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Performance Analysis of Adaptive Backstepping Control on Robotic ARM

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Abstract- **In this paper Adaptive Backstepping is implemented on the system.Robotic arm is extensively used in applications that requires high precision and accuracy such as biomedical and laser treatments. The parameters of the robotic arm are assumed to be initially unknown. They can be estimated by using the Adaptive Backstepping mechanism design. Simulation results are presented to show the performance of the AdaptiveBackstepping control and found to be satisfactory.**

Keywords-Adaptive Backstepping controller (ABSC), Robotic Arm

I. INTRODUCTION

Robot manipulators have been widely used in our current society, especially in manufacturing industries. They make their appearance in almost every automatic assembly line. The efficiency and accuracy of the robot manipulators has a great influence on the production and quality of the product. A robot manipulator is a movable chain of links interconnected by joints. One end is fixed to the ground, and a hand or end effector that can move freely in space is attached at the other end .Among the rigid as well as flexible robotic manipulators, the latter is superior as it possesses many advantages such as lower energy consumption, faster response, smaller actuator requirement, safer operation, compliant structure and non-bulky design. Owing to these advantages, they are used in various applications such as sophisticated assistants for the disabled, to reduction of the launch cost in space exploration, handling waste material in hazardous plants where access to underground storage is limited and also for biomedical and laser treatments.

Benaskeur A and Desbiens [1] proposed a nonlinear lyapunov based controller where inner loop uses a backstepping approach to stabilize the inverted pendulum. Adaptive backstepping controller is designed by treating every constant parameters in the system as unknowns in [2] and [3]. Adaptive position control for an electrohydraulic actuator based on adaptive backstepping control scheme is proposed in [4].Adaptive backstepping design for strict feedback systems are proposed by Kristic etal, [5].PID is the most conventional controller but it is limited in performance as it uses only feedback control to minimize the error leading to slow response [6]. The control of a flexible link manipulator using neuro sliding mode is discussed in [7]. Adaptive backstepping control of RLV is proposed in [8]. Backstepping control design has been proposed for electrohydraulic servo system and spacecraft attitude control in [9], [10].

In this paper, Adaptive Backstepping controlleris designed to regulate the position of robotic arm.The Paper has been organized as follows. Section IIdeals with the modelling of robotic arm .Section III deals with the Theory of controller design. Section IV deals with the Design of Adaptive backstepping controller for the system. InSection V the Simulation results are shown with somediscussions on it. Section VI is the Conclusion part.

II. MODELLING OF THE ROBOTIC ARM

The modelling equation of the Robotic arm which is shown in Fig.1 is given by eqn. (1)

$$\ddot{\theta} = \frac{-g}{l} sin\theta - \frac{v}{ml^2}\dot{\theta} + \frac{1}{ml^2}u \tag{1}$$

Where l is the length of the pendulum, g is the acceleration due to gravity, θ is the rod angle from the vertical position, v is the applied voltage, m is the mass of the pendulum and u is the control input.

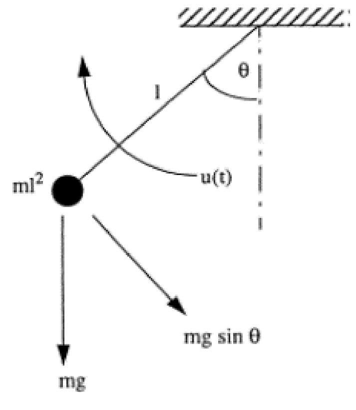

Fig1.Robotic Arm

Let $x_1 = \theta, x_2 = \dot{\theta}$. Then the eqn. (1) becomes

$$\dot{x_1} = x_2$$
$$\dot{x_2} = \frac{-g}{l} sin\, x_1 - \frac{v}{ml^2}x_2 + \frac{1}{ml^2}u \tag{2}$$

The parameters of the model are obtained as l = 1m,m = 2kg, v = 6kgm^2/s Then the system dynamics becomes

$$\dot{x_1} = x_2$$
$$\dot{x_2} = -9.8\, sin x_1 - 3x_2 + 0.5u \tag{3}$$

III. THEORY OF CONTROLLER DESIGN

A. BASIC BACKSTEPPING TECHNIQUE

Backstepping designs by breaking down complex nonlinear systems into smaller subsystems, then designing control Lyapunov functions and virtual controls for these subsystemsand finally integrating these individual controllers into the actual controller, by stepping back through the subsystems [5].

Consider a system of the form

$$\dot{x} = f(x) + g(x)\zeta_1$$
$$\dot{\zeta_1} = f_1(x,\zeta_1) + g_1(x,\zeta_1)\zeta_2$$
$$\dot{\zeta_2} = f_2(x,\zeta_1,\zeta_2) + g_2(x,\zeta_1,\zeta_2)\zeta_3$$
.
.
.
$$\dot{\zeta_k} = f_k(x,\zeta_{1,\dots\dots,}\zeta_k) + g_2(x,\zeta_1,\dots\dots\dots,\zeta_k)u \qquad (4)$$

To show how to find a control Lyapunov function and a control law, a short design example is considered. The system that is to be controlled is given below.

$$\dot{x} = f(x) + g(x)\zeta_1$$

$$\dot{\zeta} = a(x,\zeta) + g_1(x,\zeta)u \qquad (5)$$

Where x Ɛ R^n and ζ Ɛ R are state variables and u Ɛ R is the control input. First ζ is regarded as a control input for the x-subsystem. ζ can be chosen in any way to make the x-subsystem globally asymptotically stable. The choice is denoted $\zeta^{des}(x)$ and is called a virtual control law. For the x-subsystem a control Lyapunov function,$V_1(x)$ can be chosen so that with the virtual control law, the time derivative of Lyapunov function becomes negative definite.

$$V_1\dot{(x)}=V_{1x}\dot{x} = V_{1x}(x)\,(f(x) + g(x)\,\zeta^{des}(x)) < 0,\ x \neq 0 \quad (6)$$

A new state is introduced which represents the error variable

$$\tilde{\zeta} = \zeta - \zeta^{des}(x) \qquad (7)$$

The system shown in equation (5) is then written in terms of these new variables

$$\dot{x}= f(x) + g(x)(\tilde{\zeta} + \zeta^{des}(x))$$

$$\dot{\tilde{\zeta}}= a(x,\tilde{\zeta} +\zeta^{des}(x))+ b\,(x,\tilde{\zeta} +\zeta^{des}(x)))\,u - \frac{\partial\zeta^{des}(x)}{\partial x}(f(x) + g(x)(\tilde{\zeta} + \zeta^{des}(x))) \qquad (8)$$

For the system given above a control Lyapunov function is constructed from $V_1(x)$ by adding a quadratic term which penalizes the error variable$\tilde{\zeta}$.

$$V_2(x,\tilde{\zeta})=V_1(x) +\frac{1}{2}\tilde{\zeta}^2$$

Differentiating $V_2(x,\tilde{\zeta})$ with respect to time

$$\dot{V_2}(x,\tilde{\zeta}) = V_{1x}(x)\,(f(x) + g(x)\zeta^{des}(x) + g(x)\tilde{\zeta}) + \tilde{\zeta}\,(a\,(x,\tilde{\zeta} +\zeta^{des}(x)))\,) + \tilde{\zeta}\,(b\,(x,\tilde{\zeta} +\zeta^{des}(x)))\,u - \frac{\partial\zeta^{des}(x)}{\partial x}(f(x) + g(x)(\tilde{\zeta} + \zeta^{des}(x)))\quad(9)$$

Equation (9) can be rewritten in the following way if the variables that the functions depend on are omitted. To guarantee stability $\dot{v_2}$ has to be negative definite. This can be achieved by choosing the control input, u in eqn. (9) as

$$U=\frac{1}{b}\left(\frac{\partial\zeta^{des}(x)}{\partial x}(f + g(\tilde{\zeta} + \zeta^{des}(x))\text{-a-}V_{1g}\text{- k}\tilde{\zeta}\right) \qquad (10)$$

Where k > 0. Then $\dot{V_2}$becomes

$$\dot{V_2}= V(f+g\zeta^{des}) - k\,\tilde{\zeta}^2 \leq 0 \qquad (11)$$

If u is not the actual control input but a virtual control law consisting of state variables, then the system can be further expanded by starting over again. Hence the backstepping design procedure is recursive.

B. *ADAPTIVE BACKSTEPPING CONTROLLER DESIGN*

The Backstepping controller design guarantees that by employing a static feedback, the closed loop state remains bounded in the presence of uncertain bounded nonlinearities. While the Adaptive Backstepping Controller design employ a form of nonlinear integral feedback and the underlying idea in the design of this dynamic part of feedback is parameter estimation. The dynamic part of the controllers designed as a parameter update law with which the static part is continuously adapted to new parameter estimates.

Adaptive Backstepping Controllers are dynamic and more complex than the static controllers. What is achieved with this complexity is that, an Adaptive Backstepping Controller guarantees not only that the plant ’x,’ remains bounded, but also regulation and tracking of a reference signal. In its basic form, the Adaptive Backstepping Control design employs overparametrization and this means that the dynamic part of the controller is not of minimal order. Consider

$$\dot{x_1}=x_2+ \theta\emptyset(x_1)$$
$$\dot{x_2} = u$$
(12)

Whereθ is a known constant parameter and x_2 as thefirst control input.Denote θ o as the estimated value for the parameter θ and the estimation error θe is given by

$$\theta_e = \theta - \theta_0 \qquad (13)$$

Next the candidate Lyapunov function is selected as

$$v_2(x,\theta_e)=\frac{1}{2}{x_1}^2 + \frac{1}{2\gamma}{\theta_e}^2 \qquad (14)$$

Where γ is the adaptation gain. With the control law.

$$x_2 = -k_1 - \theta\emptyset(x_1) =\propto_1(x_1,\theta) \qquad (15)$$

And the adaptation law

$$\dot{\theta_0} = \gamma\emptyset(x_1)x_1 \qquad (16)$$

The derivative of the candidate Lyapunov function becomes negative definite and is given by

$$\dot{v_1} = -k_1 {x_1}^2 < 0 \qquad (17)$$

In the eqn. (15) $\propto_1$ is called a stabilizing function for x_2

The deviation of x_2 from the stabilizing function is given by

$$Z = x_2 - \propto_1 (x_1, \theta) \qquad (18)$$

Augmenting the Lyapunov function by adding the error Variable

$$v_2(x, Z, \theta_e) = v_1(x_1, \theta_e) + \frac{1}{2} Z^2 \qquad (19)$$

By the proper selection of 'u,' the overall Lyapunov function' V_2,' becomes negative definite which implies that as x_1 tends to zero, then z also tends to zero asymptotically.

IV. ADAPTIVE BACKSTEPPING CONTROLLER DESIGN FOR ROBOTIC ARM

The state variables are selected as $x_1 = \theta$, $x_2 = \dot{\theta}$ .the control variable is u. the system equation can now be expressed as in (3)

$$\dot{x_1} = x_2$$
$$\dot{x_2} = -9.8 \sin x_1 - 3x_2 + 0.5u$$

The control law is to be designed such that the system stabilizes for whatever be the initial conditions. For applying the Adaptive Backstepping Control design procedure, thesystem can now be expressed as

$$\dot{x_1} = x_2$$
$$\dot{x_2} = -\emptyset_1 \sin x_1 - \emptyset_2 x_2 + \emptyset_3 u \qquad (20)$$

Where $\emptyset_1, \emptyset_2, \emptyset_3$ are the unknown parameters in the system

The first error variable is defined as

$$e = x_1 - \theta_{sp} \qquad (21)$$

Where θ_{sp} is the desired set point.using the lyapunov function

$$V_1 = \frac{1}{2} e^2 \qquad (22)$$

And using the derivative of the Lyapunov function, the virtual control law can be formulated as

$$x_{2des} = -k_1 e + \dot{\theta_{sp}} \qquad (23)$$

Where $k_1 > 0$ and is a design parameter which guarantees $\dot{V_1} < 0$. The second error variable ζ is defined as

$$\zeta = x_2 - x_{2des} \qquad (24)$$

By augmenting the Lyapunov function V_1 with the error variable ζ and the unknown parameters in the system, we get

$$V_2 = \frac{1}{2} e^2 + \frac{1}{2} \zeta^2 + \frac{1}{2\gamma_1} {\emptyset_{1e}}^2 + \frac{1}{2\gamma_2} {\emptyset_{2e}}^2 + \frac{1}{2\gamma_3} {\emptyset_{3e}}^2 (24)$$

Where $\emptyset_{1e,} \emptyset_{2e,} \emptyset_{3e}$ are the parameter estimationerrors of $\emptyset_1, \emptyset_2, \emptyset_3$ where $\emptyset_{*e} = \emptyset - \emptyset_{*0}$ and * stands for 1, 2, 3. The variables $\emptyset_{10,} \emptyset_{20,} \emptyset_{30}$ are the parameter estimates with $\gamma_{1,} \gamma_{2,} \gamma_3$ are the adaptation gain constants. With thecontrol law

$$u_{des} = \frac{1}{\emptyset_{30}} (-k_2 \zeta + \ddot{\theta_{sp}} + k_1 \dot{e} + \emptyset_{10} \sin x_1 + \emptyset_{20} x_2) \qquad (25)$$

And the parameter update laws given by

$$\dot{\emptyset_{10}} = -\gamma_1 \zeta \sin x_1$$
$$\dot{\emptyset_{20,}} = -\gamma_2 \zeta x_2 \quad \dot{\emptyset_{30,}} = \gamma_3 \zeta u \qquad (26)$$

The derivative of the augmented Lyapunovfunction becomes negative definite

$$\dot{V_2} = -k_1 e^2 - k_2 \zeta^2 \leq 0 \qquad (27)$$

Where $k_1 > 0$; $k_2 > 0$. Therefore by Laselles theorem, the system is globally asymptotically stable at the equilibrium point of the system.

V SIMULATION RESULTS AND DISCUSSION

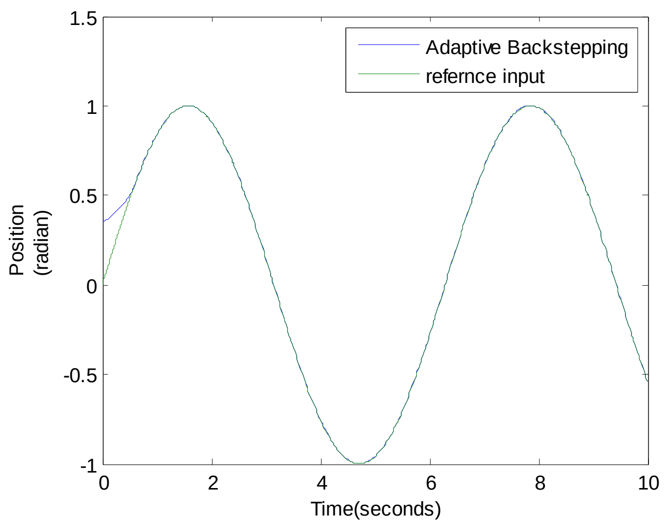

Fig: 1 Tracking of Robotic Arm

Fig.1 indicates tracking of robotic arm with Adaptive Backstepping with sinusoidal reference input. It is inferred that the system tracks the reference input very well. Fig. 2 shows that position of robotic arm is regulated better as the gain value is increased using Adaptive Backstepping.

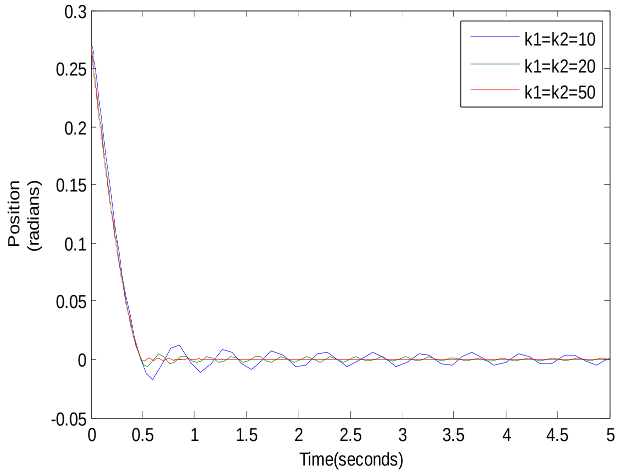

Fig. 2 Regulationof position of robotic arm with ABSC

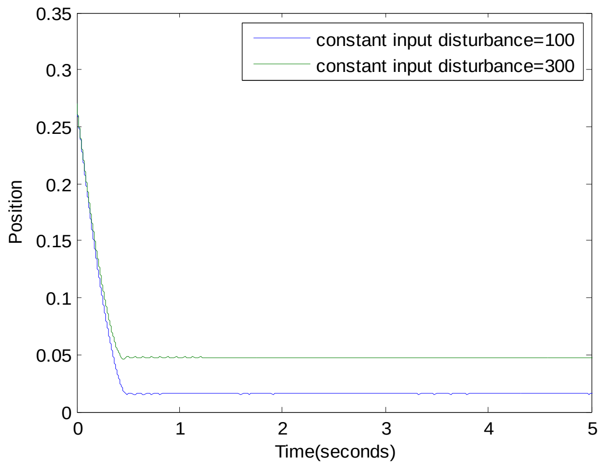

Fig. 3 Disturbance Rejection of robotic arm with ABSC

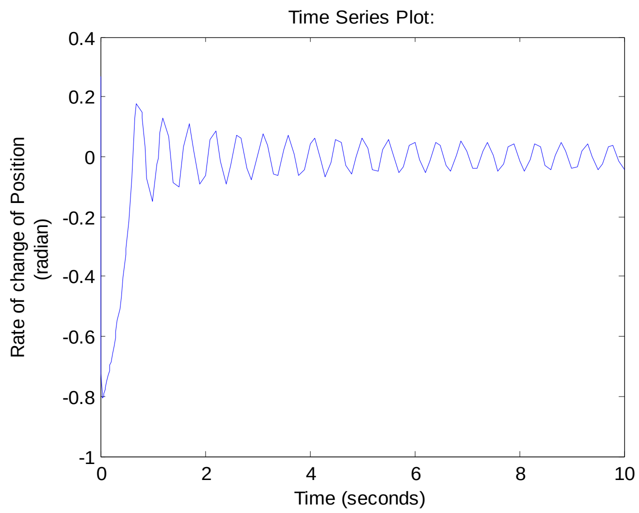

Fig. 4Rateof change of position of robotic arm with ABSC

Fig.3 indicates the error tolerance of robotic arm with Adaptive Backstepping for external disturbances of gain 100 and 300 and system attains tolerance of 5% up to this values. Fig.4 indicates the rate of change of position of robotic arm using Adaptive Backstepping.

VI CONCLUSIONS

In this paper Adaptive Backstepping control has been implemented on Robotic Arm.Apart from the Backstepping design procedure in whichonly non-linearities had been taken care of, in the Adaptive Backstepping design uncertainties associated with the constant parameters of the system is also dealt with.Simulation results shows that Adaptive Backstepping gives better disturbance rejection for the system and also the system tracks and regulated very well.

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