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Research Article

ADAPTIVE ROBUST CONTROL OF SCARA ROBOT WITH FOUR DEGREES OF FREEDOM USING ADAPTIVE FUZZY ESTIMATOR

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ABSTRACT

In this paper, a hybrid method for adaptive control of industrial Scara robots with 4 degrees of freedom is presented. One of the benefits of the proposed controller is to design the control law, the controller is able to deliver real values without knowing the robot model-dependent parameters such as mass, length of each link of the robot or moment of inertia. In many robot applications, the weight and moment of inertia of the robot links are constantly changing and the use of a fixed control law for the robot reduces system performance. To resolve this issue, we use the adaptive control law, since this is not a model of dynamic control law in the face of such uncertainty or external disturbance is not robust, an adaptive fuzzy estimator will be used to identify uncertainties. Combining this estimator with the control law will result in robustness of the system against any kind of uncertainty.

Keywords: Adaptive Control, Uncertainty, On Modeled Dynamic, Adaptive Fuzzy Estimator.

INTRODUCTION

The robot dynamics and kinematics are involving highly nonlinear equations, with coupling and uncertainty in the models. To overcome this problem proportional - integral - derivative control law is used in industrial robots. However, some of these controls are useful for tuning purposes but not for the purpose of tracking. Control law based on the proper functioning of the model is very suitable for this purpose. However, an accurate model of the robot is so complex and computational due to the complexity of the equations[1]. When the parameters of the dynamic model of the robot vary unpredictably by time[2], an exact model of the robot cannot be accessed in the environment[3]. For example, when the robot is moving objects with different sizes the dynamic equations of the robot due to the increased weight of the robot links will change. Therefore, precise control of the robot is so difficult, so to achieve a good performance under changing environmental conditions, adaptive control law is proposed. In recent years, different adaptive controllers for nonlinear systems have been presented. For example, adaptive control for a system of not-modeled non-linear dynamics[4], improve range of nonlinear parameters[5], adaptive control scheme for nonlinear uncertainty[6] and so on[7-17] have been proposed. Lyapunov-based adaptive control for uncertain external disturbances and not-modeled dynamics is not appropriate and it does not guarantee the stability[14]. One of the key issues in all control methods for tracking the desired trajectory in the presence of uncertainty[21]. In[18,19], a lot of attention has been paid on robust control of robots has to overcome uncertainties, and different methods for tracking control of robot have been developed taking into account uncertainties such as sliding mode control, robust control and robust adaptive control. So the art of control to overcome uncertainties, nonlinearity and coupling factors of various aspects of the robot robust control[22] is observed. Fuzzy control as well as a robust control method that does not require any knowledge of the system model can be used[20]. In this paper, scara an industrial robot with four degrees of freedom adaptive control law based on lyapunov method, will be controlled. Since this control method is just robust against parameter uncertainty and not the not-modeled dynamic and external disturbances, a new method is presented for robot control that is an adaptive fuzzy estimator used to identify and overcome the uncertainties and to control the robot the fuzzy estimator will be combined with the control law. As a result, the control law is robust against all uncertainties. The rest of the paper would be as follows: section 2 presents the modeling of scara robot, the proposed control method is discussed in section 3, the adaptive fuzzy estimator is presented in section 4, simulation results and conclusions are presented in section 5 and 6, respectively.

Modeling of Robot

It is assumed that the trajectory of permanent magnet DC motors is used. As a result, the robot dynamic equation is expressed as follows:

In this equation $q \in R^n$, the position vector of the joints D(q) which is the $n \times n$ matrix relating to inertia matrix, $C(q, q^{\cdot})q^{\cdot} \in R^n$ robots acceleration vector of keriolis and the center of lateral acceleration $G(q) \in R^n$ and gravitational acceleration vector and the end vector of joint torques$\tau \in R^n$.

In The electric motors we have:

$$J\ddot{\theta_m} + B\dot{\theta_m} + r\tau = \tau_m \qquad (2)$$

The electric motor torque vector $are\ \tau_m \in R^n$, and matrix-vector engine position $\theta_m \in R^n$ and r ‹B ‹ J are $n \times n$ matrixes, diameter of the coefficients of inertia, damping and engine reduction gears.

The relation between motor speed and robot interface speed is obtained from the following equation:

$$r\dot{\theta_m} = \dot{q} \qquad (3)$$

According to equation (1), (2), (3 the dynamic equation of the robotic system can be written as follows:

$$(Jr^{-1} + D(q)r)\ddot{q} + (Br^{-1} + C(q, q^{\cdot})r)\dot{q} + rG(q) = \tau_m \quad (4)$$

$$\alpha\ddot{q} + \beta\dot{q} + \gamma = \tau_m \qquad (5)$$

Designing the proposed controller

Industrial robots are systems with multiple inputs and multiple outputs and are usually based on the control torque control strategy that depends on robot model. To achieve the control rule we will use of the model namy system as we know namy model system is known and control law is dependent on what are the actual values close to the nominal values. Control law to track the target is expressed as follows:

$$\hat{\alpha}\left(\ddot{q_d} + k_d(\dot{q_d} - \dot{q}) + k_p(q_d - q)\right) + \hat{\beta}\dot{q} + \hat{\gamma} = \tau_m \qquad (6)$$

$$e = q_d - q \qquad (7)$$

Equation (5) and (6) one can easily reach the following equation:

$$(\alpha - \hat{\alpha})\ddot{q} + (\beta - \hat{\beta})\dot{q} + (\gamma - \hat{\gamma}) = \hat{\alpha} \times (\ddot{e} + k_d\dot{e} + k_p e) \quad (8)$$

If we assume that $\tau_m = YP$ so that Y are the varied parameters and P are fixed parameters and thus equation (8) can be simplified to the following.

$$Y \times (P - \hat{P}) = \hat{\alpha} \times (\ddot{e} + k_d\dot{e} + k_p e) \qquad (9)$$

So we have:

$$(\ddot{e} + k_d\dot{e} + k_p e) = \hat{\alpha}^{-1} \times Y \times (P - \hat{P}) \qquad (10)$$

Now the present law for designing $\hat{P}$ is calculated. In this method adaptive controller based on the theory of by lyapunov is used. Estimation error of the difference between dependent parameters is presented as $P - \hat{P}$. Precise adjustment of $\hat{P}$ might even decrease $\ddot{e} + k_d\dot{e} + k_p e$ and will converge it to zero. Thus, equation (10) is used for the proposed lyapunov function. The proposed function is shown below:

$$V = \frac{1}{2}x^T sx + \frac{1}{2\beta}(p - \hat{p})^T(p - \hat{p}) \qquad (11)$$

In the above s isequation positive definite matrix and βa positive value are. We use direct method for designing a Robust Control Act of Lyapunov. State space form is displayed as the following.

$$\dot{x} = Ax + Bw \qquad (12)$$

$$x = \begin{bmatrix} e \\ \dot{e} \end{bmatrix} \quad A = \begin{bmatrix} 0 & I \\ -k_p & -k_d \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 1 \end{bmatrix} \qquad (13)$$

$$D(q)\ddot{q} + C(q, \dot{q})\dot{q} + G(q) = \tau \quad (1)$$

$$w = \hat{D}^{-1}(q) \times Y \times (P - \hat{P}) \quad (14)$$

By taking the derivative of the Lyapunov function we have:

$$\dot{V} = \frac{1}{2}x^T(A^T s + sA)x + x^T sBw - \frac{1}{\beta}(\dot{\hat{p}})^T(p - \hat{p}) \quad (15)$$

$$\dot{V} = -\frac{1}{2}x^T Qx + x^T sBw - \frac{1}{\beta}(\dot{\hat{p}})^T(p - \hat{p}) \quad (16)$$

Since Q is a positive definite matrix and also due to A, we can calculate the s matrix by the following riccati equation:

$$A^T s + sA + Q = 0 \qquad (17)$$

As a result, the first term of equation (16) is negative that Guarantees requirement for $\dot{V}$then we have

$$x^T sB\hat{D}^{-1}(q) \times Y \times (P - \hat{P}) - \frac{1}{\beta}(\dot{\hat{p}})^T(p - \hat{p}) = 0 \quad (18)$$

$$(\hat{p})^T = \int_0^t (x^T\ s\ B\ \hat{D}^{-1}(q)\ Y\ \delta)\ dt\ + \hat{p}^T(0) \quad (19)$$

Which $\hat{p}^T(0)$is initial value parameter.

Designing the fuzzy estimator in order to estimate the uncertainty

In this section, an adaptive fuzzy system is designed to calculate the uncertainty. Considering the uncertainty of the system of equations as shown below:

$$\hat{\alpha}\ddot{q} + \hat{\beta}\dot{q} + \hat{\gamma} + d = \tau_m \quad (20)$$

In the above equation d represents the dynamics of model uncertainties, such as external disturbances. The closed loop system would be:

$$\hat{\alpha}\ddot{q} + \hat{\beta}\dot{q} + \hat{\gamma} + d = \hat{\alpha}\left(\ddot{q_d} + k_d(\dot{q_d} - \dot{q}) + k_p(q_d - q)\right) + \hat{\beta}\dot{q} + \hat{\gamma} + \hat{d} \qquad (21)$$

$$(\ddot{e} + k_d\dot{e} + k_p e) = \hat{\alpha}^{-1} \times Y \times (d - \hat{d}) \quad (22)$$

Suppose that the output of the fuzzy system $\hat{d}$ is a dual input. If to any input fuzzy we consider three functions. The total estimated area is covered by 9 rules. Fuzzy rules using Mamdany inference engine is constructed as follows:

Rule$l$: If $x_1$equal toA_l and x_2 equal to B_l

Then $\hat{d}$ is equal to C_l , l law is determined for $l = 1, \ldots, 9$, and A_l ‹B_l ‹C_l are functions $related\ to\ x_1$, x_2 and $\hat{d}$. Three functions P ‹ Z and J J for input under consideration is shown in Figure 1.

Assigned functions output Gaussian function is expressed as follows:

$$\mu_{cl}(v) = \exp\left(-\left(\frac{(v - \hat{y}_l)^2}{2\sigma^2}\right)\right) \qquad (23)$$

And the rules are written as follows (Table 1).

Considering Mamdany inference engine, Single-fuzzy mechanism and non-fuzzy mechanism the $\hat{d}$ mean center is calculated as follows:

$$\hat{d} = \sum_{l=1}^{9} \hat{p}_l\, \delta_l = \hat{p}^T \delta \qquad (24)$$

In which that is $\delta = [\delta_1 \ldots \delta_9]^T$ and δ_l has a positive amount and can be calculated of the following:

$$\delta_l = \frac{\mu_A(x_1)\mu_B(x_2)}{\sum_{l=1}^{9} \mu_{Al}(x_1)\mu_{Bl}(x_2)} \qquad (25)$$

Input system errors are considered and derive fuzzy the position error in which it is $\mu_A, \mu_B \in [0,1]$ also $\hat{p}^T = [\hat{p}_1 \dots \hat{p}_9]$ which parameters are fixed

$$x_1 = e \text{ and } x_2 = \dot{e}$$

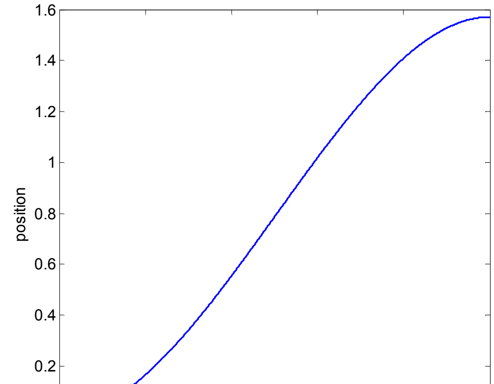
Considering that the fuzzy system is considered as a public approximation we have:

$$d = \sum_{l=1}^{9} p_l\, \delta_l + \varepsilon = p^T \delta + \varepsilon \qquad (26)$$

In the above equationε is determined Measurement error. With replacement (24) and (26) in (22) we have:

$$\ddot{e} = -k_d \dot{e} - k_p e + \hat{\alpha}^{-1} \times Y \times (p^T - \hat{p}^T)\, \delta + \hat{\alpha}^{-1} \times Y \times \varepsilon \quad (27)$$

Like the previous case the equations taken to form of the state space: $\dot{x} = Ax + Bw \qquad (28)$



$x = \begin{bmatrix} e \\ \dot{e} \end{bmatrix} \qquad A = [\ldots\ -k_p \quad -k_d]$

$$w = \hat{\alpha}^{-1} \times Y \times (p^T - \hat{p}^T)\, \delta + \hat{\alpha}^{-1} \times Y \times \varepsilon \quad (30)$$

Figure 2: Optimal path tracking

To obtain the adaption law the following lyapunov equation is offered:

$$V = \frac{1}{2} x^T s x + \frac{1}{2\rho} (p - \hat{p})^T (p - \hat{p}) \quad (31)$$

Law to be calculated as follows:

$$\hat{p} = \int_0^t (\rho x^T\, s\, B\, \delta)\, dt + \hat{p}^T(0) \qquad (32)$$

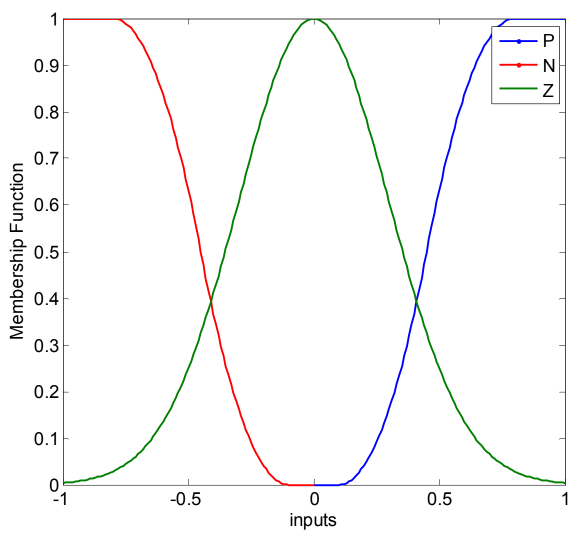


Figure 1: The functions to fuzzy input

Table1: fuzzy rules

X2 \ X1	P	Z	N
P	PH	PM	Z
Z	PM	Z	NM
N	Z	NM	NH

Simulation Results

In this section, the proposed control law on Scara industrial robot with four degrees of freedom is implemented. Optimal path for the tracking should be smooth and differentiable for this purpose considers the optimal path specified in Figure 2.

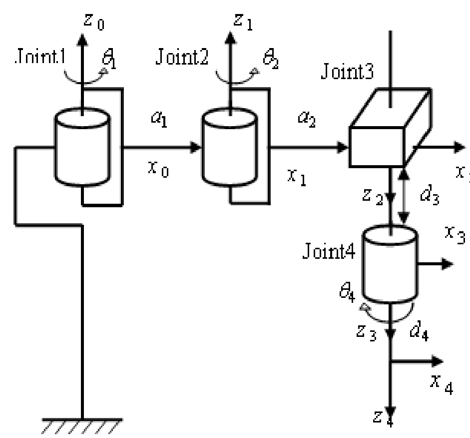


Figure 3: Scara robot with four degrees of freedom

First simulation: In this simulation the adaptive control law is used and it is assumed that there is not any external perturbation or not-modeled dynamics. The error description can be seen in figure 4 indicates that the control law works well. Figure 5 also shows the torque applied on any joint.

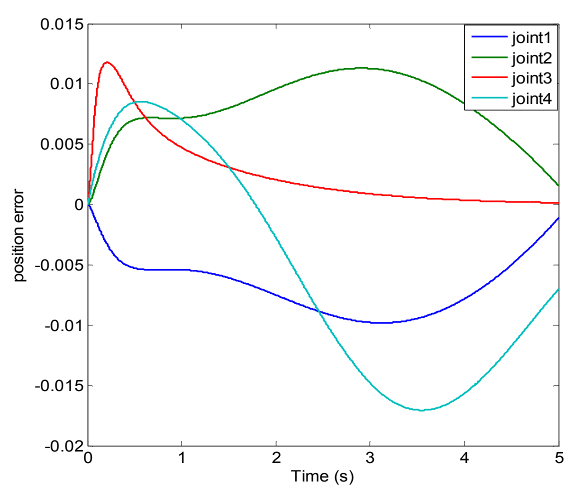


Figure 4: The error of the robot joints

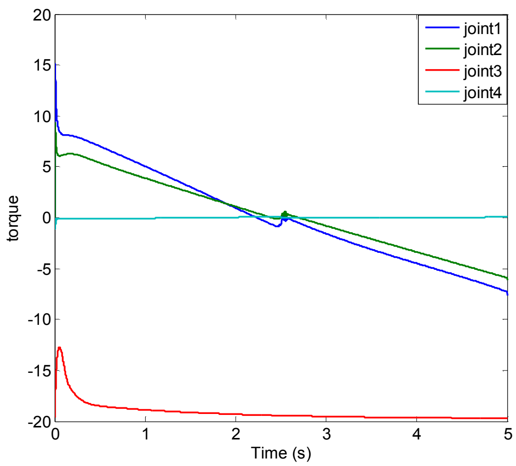


Figure 5: The torque exerted on the joints

The second simulation: In this simulation the adaptive control law is used and it is assumed that the external perturbation d exists. The error description can be seen in Figure 6 which indicates that the control law is not robust against external disturbances. Also is shown in Figure 7 torque to each joint which can be seen that the oscillating torque is immense and difficult in practice.

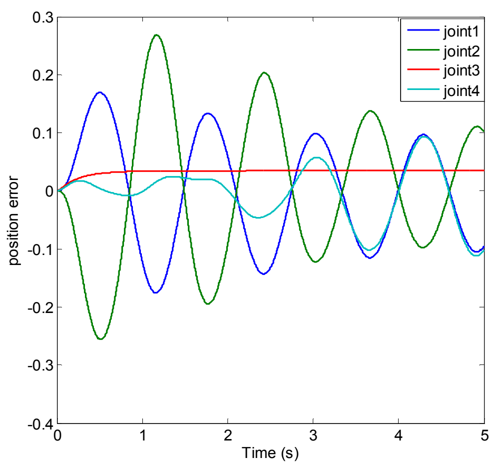


Figure 6: The error of the robot joints.

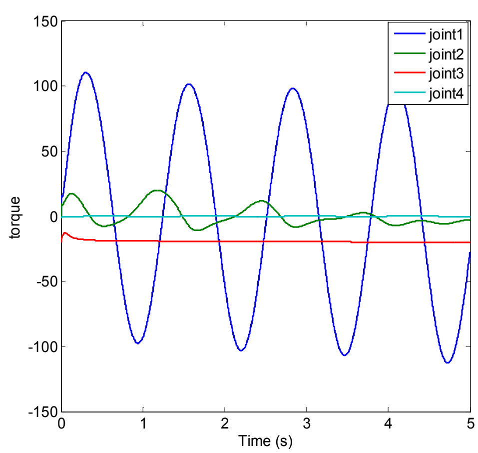


Figure 7: The torque exerted on the joints

Third simulation: the simulation of the adaptive control with fuzzy adaptive observer estimate is used to control the robot. The second simulation assumes that there is an external perturbation. Any joint can be seen in Figure 8, the error is much reduced, which indicates proper operation of the control law. The torque exerted on the joints figure 9 which as it can be seen the torque is reduced.

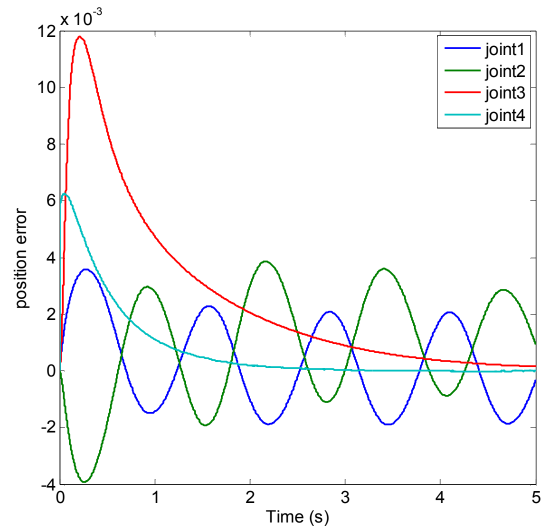


Figure 8: The error of the robot joints.

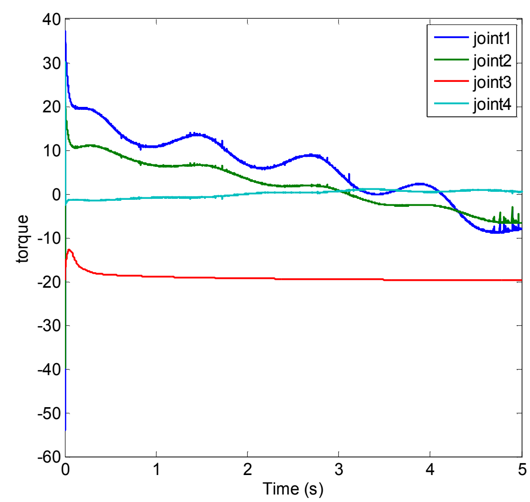


Figure 9: The torque exerted on the joints

RESULTS

Adaptive controller based on lyapunov method is robust against parameter uncertainty, and since in all control systems non-parametric uncertainty exists, controller performance is reduced. So in this paper a fuzzy adaptive estimator is used to compensate for non-parametric uncertainties. So that the lyapunov based adaptive control law, combined with a fuzzy adaptive observer estimate is achieved. The simulation results show well performance of the control law.

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