ISSN:2231-0711

Qing Liu et al | IJCSET |June 2013 | Vol 3, Issue 6, 211-214

Research of Adaptive Iterative Learning Algorithm for Industrial Manipulator

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***Abstract*—A three degree dynamic model of manipulator included a screw-nut auxiliary is introduced. Considering the random disturbance and the to the manipulator in practical situation , the adaptive iterative learning controller is designed. The simulation was conducted under MATLAB environment ,the result shows that the controller can efficiently track the trajectory with high accuracy. The result of the change of screw-nut auxiliary's parameters on the controller's tracking effect is also analyzed.**

Key Words: manipulator; dynamic; adaptive iterative learning; screw-nut auxiliary; simulation

I. INTRODUCTION

Currently there are many robot trajectory tracking control algorithm. Such as, independent PD algorithm , feed forward PD+ algorithm ,computed torque method algorithm, iterative algorithm, etc[1]. Among these algorithms, the iterative algorithm can achieve the controlled object's actually trajectory tracks the desired trajectory with high accuracy, and does not rely on accurate mathematical model of the system[2]. This paper combined the advantage of feed forward PD+ algorithm and iterative algorithm, and adaptive iterative control algorithm is designed for three joints manipulator trajectory tracking control , this algorithm has the performance of fast asymptotic convergence.

During the process of the simulation study, in addition to the error of manipulator itself, the parameters of the screw are also found the factors which can affect the trajectory tracking error of the algorithm.

II. DYNAMICAL MODEL OF THE MANIPULATOR

As is shown in figure 1,the 1st joint of ball screw assembly implements the rising and falling of the entire arm. The 2nd and 3rd joint is rotate joints, q_1 is the displacement of the nut , m_1 is the mass of the nut and the connecting element between the nut and the rear arm. The length of the rear arm and the forearm are l_1 and l_2 ,their mass are m_2 , m_3 .

The dynamical equation of the manipulator can be written as the following formula[7]:

$$\tau_i = M(q(t))\ddot{q}(t) + C(q(t), \dot{q}(t))\dot{q}(t) + G(q(t)) \quad (1)$$

Where $q(t) \in R^n, \dot{q}(t) \in R^n, \ddot{q}(t) \in R^n$ are namely the displacement, velocity and acceleration of the joints, $M(q(t)) \in R^{n\times n}$ is the Inertia Matrix of the manipulator. $C(q(t), \dot{q}(t))\dot{q}(t)$ is the Centrifugal and Coriolis force, $G(q(t)) \in R^n$ is gravity terms, $\tau_i \in R^n$ are the controlling force or torque of the robot.

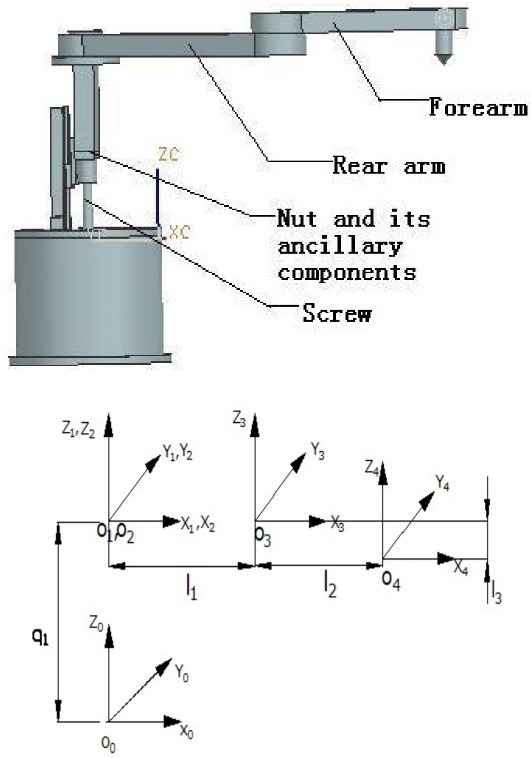

Figure.1 Structure of the robot and the simplified D-H coordinates

The above dynamical equation has a property ,which can be expressed as[8]:

$$G(q) + C(q,\dot{q})\dot{q}_d = \psi(q,\dot{q})\zeta^T(t) \quad (2)$$

Where $\psi(q,\dot{q}) \in R^{n\times(m-1)}$ is a matrix about the joint variables q , $\zeta(t) \in R^{m-1}$ is a matrix about the physical parameter variables of the manipulator.

$$\zeta(t)=\begin{bmatrix}-\frac{1}{2}l_1l_2m_3\dot{q}_{2d} & -\frac{1}{2}l_1l_2m_3\dot{q}_{3d} & m_1+m_2+m_3 & 0\end{bmatrix}$$

Where τ_1 is the driving force of the moving joint, but the screw vice is driven by the rotation of the motor, therefore τ_1 should be converted to the driving torque T of the motor.

The relationship between the driving torque T and the driving force τ_1 can be expressed as the following formula [4]:

$$T=\tau_1 r\Lambda \qquad (3)$$

The axial movement q_1 generated by the screw vice when it turns ϕ is: $q_1=\phi r\tan\delta$;when the nut moves up $\Lambda=\Lambda_u$,when it move down, $\Lambda=\Lambda_d$,both of them are expressed in the formula (4);

$$\begin{cases}\Lambda_u=-\dfrac{S_x-f\cos\delta}{S_z-f\sin\delta}\\ \Lambda_d=-\dfrac{S_x+f\cos\delta}{S_z+f\sin\delta}\end{cases} \qquad (4)$$

where $\delta=\dfrac{p}{2\pi r}$, $S_x=-\dfrac{\sin\delta\cos\psi}{\sqrt{1-(\sin\delta\sin\psi)^2}}$, $S_z=\dfrac{\cos\delta\cos\psi}{\sqrt{1-(\sin\delta\sin\psi)^2}}$, p is the pitch of screw, r is the diameter of the screw, ψ is the tooth type angle of the screw.

Therefore, the dynamical equation of the robot shown in figure 1 can be written as :

$$\begin{cases}T=(m_1+m_2+m_3)gr\Lambda+(m_1+m_2+m_3)r^2\Lambda\tan\delta\\ \tau_2=(\frac{1}{3}m_2l_1^2+\frac{1}{3}m_3l_2^2+m_3l_1^2+m_3l_1l_2c_3)\ddot{q}_2+\\ (\frac{1}{3}m_3l_2^2+\frac{1}{2}l_1l_2c_3m_3)\ddot{q}_3-m_3l_1l_2s_3\dot{q}_3\dot{q}_2-\frac{1}{2}m_3l_1l_2s_3\dot{q}_3^2\\ \tau_3=(\frac{1}{3}m_3l_2^2+\frac{1}{2}m_3l_1l_2c_3)\ddot{q}_2+\frac{1}{3}m_3l_3^2\ddot{q}_3+\frac{1}{2}l_1l_2s_3m_3\dot{q}_3^2\end{cases} \qquad (5)$$

III. ADAPTIVE ITERATIVE LEARNING ALGORITHM

A. Description of the Problem

In actual operations of the robot, it will be influenced by the uncertainties from itself and the friction and interference from the external environment, the system can be described by the following formula:

$$\tau_i+d_i=M(q_i(t))\ddot{q}_i(t)+G(q_i(t))+C(q_i(t),\dot{q}_i(t))\dot{q}_i(t) \qquad (6)$$

Where $i\in z^+$ is the number of iterations, the angular displacement, Angular velocity and angular acceleration of the joints after the i^{th} iteration are $q_i(t),\dot{q}_i(t),\ddot{q}_i(t)$, d_i is the random perturbations.

According to the literature [3], there is a theorem for the system shown in formula (3): if utilize the control law expressed in formula (4), then $\tilde{q}_i(t)=q_d(t)-q_i(t)$ and $\dot{\tilde{q}}_i(t)=\dot{q}_d(t)-\dot{q}_i(t)$ are bounded, $\forall t\in[0,T],\lim_{i\to\infty}\tilde{q}_i(t)=0$ $\lim_{i\to\infty}\dot{\tilde{q}}_i(t)=0,$,the process of the proving can be referred in literature [3].

$$\begin{cases}\tau_i(t)=K_P\tilde{q}_i(t)+K_D\dot{\tilde{q}}_i(t)+\varphi(q_i(t),\dot{q}_i(t),\dot{\tilde{q}}_i(t))\hat{\theta}_i(t)\\ \hat{\theta}_i(t)=\hat{\theta}_{i-1}(t)+\Gamma\varphi^T(q_i(t),\dot{q}_i(t),\dot{\tilde{q}}_i(t))\dot{\tilde{q}}_i(t)\end{cases} \qquad (7)$$

Where $\hat{\theta}_1(t)=0$, $\varphi(q_i(t),\dot{q}_i(t),\dot{\tilde{q}}_i(t))\in R^{n\times n}$,and $\varphi(q_i(t),\dot{q}_i(t),\dot{\tilde{q}}_i(t))=[\psi(q_i(t),\dot{q}_i(t))\operatorname{sgn}(\dot{\tilde{q}}_i)]$ the matrixes $K_P,K_D\in R^{n\times n}$ and $\Gamma\in R^{m\times m}$ are positive definite matrix of symmetric.

B. Simulation and Performance Analysis

The simulation is conducted for the robot shown in figure 1 and the control law expressed in formula (7) under the environment of MATLAB. The parameters of the manipulator are : $m_1=2.5647kg$, $m_2=6.0744kg$, $m_3=5.226kg$, $l_1=350mm$, $l_2=280mm$, $p=5mm$, $r=16mm$, $\psi=15^\circ$, $f=0.15$ (the Coefficient between steel screw and bronze nut is 0.19[5],its recommended value in literature [6] is 0.15~0.18), $\Lambda_u=0.2064$, $\Lambda_d=0.1046$, $K_P=K_D=diag[10,10,10]$, $\Gamma=diag[15,15,15,15,15]$ .The centroid of the nut portion the arms of the robot are all in their centers .The system shown in formula (6)can be expressed as :

$$\begin{bmatrix}m_{11}&m_{12}&m_{13}\\m_{21}&m_{22}&m_{23}\\m_{31}&m_{32}&m_{33}\end{bmatrix}\begin{bmatrix}\ddot{q}_1(t)\\\ddot{q}_2(t)\\\ddot{q}_3(t)\end{bmatrix}+\begin{bmatrix}c_{11}&c_{12}&c_{13}\\c_{21}&c_{22}&c_{23}\\c_{31}&c_{32}&c_{33}\end{bmatrix}\begin{bmatrix}\dot{q}_1(t)\\\dot{q}_2(t)\\\dot{q}_3(t)\end{bmatrix}+\begin{bmatrix}G_1\\G_2\\G_3\end{bmatrix}=\begin{bmatrix}T\\\tau_2\\\tau_3\end{bmatrix} \qquad (8)$$

Where $m_{12}=m_{21}=m_{13}=m_{31}=0$,

$m_{11}=(m_1+m_2+m_3)r^2\Lambda\tan\delta$,

$m_{22}=\frac{1}{3}m_2l_1^2+\frac{1}{3}m_3l_2^2+m_3l_1^2+l_1l_2m_3c_3$,

$m_{23}=m_{32}=\frac{1}{3}m_3l_2^2+\frac{1}{2}l_1l_2c_3m_3$, $m_{33}=\frac{1}{3}m_3l_3^2$,

$c_{11}=c_{12}=c_{13}=c_{21}=c_{31}=c_{33}=0$, $c_{22}=-\frac{1}{2}l_1l_2s_3m_3\dot{q}_{i3}$,

$c_{23}=-\frac{1}{2}m_3l_1l_2s_3\dot{q}_{i3}-\frac{1}{2}m_3l_1l_2s_3\dot{q}_{i2}$, $c_{32}=\frac{1}{2}l_1l_2s_3m_3\dot{q}_{i2}$,

$G_1=(m_1+m_2+m_3)gr\Lambda$, $G_2=G_3=0$.

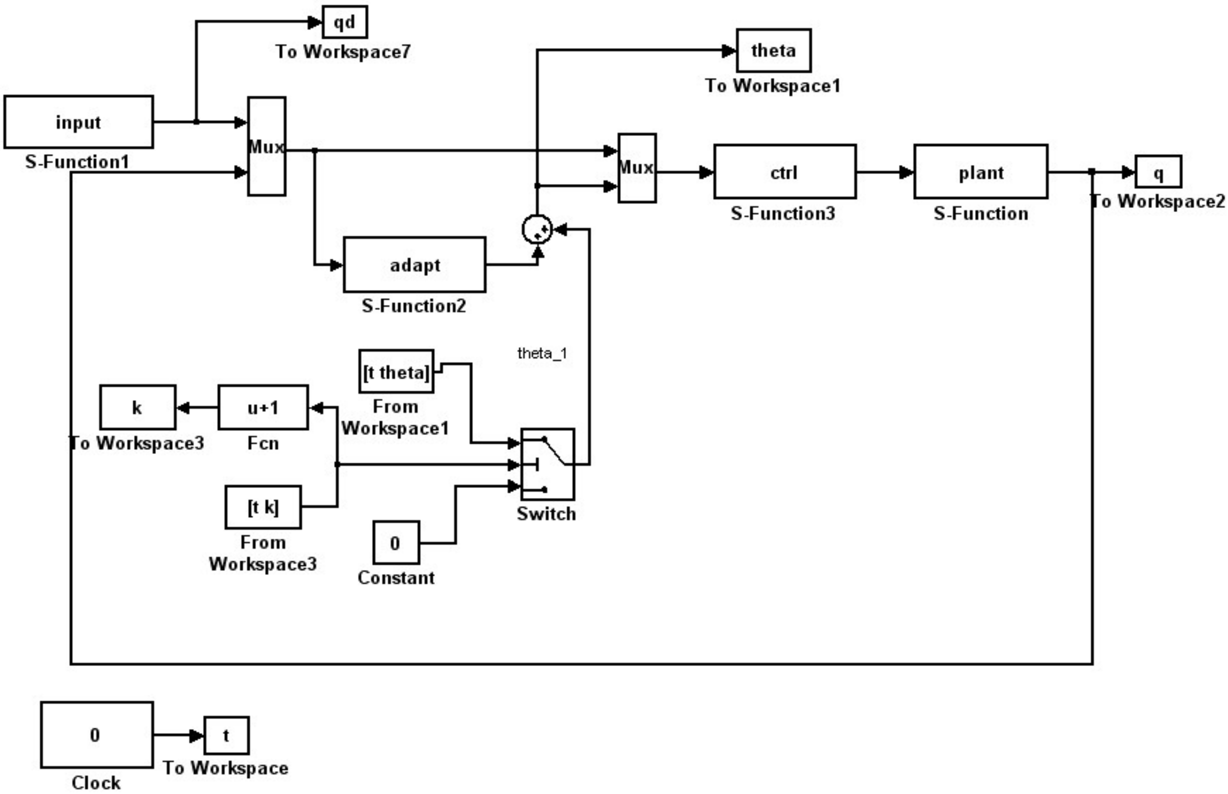

Figure.2 The simulink block diagram of the main function

The simulation is conducted under the MATLAB environment ,figure 2 is the manipulator's simulink block diagram of the main function. In figure 2, 'ctrl' is the controller subprogram, 'adapt' is adaptive subprogram, 'plant' is the subprogram of the controlled object, 'input' is the input command subprogram.

The number of the iteration is 5,the duration of the simulation is 4s, $d_{i1}(t) = d_{i2}(t) = d_{i3}(t) = d_m \sin(t)$, d_m changes randomly in [-1,1].The position command signal of the screw ,rear arm ,forearm are $q_{1d} = \sin(\pi t/4)$, $q_{2d} = \sin(2\pi t)$, $q_{3d} = \cos(2\pi t)$ .The initial state of the controlled object is $[0; \pi/4; 0; 2\pi; 1; 0]$ .The results of the trajectory tracking control are shown in figure 3~figure 5.

C. The Impact On Tracking Error of Λ

If the value of Λ becomes larger than it is in formula (2)($f = 0.19$, $\Lambda_u = 0.3064$, $\Lambda_d = 0.1428$).The motor that drives the screw is simulated, the results are shown in figure 6~figure 7.As are shown in the figures, when Λ becomes larger, the angular displacement and velocity after the fifth iteration also becomes larger. Therefore, in order to reduce the trajectory tracking error of the robot, in addition to ameliorate the algorithm, the value of Λ can also be reduced .The value of Λ is affected by screw pitch, diameter, coefficient of sliding friction and tooth type angel. So, the reduction of the tooth type angel and the coefficient of sliding friction can both reduce the error of the control algorithm.

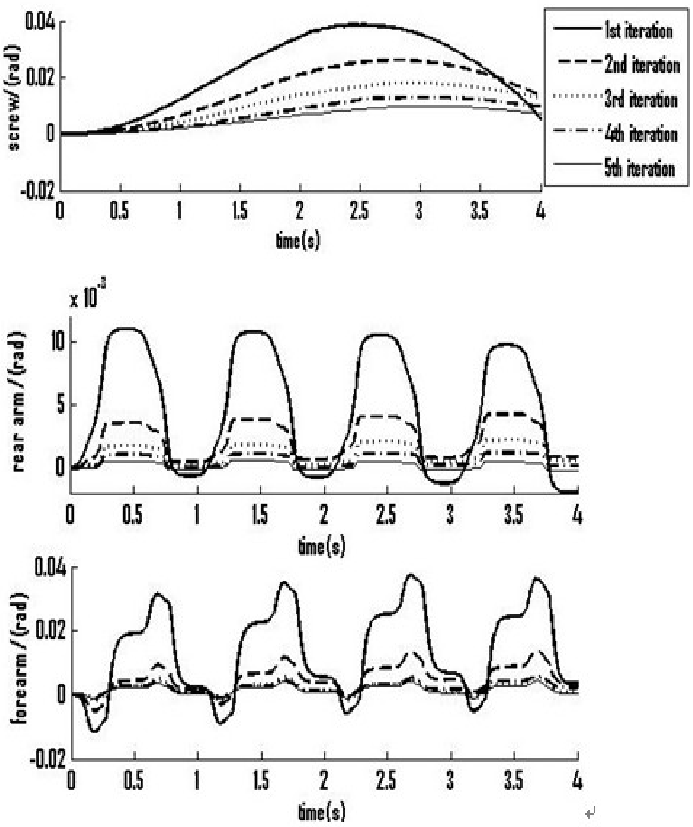

Figure.3 The position error of every joint after each iteration

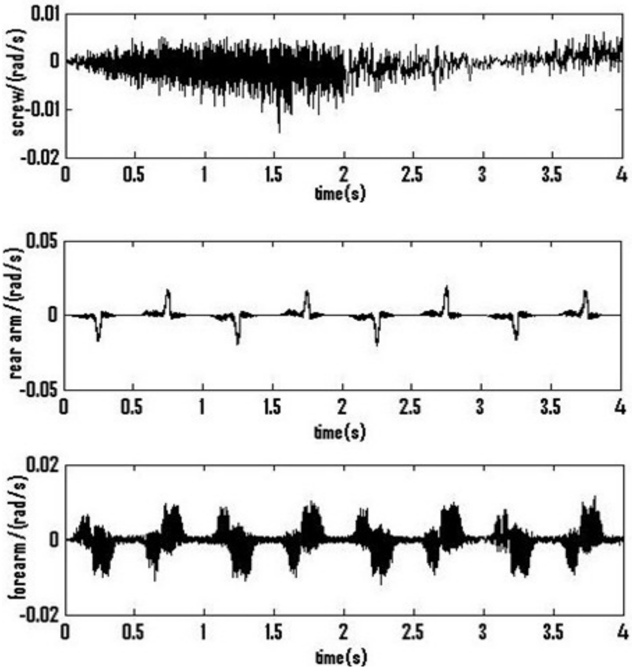

Figure.4 The velocity error of each joint after the fifth iteration

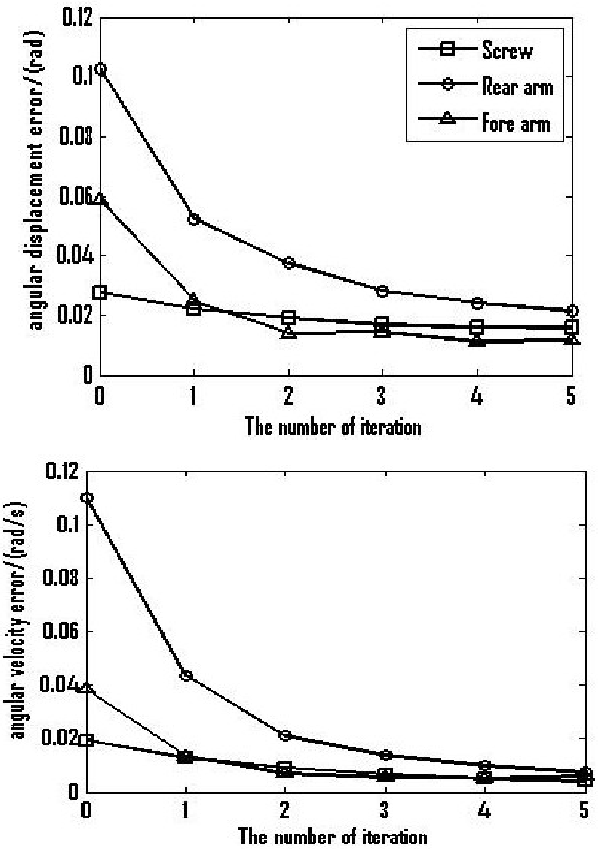

Figure.5 The maximum absolute angular error and angular velocity error during the five iterations

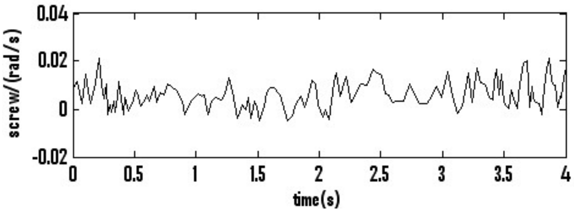

Figure.6 The velocity error of the screw when Λ becomes larger

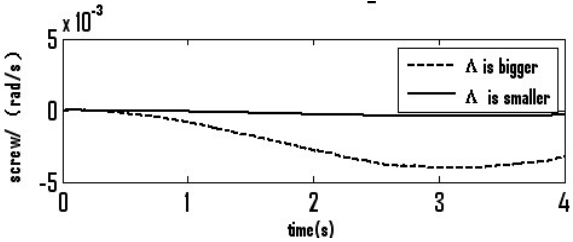

Figure.7 Corresponding to different values of Λ ,the different value of angular error of the screw

IV. CONCLUSION

In this paper, the dynamical equations of a three joints manipulator which has a ball screw pair are established .

Based on the equations, a simulation about the adaptive iterative control algorithm is conducted. The simulation results shows that the algorithm can realize the angular displacement and angular velocity converges to the ideal value ,and it has a good performance in tracking the target trajectory. At last, based on the special structure of the manipulator, it is obtained that the parameters of the ball screw pair can be one of the influencing factors of the accuracy of the algorithm.

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