Compatible MPID Optimal Controller for Flexible Operation of Two Link Manipulator

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Abstract

Robotic arms or manipulators are interrelated to electro mechanical modulations criteria's. The controls of this type of manipulators are very authentic and difficult too. For flexible operation of robotic manipulators, controlling should be required for their tip vibrations and torque responses. In this article we initiate the proto type differences between responses of torques with PID Controller in open loop as well as in closed loop condition. For the closed loop, the physical phenomenon of PID Changes named as Modified PID Controller. The MPID Controller provides better performance rather than open loop PID at far end of two link Manipulator arm. The Electro mechanical modeling of the two link manipulator was done by using State Space technique named as an M-File. The entire graphical representations are providing by using MATLAB/Control tool box.

Keywords: *two link manipulator, MPID Controller, Robotic Manipulator, electro mechanical modeling*

1. Introduction

Now a day's robots become authentic and emerging, complex objects. To perform an assigned task or to attain a desired position, a manipulator is required to accelerate from rest, travel at specified path, and finally decelerate to stop. To accomplish this, trajectory, controlling torques is applied by the actuators at the manipulator joints. This torques is computed from the equations of motion of the manipulator, which describe the dynamics of the manipulator. The dynamic model is very useful for mechanical design of the structure, choice of actuator, computer simulation of performance, determination of control strategies, and design of control system. The dynamic model and generated trajectory constitute the inputs to the motion-control system of the manipulator. The problem of manipulator control is to find the time behavior of the forces and torques delivered by the actuators for executing the assigned task. Both the manipulator motion control and its force interaction with the environment are monitored by the control algorithm [6]. The above exposed problems will lead to the study of control systems for manipulator and several techniques.

The tasks to be performed by the manipulator are to move the end-effectors along a desired trajectory, and to extract a force on the environment to carry out the desired task. The controller of manipulator has to control both tasks, the former is called position control (or trajectory control) and the latter force control. A schematic sketch of a typical controller is shown below. The positions, velocities, forces, torques are measured by sensors and based on

these measurements and the desired behavior, the controller determines the inputs to the actuators on the robot so that the end effectors carries out the desired task as closely possible [4].

2. PID Controller

A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired set point by calculating and then outputting a corrective action that can adjust the process accordingly.

The PID controller calculation (algorithm) involves three separate parameters; the Proportional, the Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral determines the reaction based on the sum of recent errors and the Derivative determines the reaction to the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element.

By "tuning" the three constants in the PID controller algorithm the PID can provide control action designed for specific process requirements [11]. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability. Some applications may require using only one or two modes to provide the appropriate system control [4]. This is achieved by setting the gain of undesired control outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are particularly common, since derivative action is very sensitive to measurement noise, and the absence of an integral value may prevent the system from reaching its target value due to the control action [13].

Figure 1. Block Diagram of PID Controller

2.1. Control Loop Basics

A familiar example of a control loop is the action taken to keep one's shower water at the ideal temperature, which typically involves the mixing of two process streams, cold and hot water. The person feels the water to estimate its temperature. Based on this measurement they perform a control action: use the cold water tap to adjust the process. The person would

repeat this input-output control loop, adjusting the hot water flow until the process temperature stabilized at the desired value. Feeling the water temperature is taking a measurement of the process value or process variable (PV). The desired temperature is called the set point (SP). The output from the controller and input to the process (the tap position) is called the manipulated variable (MV). The difference between the measurement and the set point is the error (e), too hot or too cold and by how much. As a controller, one decides roughly how much to change the tap position (MV) after one determines the temperature (PV), and therefore the error [2]. This first estimate is the equivalent of the proportional action of a PID controller. The integral action of a PID controller can be thought of as gradually adjusting the temperature when it is almost right. Derivative action can be thought of as noticing the water temperature is getting hotter or colder, and how fast, and taking that into account when deciding how to adjust the tap [7].

Making a change that is too large when the error is small is equivalent to a high gain controller and will lead to overshoot. If the controller were too repeatedly make changes that were too large and repeatedly overshoot the target, this control loop would be termed unstable and the output would oscillate around the set point in either a constant, growing, or decaying sinusoid. A human would not do this because we are adaptive controllers, learning from the process history, but PID controllers do not have the ability to learn and must be set up correctly. Selecting the correct gains for effective control is known as tuning the controller. If a controller starts from a stable state at zero error ($PV = SP$), then further changes by the controller will be in response to changes in other measured or unmeasured inputs to the process that impact on the process, and hence on the PV. Variables that impact on the process other than the MV are known as disturbances and generally controllers are used to reject disturbances and/or implement set point changes. Changes in feed water temperature constitute a disturbance to the shower process.

In theory, a controller can be used to control any process which has a measurable output (PV), a known ideal value for that output (SP) and an input to the process (MV) that will affect the relevant PV. Controllers are used in industry to regulate temperature, pressure, flow rate, chemical composition, speed and practically every other variable for which a measurement exists. Automobile cruise control is an example of a process which utilizes automated control [5].

Due to their long history, simplicity well grounded theory and simple setup and maintenance requirements, PID controllers are the controllers of choice for many of these applications.

2.2. PID Controller Theory

This section describes the ideal parallel or non-interacting form of the PID controller. For other forms please see the Section "Alternative notation and PID forms". The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). Hence

$$MV(t) = P_{out} + I_{out} + D_{out} \quad \dots\dots\dots (1)$$

While PID controllers are applicable to many control problems, they can perform poorly in some applications.

PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate or "hunt" about the control set point value. The control system performance can be improved by combining the feedback (or closed-loop) control of a PID controller with feed-forward (or open-loop)

control. Knowledge about the system (such as the desired acceleration and inertia) can be "fed forward" and combined with the PID output to improve the overall system performance. The feed-forward value alone can often provide the major portion of the controller output. The PID controller can then be used primarily to respond to whatever difference or "error" remains between the set point (SP) and the actual value of the process variable (PV). Since the feed-forward output is not affected by the process feedback, it can never cause the control system to oscillate, thus improving the system response and stability [9].

For example, in most motion control systems, in order to accelerate a mechanical load under control, more force or torque is required from the prime mover, motor, or actuator. If a velocity loop PID controller is being used to control the speed of the load and command the force or torque being applied by the prime mover, then it is beneficial to take the instantaneous acceleration desired for the load, scale that value appropriately and add it to the output of the PID velocity loop controller. This means that whenever the load is being accelerated or decelerated, a proportional amount of force is commanded from the prime mover regardless of the feedback value [1]. The PID loop in this situation uses the feedback information to affect any increase or decrease of the combined output in order to reduce the remaining difference between the process set point and the feedback value. Working together, the combined open-loop feed-forward controller and closed-loop PID controller can provide a more responsive, stable and reliable control system.

Another problem faced with PID controllers is that they are linear. Thus, performance of PID controllers in non-linear systems (such as HVAC systems) is variable. Often PID controllers are enhanced through methods such as PID gain scheduling or fuzzy logic. Further practical application issues can arise from instrumentation connected to the controller. A high enough sampling rate, measurement precision, and measurement accuracy are required to achieve adequate control performance. A problem with the Derivative term is that small amounts of measurement or process noise can cause large amounts of change in the output. It is often helpful to filter the measurements with a low-pass filter in order to remove higher-frequency noise components. However, low-pass filtering and derivative control can cancel each other out, so reducing noise by instrumentation means is a much better choice [10]. Alternatively, the differential band can be turned off in many systems with little loss of control. This is equivalent to using the PID controller as a *PI* controller.

2.3. PID Control Parameters

PID control parameters are obtained by using RH criterion which is shown below.

$$Kp + Kds + \frac{Ki}{s} = \frac{sKp + Kds^2 + Ki}{s} \quad (2)$$

Closed loop transfer function

$$\begin{aligned} TF &= \frac{\frac{1}{Js^2 + Bs} * \frac{s^2Kd + sKp + Ki}{s}}{1 + \frac{s^2Kd + sKp + Ki}{s} * \frac{1}{Js^2 + Bs}} \\ &= \frac{\frac{s^2Kd + sKp + Ki}{s(Js^2 + Bs)}}{\frac{s(Js^2 + Bs) + s^2Kd + sKp + Ki}{s(Js^2 + Bs)}} \end{aligned} \quad (3)$$

$$= \frac{s^2 Kd + sKp + Ki}{Js^3 + Bs^2 + s^2 Kd + sKp + Ki}$$

$$\text{Characteristic equation} = Js^3 + Bs^2 + s^2 Kd + sKp + Ki = 0 \quad (4)$$

$$\frac{C}{R} \sim \frac{GH}{1+GH} = Kp(1 + T_d s + \frac{1}{T_i s}) \quad (5)$$

By using RH criterion,

s^3	J	Kp	0
s^2	$(B + Kd)$	Ki	0
s^1	$\frac{Kp(B + Kd) - JK_i}{B + Kd}$	0	
s^0	Ki		

$$\frac{Kp(B + Kd) - JK_i}{B + Kd} > 0 \quad (6)$$

$$Ki > 0 \quad (7)$$

$$Kp(B + Kd) - JK_i > 0 \quad (8)$$

$$\frac{Kp(B + Kd)}{J} > Ki \quad (9)$$

$$Ki < \frac{Kp(B + Kd)}{J} \quad (10)$$

$$Ki < 80 \quad (11)$$

$$Kp = 4.1 \quad (12)$$

$$Kd = 0.8075 \quad (13)$$

$$Kp + Kds = \frac{4.1 + 0.8075s}{0.5s + 1} \quad (14)$$

$$\frac{C}{R} \sim \frac{GH}{1+GH} = Kp(1 + T_d s + \frac{1}{T_i s}) \quad (15)$$

$$= Kp + KpT_d s + \frac{Kp}{sT_i}$$

$$= Kp + Kds + \frac{Ki}{s}$$

$$Kp = 4.1$$

$$Kd = 0.80$$

$$Ki = 70$$

$$Kd = KpT_d$$

$$T_d = \frac{Kd}{Kp}$$

$$Ki = \frac{Kp}{T_i}$$

$$T_i = \frac{Kp}{Ki}$$

	<i>Firstlink</i>	<i>Secondlink</i>	
For rigid controller	$Kp = 40$	$Kp = 40$	(16)
	$T_i = 2$	$T_i = 2$	
	$T_d = 4$	$T_d = 4$	

$$\omega_n = 25$$

$$Kp = 10$$

$$Kd = 1.3$$

$$Ki = 10$$

$$T_d = \frac{Kp}{Kd} = \frac{1.3}{10} = 0.13$$

$$T_i = \frac{Kp}{Ki} = \frac{10}{10} = 1$$

Therefore PID parameters are obtained as shown in Eq.16 and are used in Simulink program for further results.

2.4. Cascade Control

One distinctive advantage of PID controllers is that two PID controllers can be used together to yield better dynamic performance. This is called cascaded PID control. In cascade control there are two PIDs arranged with one PID controlling the set point of another. A PID controller acts as outer loop controller, which controls the primary physical parameter, such as fluid level or velocity. The other controller acts as inner loop controller, which reads the output of outer loop controller as set point, usually controlling a more rapid changing parameter, flow rate or acceleration [14]. It can be mathematically proved that the working frequency of the controller is increased and the time constant of the object is reduced by using cascaded PID controller.

2.5. Physical Implementation of PID Control

In the early history of automatic process control the PID controller was implemented as a mechanical device. These mechanical controllers used a lever, spring and a mass and were often energized by compressed air. These pneumatic controllers were once the industry standard.

Electronic analog controllers can be made from a solid-state or tube amplifier, a capacitor and a resistance. Electronic analog PID control loops were often found within more complex electronic systems, for example, the head positioning of a disk drive, the power conditioning of a power supply, or even the movement-detection circuit of a modern seismometer. Nowadays, electronic controllers have largely been replaced by digital controllers implemented with microcontrollers or FPGAs [6].

Most modern PID controllers in industry are implemented in software in programmable logic controllers (PLCs) or as a panel-mounted digital controller. Software implementations have the advantages that they are relatively cheap and are flexible with respect to the implementation of the PID algorithm.

3. Controllability & Observability

3.1. Controllability

In control problems two basic questions need to be answered in deciding whether or not a control solution exists. These questions may be posed as: (i) Can we transfer the system from any other desired state in finite time by application of a suitable control force?(ii) Knowing the output vector for a finite length of time, can we determine the initial state of the system. The answers to these basic questions were conceptualized by Kaman into what is known as controllability and Observability are advanced below: A system is said to be completely controllable if it is possible to transfer the system state from any initial state $x(t_0)$ to any other desired state $x(t)$ in specified finite time by a control vector $u(t)$. A system is said to be completely observable, if every state $x(t_0)$ can be completely identified by measurements of the output $y(t)$ over a finite time interval. A system is said to be completely observable, implies that some of its state variables are shielded from observation. The test of controllability due to Kaman which can be applied to any state model (canonical or otherwise) is stated below. A general n^{th} order multi-input linear time-invariant system (with an m -dimensional control vector),

$$\dot{X} = AX + BU \quad (17)$$

is completely controllable if and only if the rank of the composite matrix Q_c is n .

$$Q_c = [B : AB : \dots : A^{n-1}B] \quad (18)$$

3.2 Observability

The Kaman's test of Observability is as follows:

A general n^{th} order multi-input multi output linear time invariant system.

$$\begin{aligned} \dot{X} &= AX + BU \\ Y &= CX \end{aligned} \quad (19)$$

is completely observable if and only if the rank of composite matrix is n .

$$\text{Where } Q_c = [C^T : A^T C^T : \dots : (A^T)^{n-1} C^T] \quad (20)$$

3.3 Duality Property

Comparing the equations of both controllability and Observability the following observations are made (i) The pair (AB) is controllable implies that the pair $(A^T B^T)$ is observable. (ii) The pair (AC) is observable implies that the pair $(A^T C^T)$ is controllable. Thus the concepts of controllability and Observability are dual concepts.

4. Simulation of Open Loop Two Link Rigid Manipulator using PID Controller

Figure 2. Open Loop PID Controller Response of Two Link Rigid Manipulator

5. Simulation of Two Link Rigid Manipulator using MPID Controller

Figure 3. MPID Controller Model for Two Link Rigid Manipulator

6. Results and Discussions

The test system was simulated by using M-File programming in MATLAB/Control tool box. Here theta1 and theta2 are two state variables are assigned as a two states. The entire dynamic two link rigid manipulator was modeled and simulated by using iterative

methodology in state variable approach. Time (sec) has represented on x-axis and torque and tip vibrations are represented on y-axis respectively.

Figure 4. Response of Two Link Manipulator for Theta1 status using PID Controller

Figure 5. Response for Theta 1 of Two Link Rigid Manipulator using MPID Controller

Figure 4 shows the open loop response for theta 1 using a normal PID Controller. Here the two theta1 and theta2 are two state variable conditions. A rigid manipulator was showing somewhat non linear characteristics by synchronizing or interconnecting PID Controller as a controlling one. The referral figure.4 shows, manipulator with different variation from their initial state. Statically, these non-linear tip vibrations and model torque responses at far end are modified and diagnosis by interconnected Modified PID Controller with different variable states.

Figure 5 shows the modified response of Thata1 for two link rigid manipulator using MPID Controller. Here the Modified controller helps to eliminate then altered and un-ordered tip vibrations and non-linear torque characteristics. From figure 4&5, we may observe the variations for responses caused by PID and MPID Controllers. Apart from that, MPID also provides better accuracy and less settling time, maximum peak overshoot occurrence, and

better feedback performance. Time (sec) has represented on x-axis and torque and tip vibrations are represented on y-axis respectively.

Figure 6. Response of Two Link Manipulator for Theta2 Status using PID Controller

Figure 7. Response for Theta 2 of Two Link Rigid Manipulator using MPID Controller

Figure 6 shows response of two link rigid manipulator's theta 2 responses in open loop status using PID controller. Here from the above graphical representation we observe that tip vibrations and torque responses are abuse and un-identified one. Here the same are eliminated by using a MPID Controller contains a robust feedback nature, providing a better performance form far end. The Figures 6 and 7 shows a physical and parametric variations between PID & MPID Controllers responses for tip deflection and pay load torque response of two link rigid manipulator. Here form the defined graphical views observed that the better performance were shown by using MPID Controller at far end, in case of settling time and maximum peak overshoot and prototype feedback implementation. Time (sec) has represented on x-axis and torque and tip vibrations are represented on y-axis respectively.

Figure 8. Performance Evaluation of PID and MPID in Two Link Manipulator

The PID controller is designed for control of the two link rigid manipulator using iterative method. Here response of θ_1 and θ_2 are obtained in controlled states. But rise time is 1.5sec, settling time is 4.9 sec and the peak over shoot is 0.04 for Theta 1 and rise time is 1.4sec settling time is 4.86sec and peak overshoot is 0.01 for Theta 2.

The following table shows variation between PID and MPID Controller using for flexibility of two link rigid manipulator at far end.

Table 1. Variation between time Domain Specifications for Utilization of PID and MPID Controller

	PID Controller		MPID Controller	
	Theta1	Theta2	Theta1	Theta2
Rise Time	1.5sec	1.4sec	1.2sec	0.6 sec
Settling Time	4.9 sec	4.86sec	3.2sec	3.26sec
Maximum Peak overshoot	0.04	0.01	0.08	0.099

In case of MPID Controller the rise time becomes 1.2sec, settling time 3.2sec and peak over shoot is 0.08 for Theta 1 and rise time is 0.6 sec settling time is 3.26sec and peak overshoot is 0.099 for Theta 2. Hence the better rise time and settling time and maximum peak overshoot was occurring for overall test system.

7. Conclusion

The modified PID Controller will show the better performance rather than a normal PID Controller. Here in this paper we conclude that, MPID shows better rise and settling time and maximum peak overshoots characteristics. The entire two link rigid manipulator was modeled and investigated, simulated. The simulation was done by using state variable approach in M-

File programming of control tool box. In MPID, M initiates for Modification of feed back in different iterations. That number of iteration was assigned by using state variable approach technique. The feedback of corresponding PID controller states better performance in two link rigid manipulator's tip vibrations and pay load torque responses at far end. Hence the MPID helpful to flexible environment in two link manipulator named as a optimal PID Controller.

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