tag{1}$$

and;

$$\boldsymbol{CS_1(z) = \frac{0.09516}{Z-0.9048}\ , T = 0.1} \tag{2}$$

The time delay occurs when a sensor or an actuator are used with a physical separation. Equation (3) shows the mathematical plant model (in *s-plane*). Discrete transfer functions of this model has been obtained using ZOH method, and the selected sampling period (T) is 0.1, equation (4 and 5) show the discrete transfer functions, (in *z-plane*).

$$\boldsymbol{CS_2(s) = \frac{1}{S^2 \times (S+1)}} \tag{3}$$

$$\boldsymbol{CS_2(z) = Z^{-2} \times CS_1(z)} \tag{4}$$

$$CS_2(z) = Z^{-2} \times \frac{0.09516}{Z - 0.9048}, T = 0.1 \quad (5)$$

Proportional (P) control: Proportional algorithm is used to responds immediately to difference of control input variables by immediately changing its influences variables, but this type of control is unable to eliminate the control input difference. Figure 1 shows the block diagram of proportional controller.

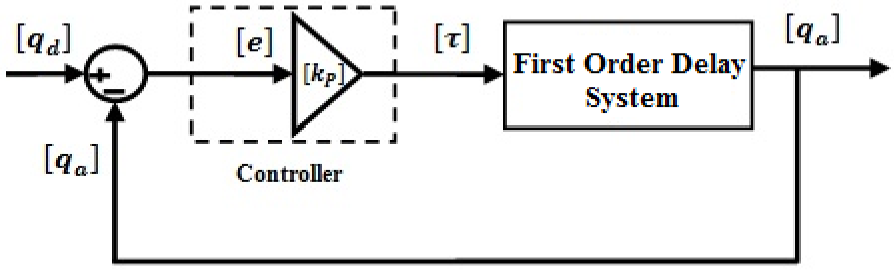

Figure 1. Block Diagram of Proportional Controller

Proportional plus Derivative (PD) control: This type of linear controller is widely used in control process where the results are sensitive to exceeded of set point. This controller, like Proportional controller, has permanent variation in presence of self-limitation control. In mathematically, the formulation of Proportional-Derivative part calculated as follows;

$$U_{PD} = K_p \times e + K_v(\frac{de}{dt}) = K_p \times e + K_v\dot{e} \quad (6)$$

The Derivative component in this type of methodology is used to cancel outs the change process variables change in presence of quick change in controllers input. Figure 2 shows the block diagram of Proportional-Derivative (PD) controller.

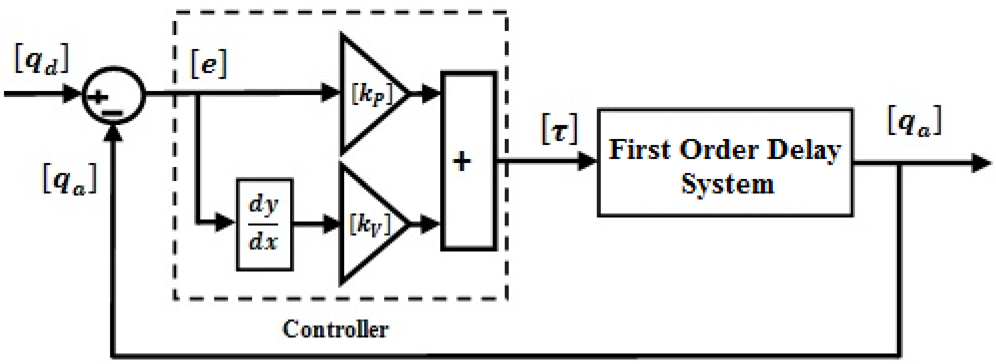

Figure 2. Block Diagram of PD Controller

Integral (I) control: This category, integrate the input signal deviation over a period of time. This part of controller is used to system stability after a long period of time. Figure 3 shows the block diagram of Integral (I) controller with application to robot manipulator. In contrast of Proportional type of controller, this type of controller used to eliminate the deviation. In mathematically, the formulation of integral part calculated as follows;

$$I = \frac{1}{T}\int e.dt = \sum e \quad (7)$$

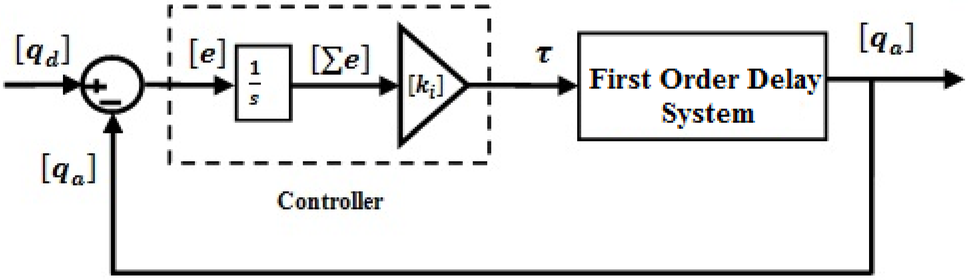

Figure 3. Block Diagram of Integral Controller

Proportional plus Integral (PI) control: According to integral type of controller, it takes relatively long time. The proportional type controller used to immediately response to the input variations. The proportional-integral (PI) controller has the advantages of both proportional and integral controller; it is rapid response to the input deviation as well as the exact control at the desired input. Figure 4 shows the block diagram of PI controller.

$$U_{PI} = K_p \times e + K_i(\frac{1}{T}\int e.dt) = K_p \times e + K_i \sum e \quad (8)$$

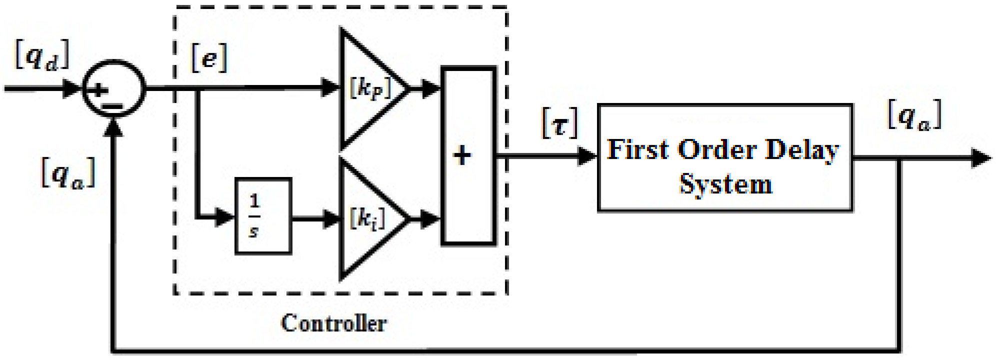

Figure 4. Block Diagram of PI Controller

3. Methodology

The combination of proportional (P) component, integral (I) component with a derivative (D) controller offered advantages in each case. This type of controller has rapid response to the input deviation, the exact control at the desired input as well as fast response to the disturbances. The PID controller takes the error between the desired variables and the actual variables to control the first order delay system. A proportional-derivative integral control system can easily be implemented. This method does not provide sufficient control for systems with time-varying parameters or highly nonlinear systems. Figure 5 shows the block diagram of PID controller. The formulation of PID controller calculated as follows;

$$U_{PID} = K_p \times e + K_i(\frac{1}{T}\int e.dt) + K_v(\frac{de}{dt}) = K_p \times e + K_i \sum e + K_v \dot{e} \quad (9)$$

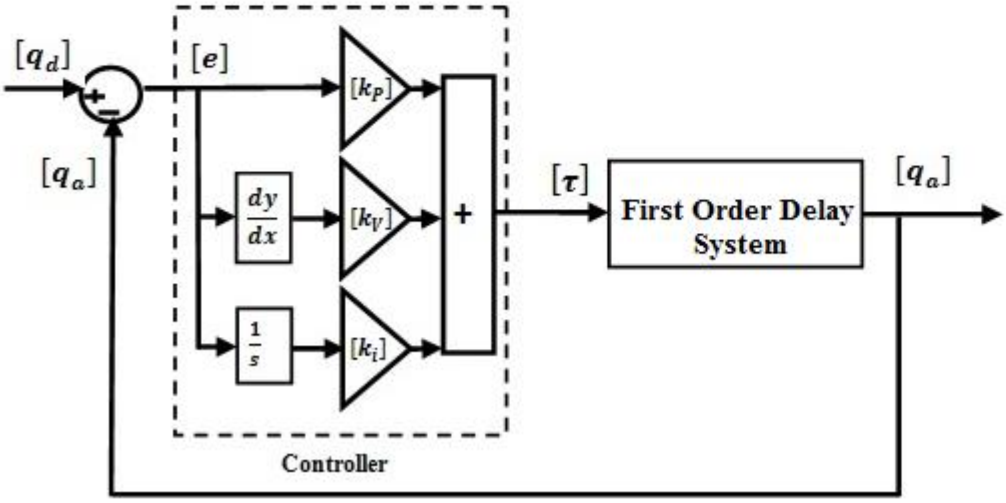

Figure 5. Block Diagram of PID Controller

To improve the system performance as well stability based on pure PID controller we have the following challenge:

- Limiting the performance of the system according to the required velocities and accelerations.

Regarding to type of system (first order delay), the rate of speed is the main objective in this research. To improve the performance of PID controller as well stability surface design is introduced. Uncertainties are very important challenges and caused to overestimation of the bounds. As this point if $S = K_1 e + \dot{e} = 0$ is chosen as desired surface, if the system's dynamic is derived to surface and used to reduce the challenge of uncertainty then the linearization and decoupling through the use of feedback, can be realized. Because, when the system dynamic is on the surface the derivative of surface $\dot{S} = K_1 \dot{e} + \ddot{e}$ is equal to the zero that is a decoupled and linearized closed-loop system dynamics. Linearization and decoupling by the above method can be obtained in spite of the quality of the system dynamic model. It is well known fact that if the uncertainties are very good compensate there is no need to use adaptive control which create the high computation burden.

According to the theory, the main important part to design this controller is surface, a time-varying surface $\boldsymbol{s(x,t)}$ in the state space $\boldsymbol{R^n}$ is given by the following formulation:

$$\boldsymbol{s(x,t) = (\frac{d}{dt} + \lambda)^{n-1}\, \tilde{x} = 0} \quad \textbf{(10)}$$

Based on (6) λ is the sliding surface slope coefficient and it is positive constant. The surface can be defined as Proportional-Derivative (PD), Proportional-Integral (PI) and the Proportional-Integral-Derivative (PID). The following formulations represented the three groups are:

$$\boldsymbol{S_{PD} = \lambda e + \dot{e}} \quad \textbf{(11)}$$

$$\boldsymbol{s(x,t)} = (\frac{d}{dt} + \boldsymbol{\lambda})^{\boldsymbol{n-1}} \left(\int_0^t \tilde{x}\, dt\right) = \boldsymbol{0} \quad \textbf{(12)}$$

$$\boldsymbol{S_{PI} = \lambda e + (\frac{\lambda}{2})^2 \sum e} \quad \textbf{(13)}$$

$$\boldsymbol{S_{PID} = \lambda e + \dot{e} + (\frac{\lambda}{2})^2 \sum e} \quad \textbf{(14)}$$

To have the stability and minimum error, the main objective is kept the surface slope $s(x,t)$ near to the zero. Therefore, one of the common strategies is to find input U outside of $s(x,t)$.

$$\frac{1}{2}\frac{d}{dt}s^2(x,t) \leq -\zeta|s(x,t)| \tag{15}$$

ζ is positive constant.

If $S(0)>0 \rightarrow \dot{S}(t) \leq -\zeta$ **(16)**

Derivative term of (s) is eliminated by limited integral from t=0 to t=t_{reach}

$$\int_{t=0}^{t=t_{reach}} \dot{S}(t) \leq -\int_{t=0}^{t=t_{reach}} \eta \rightarrow S\,(t_{reach}) - S(0) \leq -\zeta(t_{reach} - 0) \tag{17}$$

t_{reach} is the time that trajectories reach to the surface. If $S_{t_{reach}} = 0$ the formulation of t_{reach}calculated by;

$$0 - S(0) \leq -\eta(t_{reach}) \rightarrow t_{reach} \leq \frac{S(0)}{\zeta} \tag{18}$$

If $S(0) < 0$

$$0 - S(0) \leq -\eta(t_{reach}) \rightarrow S(0) \leq -\zeta(t_{reach}) \rightarrow t_{reach} \leq \frac{|S(0)|}{\eta} \tag{19}$$

This formulation is guarantee time to reach the sliding surface is smaller than $\frac{|S(0)|}{\zeta}$ since the trajectories are outside of $S(t)$.

$$if\ S_{t_{reach}} = S(0) \rightarrow error(x - x_d) = 0 \tag{20}$$

$$s(x,t) = (\frac{d}{dt} + \lambda) \quad \widetilde{x} = (\dot{x} - \dot{x}_d) + \lambda(x - x_d) \tag{21}$$

The change of sliding surface $(\dot{S})$ is;

$$\dot{S} = (\ddot{x} - \ddot{x}_d) + \lambda(\dot{x} - \dot{x}_d) \tag{22}$$

$$\dot{S} = \lambda\dot{e} + \ddot{e} \tag{23}$$

The final formulation of control design is:

$$U_{proposed} = K_p \times e + K_i \sum e + K_v\dot{e} + s(x,t) + s(\dot{x,t}) \tag{24}$$

4. Result and Discussion

Reduce the rise time: regarding to Figure 6, the PID controller's rise time is about 0.827 second but in proposed controller this delay is about zero second. Regarding to following Figure this method can reduce the rise time about 200%.

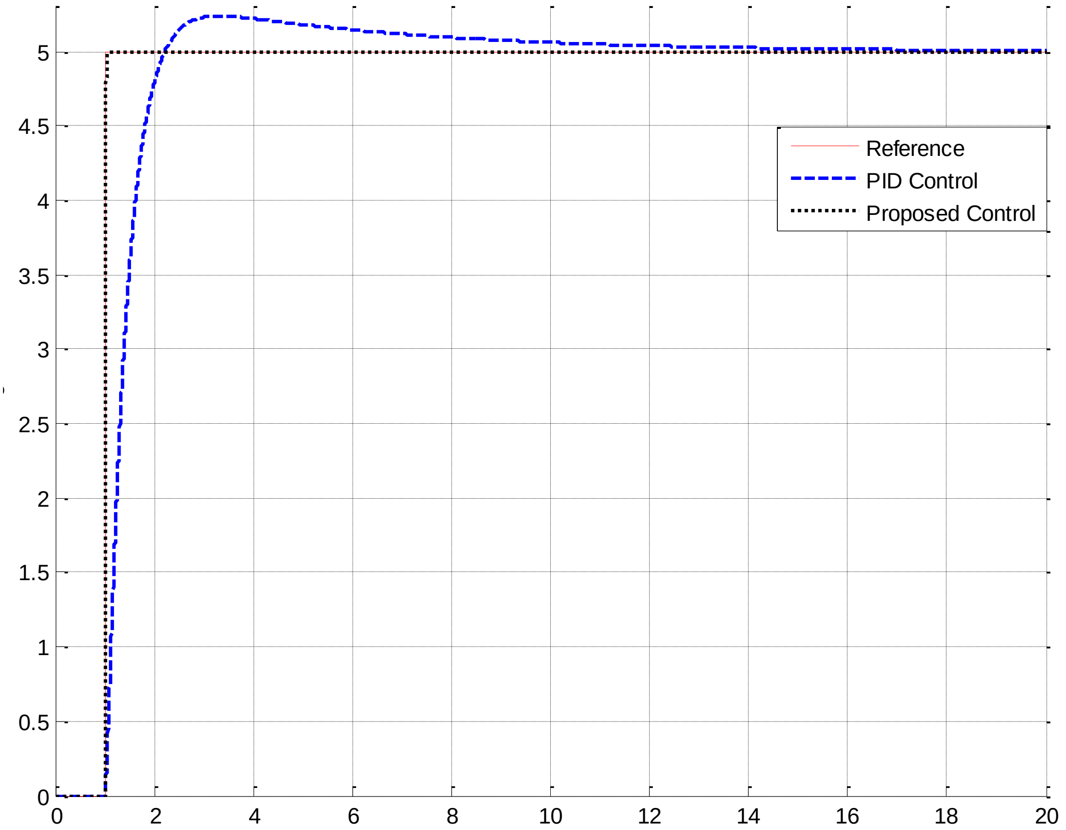

Figure 6. PID Controller and Sensor-less PID Controller

Power of Disturbance rejection: Figure 7 has been shown the power disturbance elimination in conventional PID controller and sensor-less PID controller. Regarding to the following Figure, in presence of uncertainty conventional PID controller has fluctuation and the rise time in this type of controller increase from 0.827 second to 1.289 second. Regarding to following Figure, proposed controller has not oscillation as well rise time. Regarding to the following graph, proposed method has about 12% dip in presence of uncertainty.

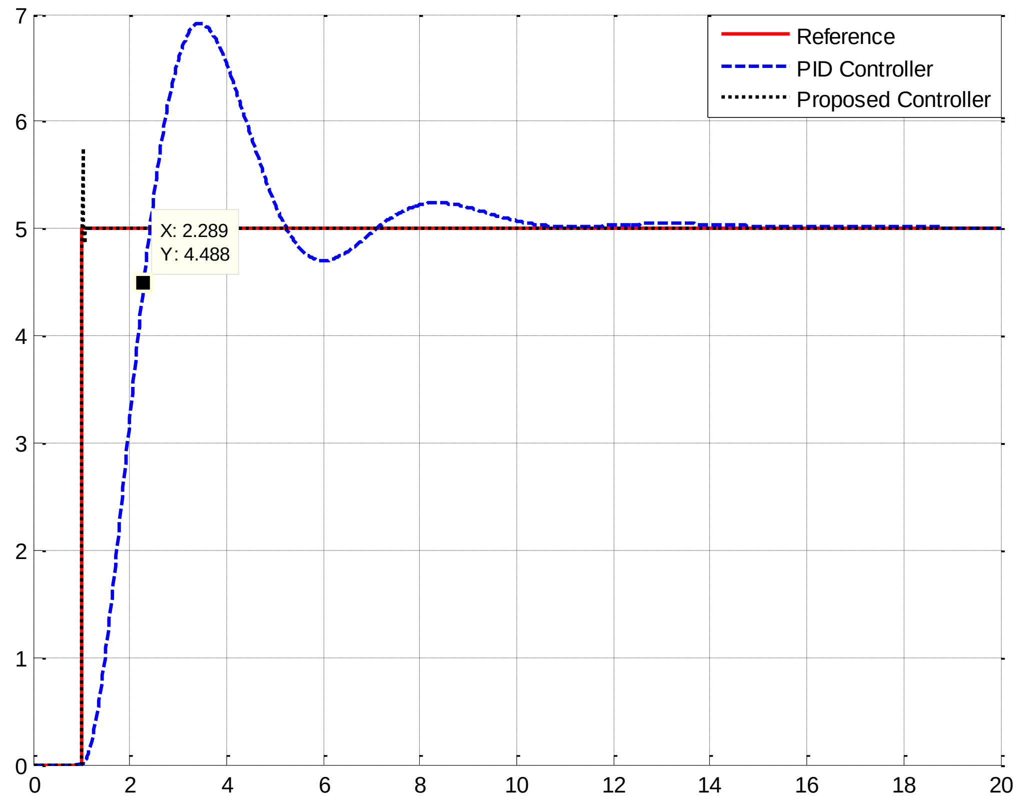

Figure 7. PID Controller and Sensor-less PID Controller in Presence of Uncertainty

5. Conclusion

Design sensor-less PID controller is investigated in this research. The main problems of first order delay system are rise-time, coupling effect and stability. To improve the coupling effect, PID controller was introduced but caused to reduce system performance as well rise-time. To improve these challenges and improve the PID controller, we design a PD surface and the integral of surface. This algorithm can improve the rise-time about 200% in certain and 300% in uncertain condition compare to conventional PID controller. This algorithm caused to improve the stability and robustness in comparison with PID controller (see Figure 7). Regarding to result and discussion, in presence of uncertainty PID algorithm has 40% overshoot which, eliminate this challenge by proposed method.

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Persian Gulf-1.

Project Title: "Design a Micro-electronic Based Nonlinear Controller for First Order Delay System"

Iranian center of Advance Science and Technology (IRAN SSP) is one of the independent research centers specializing in research and training across of Control and Automation, Electrical and Electronic Engineering, and Mechatronics & Robotics in Iran. At IRAN SSP research center, we are united and energized by one mission to discover and develop innovative engineering methodology that solve the most important challenges in field of advance science and technology. The IRAN SSP Center is instead to fill a long standing void in applied engineering by linking the training a development function one side and policy research on the other. This center divided into two main units:

- Education unit
- Research and Development unit

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Farzin Piltan. He is an outstanding scientist in the field of Electronics and Control engineering with expertise in the areas of nonlinear systems, robotics, and microelectronic control. Mr. Piltan is an advanced degree holder in his field. Currently, Mr. Piltan is the Head of Mechatronics, Intelligent System, and Robotics Laboratory at the Iranian Institute of Advanced Science and Technology (IRAN SSP). Mr. Piltan led several high impact projects involving more than 150 researchers from countries around the world including Iran, Finland, Italy, Germany, South Korea, Australia, and the United States. Mr. Piltan has authored or co-authored more than 140 papers in academic journals, conference papers and book chapters. His papers have been cited at least 3900 times by independent and dependent researchers from around the world including Iran, Algeria, Pakistan, India, China, Malaysia, Egypt, Columbia, Canada, United Kingdom, Turkey, Taiwan, Japan, South Korea, Italy, France, Thailand, Brazil and more. Moreover, Mr. Piltan has peer-reviewed at least 23 manuscripts for respected international journals in his field. Mr. Piltan will also serve as a technical committee member of the upcoming EECSI 2015 Conference in Indonesia. Mr. Piltan has served as an editorial board member or journal reviewer of several international journals in his field as follows: International Journal Of Control And Automation (IJCA), Australia, ISSN: 2005-4297, International Journal of Intelligent System and Applications (IJISA), Hong Kong, ISSN:2074-9058, IAES International Journal Of Robotics And Automation, Malaysia, ISSN:2089-4856, International Journal of Reconfigurable and Embedded Systems, Malaysia, ISSN:2089-4864.

Mr. Piltan has acquired a formidable repertoire of knowledge and skills and established himself as one of the leading young scientists in his field. Specifically, he has accrued expertise in the design and implementation of intelligent controls in nonlinear systems. Mr. Piltan has employed his remarkable expertise in these areas to make outstanding contributions as detailed follows:Nonlinear control for industrial robot manipulator (2010-IRAN SSP), Intelligent Tuning The Rate Of Fuel Ratio In Internal Combustion Engine (2011-IRANSSP), Design High Precision and Fast Dynamic Controller For Multi-Degrees Of Freedom Actuator (2013-IRANSSP), Research on Full Digital Control for Nonlinear Systems (2011-IRANSSP), Micro-Electronic Based Intelligent Nonlinear Controller (2015-IRANSSP), Active Robot Controller for Dental Automation (2015-IRANSSP), Design a Micro-Electronic Based Nonlinear Controller for First Order Delay System (2015-IRANSSP).

The above original accomplishments clearly demonstrate that Mr. Piltan has performed original research and that he has gained a distinguished reputation as an outstanding scientist in the field of electronics and control engineering. Mr. Piltan has a tremendous and unique set of skills, knowledge and background for his current and future work. He possesses a rare combination of academic knowledge and practical skills that are highly valuable for his work. In 2011, he published 28 first author papers, which constitute about 30% of papers published by the Department of Electrical and Electronic Engineering at University Putra Malaysia. Additionally, his 28 papers represent about 6.25% and 4.13% of all control and system papers published in Malaysia and Iran, respectively, in 2011.

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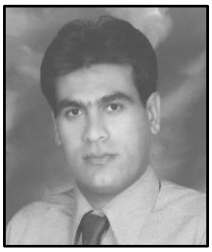

Amirzubir Sahamijoo. He is currently a senior research assistant at Institute of Advanced Science and Technology, Research Center, IRAN SSP. He is senior research assistant of team to Design Intelligent FPGA-Based Control Unit to Control of 4-DOF Medical Robot Manipulator since July, 2015 to now, research assistant of team (8 researchers) to design a Micro-electronic Based nonlinear controller for first order delay system since March, 2015 to now, research student (21 researchers) to design high precision and fast dynamic controller for multi-degrees of freedom actuator since 2014 to date, research student (9 researchers) to design Prevent the Risk of Lung Cancer Progression Based on Fuel Ratio Optimization since 2014 to date, and published 4 journal papers since 2014 to date. His current research interests are nonlinear control, artificial control system, Microelectronic Device, Internal Combustion Engine, and HDL design.

Nasri Sulaiman. He is a Senior Lecturer in the Department Electrical and Electronic Engineering at the Universiti Purta Malaysia (UPM), which is one of the leading research universities in Malaysia. He is a supervisor and senior researcher at research and training center called, Iranian Institute of Advanced Science and technology (Iranssp) since 2012. He obtained his M.Sc. from the University of Southampton (UK), and Ph.D. in Microelectronics from the University of Edinburgh (UK). He has published more than 80 technical papers related to control and system engineering, including several co-authored papers with Mr. Piltan. He has been invited to present his research at numerous national and international conferences. He has supervised many graduate students at doctoral and masters level. He is an outstanding scientist in the field of Micro-Electronics.

Dr. Nasri Sulaiman advisor and supervisor of several high impact projects involving more than 150 researchers from countries around the world including Iran, Malaysia, Finland, Italy, Germany, South Korea, Australia, and the United States. Dr. Nasri Sulaiman has authored or co-authored more than 80 papers in academic journals, conference papers and book chapters. His papers have been cited at least 3000 times by independent and dependent researchers from around the world including Iran, Algeria, Pakistan, India, China, Malaysia, Egypt, Columbia, Canada, United Kingdom, Turkey, Taiwan, Japan, South Korea, Italy, France, Thailand, Brazil and more.

Dr. Nasri Sulaiman has employed his remarkable expertise in these areas to make outstanding contributions as detailed below:

- Design of a reconfigurable Fast Fourier Transform (FFT) Processor using multi-objective Genetic Algorithms (2008-UPM)
- Power consumption investigation in reconfigurable Fast Fourier Transform (FFT) processor (2010-UPM)
- Crest factor reduction And digital predistortion Implementation in Orthogonal frequency Division multiplexing (ofdm) systems (2011-UPM)
- High Performance Hardware Implementation of a Multi-Objective Genetic Algorithm, (RUGS), Grant amount RM42,000.00, September (2012-UPM)
- Nonlinear control for industrial robot manipulator (2010-IRAN SSP)
- Intelligent Tuning The Rate Of Fuel Ratio In Internal Combustion Engine (2011-IRANSSP)
- Design High Precision and Fast Dynamic Controller For Multi-Degrees Of Freedom Actuator (2013-IRANSSP)
- Research on Full Digital Control for Nonlinear Systems (2011-IRANSSP)
- Micro-Electronic Based Intelligent Nonlinear Controller (2015-IRANSSP)
- Active Robot Controller for Dental Automation (2015-IRANSSP)
- Design a Micro-Electronic Based Nonlinear Controller for First Order Delay System (2015-IRANSSP)