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PD Iterative Self-learning Control for 3R Plane Robot Trajectory Tracking

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Abstract

In order to improve the speed and accuracy of the trajectory tracking control for 3R plane robot, a PD iterative self-learning control algorithm is proposed based on the PD iterative control algorithm. The error of target value and the actual value of this iteration is introduced into the PD learning gain to make the PD learning gain becomes a function of the error and to achieve the effect of self-learning. Simulation analysis of planar 3-link robot trajectory control shows that the proposed algorithm is better than unmodified in speed ability and accuracy.

Keywords: *PD iterative control, self-learning, planar 3-link, trajectory tracking*

1. Introduction

According to tracking problem, a variety of design methods are provided in control theory and many good results are achieved, but tracking task is achieved asymptotic by the vast majority of them [1-4]. In order to achieve the fully tracking of expect output, Iterative Learning Control (ILC) method was proposed by Arimoto et al in 1984[5]. Significant achievements are made in the development of ILC, which is applied in a wide range of industries, including robot [6, 7], rapid thermal processing [8, 9], industrial process control, functional neuromuscular stimulation [10]. Objective of ILC is to make the system tracking error gradually decreases after repeated running, and fully track the desired trajectory ultimately. The experience of the previous control of the control system is used. The deviation of actual output information measured and the target track given in advance is used to correct the not ideal control signals. An ideal input is founded by a relatively simple learning algorithm to produce the desired movement of the controlled object [11, 12]. In recent years, significant progresses are made in convergence, robustness and applied research on learning [13, 14].

The PD iterative control is the most common class of iterative learning control algorithm, the error of target value and the actual value of this iteration is introduced into the PD learning gain to make the PD learning gain which is a fixed value in the conventional algorithm becomes a function of the error to achieve the effect of self-learning. Simulation analysis of planar 3-link robot trajectory control shows that the proposed algorithm is better than unmodified in speedability and accuracy.

The paper is organized as follows. PD Iterative Self-learning Control algorithm is given in Section 2. In Section 3, the static analysis of planar 3-link robot is discussed. Finally, simulation analysis of planar 3-link robot trajectory control is discussed in Section 4.

2. Algorithm Description

2.1. PD Iterative Control

D type algorithm is sensitive to the high frequency interference of the error signal due to the differential action. This problem can be resolved by the P type control algorithm. The maximum error can be reduced and the tracking accuracy can be improved by PD type ILC algorithm. The conventional PD type iterative control law:

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$$u_{k+1}(t) = u_k(t) + k_p e_{k+1}(t) + k_d \dot{e}_{k+1}(t) \quad (1)$$

Where kp and kd is the PD type iterative control gain, $e_{k+1}(t) = y_d(t) - y_{k+1}(t)$.

2.2. PD Iterative Self-Learning Control

Conventional k_p and k_d is replaced of functions of $e_{k+1}(t)$, namely: $k_p=k_p(e_{k+1}(t))$, $k_d=k_d(e_{k+1}(t))$ on the basis of conventional PD type iterative learning control. Therefore, the improved PD-type iterative self-learning control law is:

$$u_{k+1}(t) = u_k(t) + k_p(e_{k+1}(t)) \cdot e_{k+1}(t) + k_d(e_{k+1}(t)) \cdot \dot{e}_{k+1}(t) \quad (2)$$

2.3. Determination of $k_p(e_{k+1}(t))$ and $k_d(e_{k+1}(t))$:

Nonlinear PID tuning is analyzed by Yongli Xiao et al [15] by using step response curve of the general system, shown in Figure 1. $k_p(e_{k+1}(t))$ and $k_d(e_{k+1}(t))$ are constructed based on this analysis thinking.

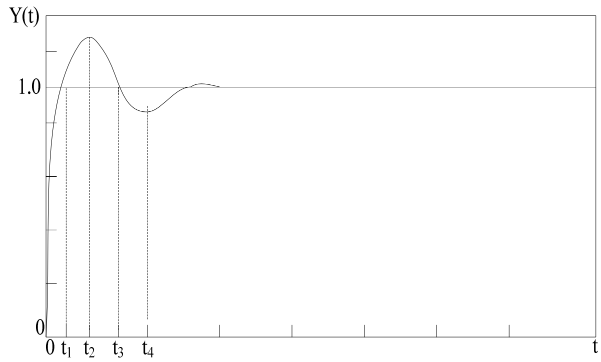


Figure 1. Step response curve of the general system

a. The proportional gain kp

To guarantee a faster response speed, k_p should initially be larger when the response time is $0 \le t \le t_1$. In order to reduce overshoot, k_p is desired to decreases gradually as $e_{k+1}(t)$ gradually decreases, which makes the system inertia gradually weakened and will not have a big overshoot. k_p is desirable to gradually increase in order to increase the role of reverse control and reduce the overshoot between t_1 and t_2. k_p is expected to gradually decreases in order to make the system return to the steady state point as soon as possible, and no longer generate a large inertia between t_2 and t_3. k_p is expected to gradually increase between t_3 and t_4,the same as between t_1 and t_2. Obviously, according to the above variation, changing of k_p as $e_{k+1}(t)$ changes is shown in Figure 2. The nonlinear function can be constructed as follows:

$$k_p(e_{k+1}(t)) = a_p + b_p(1 - \mathrm{sec}\,h(c_p e_{k+1}(t))) \quad (3)$$

Where a_p, b_p, c_p are positive real constants. Maximum value of kp is a_p+b_p when, minimum value of k_p is a_p when $e_{k+1}(t)=0$. The rate of change of k_p can be adjusted by adjusting the size of c_p.

b. The differential gain k_d

In order to inhibit the generation of overshoot and does not affect the speed of response, k_d should gradually increase when the response time is $0 \le t \le t_1$. k_d is desirable to continually increase in order to increase the role of reverse control and reduce the overshoot between t_1 and t_2. kd should gradually decreases at t_2. In order to inhibit the generation of overshoot, k_d should gradually increases again between t_2 and t_3. The symbol of error change rate should be considered when nonlinear function of k_d is constructed according to requirements of changings of k_d. Changing of k_d is shown in Figure 3 and the nonlinear function structured is:

$$k_d\left(e_{k+1}(t)\right) = a_d + b_d / \left(1 + c_d \exp\left(d_d \cdot e_{k+1}(t)\right)\right) \quad (4)$$

Where a_d,b_d,c_d,d_d are positive real constants. a_d is the minimum value of k_d, a_d+b_d is the maximum value of k_d. $k_d=a_d+b_d/(1+c_d)$ when $e_{k+1}(t)=0$. Rate of change of k_d can be adjusted as a_d is adjusted [16].

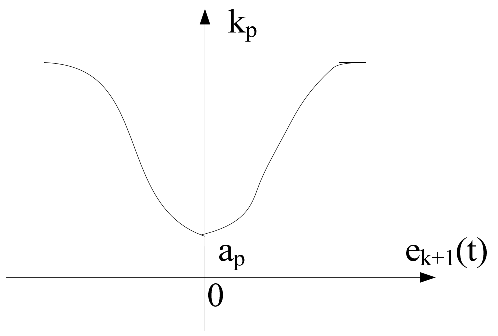


Figure 2. Curve of kp

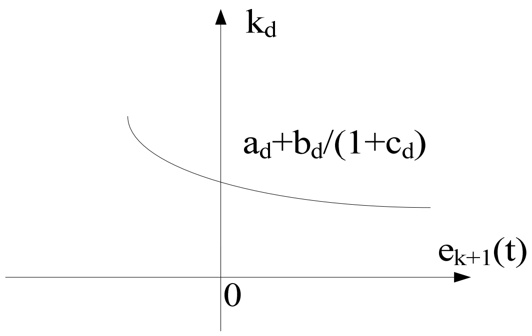


Figure 3. Curve of kd

So the law of improved PD iterative self-learning control is:

$$\begin{aligned} u_{k+1}(t) &= u_k(t) + k_p\left(e_{k+1}(t)\right)\cdot e_{k+1}(t) + k_d\left(e_{k+1}(t)\right)\cdot \dot{e}_{k+1}(t) \\ &= u_k(t) + \left(a_p + b_p\left(1-\operatorname{sech}\left(c_p e_{k+1}(t)\right)\right)\right)\cdot e_{k+1}(t) + \left(a_d + b_d/\left(1+c_d\exp\left(d_d\cdot e_{k+1}(t)\right)\right)\right)\cdot \dot{e}_{k+1}(t) \end{aligned} \quad (5)$$

3. Static Analysis of Planar 3-link Robot

A plane three-link is regarded as the simulation object, organizational chart of which is shown in Figure 4 [17].

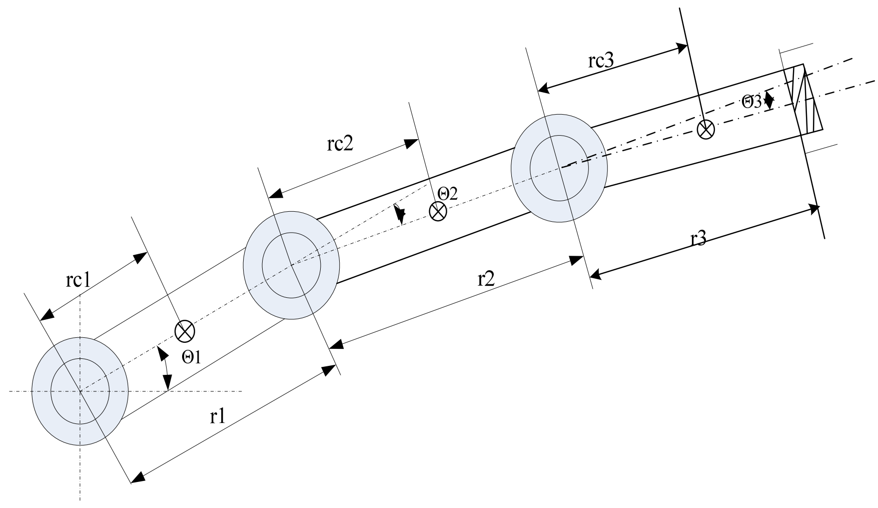


Figure 4. Organizational chart of the plane 3R robot

3.1. Kinematics Equation

Ector equation of plane 3R robot can be seen as follows:

$$R_{pl} = R_1 + R_2 + R_3 \tag{6}$$

Where R_{pl} is the straight line distance of the end of the robot relative to the origin, R_1 is the length of the connecting rod 1, R_2 is the length of the connecting rod 2, R_3 is the length of the connecting rod 3, scalar equation that R_{pl} corresponds to x and y axis is:

$$x_{pl} = r_1 \cos \theta_1 + r_2 \cos(\theta_1 + \theta_2) + r_3 \cos(\theta_1 + \theta_2 + \theta_3) \tag{7}$$

$$y_{pl} = r_1 \sin \theta_1 + r_2 \sin(\theta_1 + \theta_2) + r_3 \sin(\theta_1 + \theta_2 + \theta_3) \tag{8}$$

Where x_{pl} is the x value of the end of rod, y_{pl} is the y value of the end of rod, θ_i is the angle of the rod i relative to the rod (i -1), r_i is the length of rod i.

Equation (7) and Equation (8) are second derivative to get the equation of velocity.

3.2. Dynamics Equation

Diagram of rod 1 is shown in Figure 5. Dynamic of the rod 1 is analyzed:

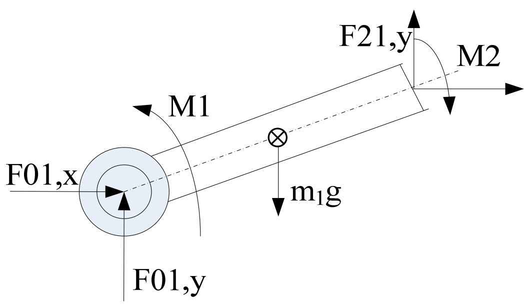


Figure 5. Diagram of rod 1

Three dynamic equations of linkage 1 can be deduced from Figure 5, and dynamic equations of other two rods are similar to rod 1:

$$\begin{cases} F_{01,x} + F_{21,x} = m_1 a_{c1,x} \\ F_{01,y} + F_{21,y} - m_1 g = m_1 a_{c1,y} \\ M_1 - M_2 - F_{21,X} r_1 s_1 + F_{21,y} r_1 c_1 - m_1 g r_{c1} c_1 = I_1 a_1 \end{cases} \tag{9}$$

Equations of payload force are

$$\begin{cases} m_{pl} \ddot{x}_{pl} = -F_{43,x} \\ m_{pl} \ddot{y}_{pl} = -F_{43,y} - m_{pl} g \end{cases} \tag{10}$$

where m_i is the quality of the rod i, m_{pl} is the quality of the payload, g is the acceleration due to gravity, I_i is the moment of inertia of rod i, a_{ci},x is the angular acceleration of center of gravity of rod i in the x direction, a_{ci},y is the angular acceleration of center of gravity of rod i in the y direction, $F_{ij,x}$ is force of rod i relative to rod j in the x direction, $F_{ij,y}$ is force of rod i relative to rod j in the y direction, M_i is torque of revolute pair i.

4. Simulation Analysis

A plane three-link is regarded as the simulation object, parameter of the robot mechanical system is assumed as m_1=4.0kg, m_2=3.0kg, m_3=3.0kg, r_1=r_2=1m, r_3=0.8m, r_{c1}=r_{c2}=0.5m, r_{c3}=0.4m, I_1=0.08kg*m^2, I_2=0.2kg*m^2, I_3=0.2kg*m^2, g=9.8067m/s². In the simulation, rotation angle trajectory of the three joint is q_{d1} = sin (pi * t / 6); q_{d2} = sin (t); q_{d3} = (pi / 8) * t, the initial position is x_0 = 2.8m, y_0 = 0m. Simulation platform is shown in Figure 6, which is composited by the input unit, control unit, control unit and output unit. A detail description of a single joint iteration unit is shown in Figure 7.

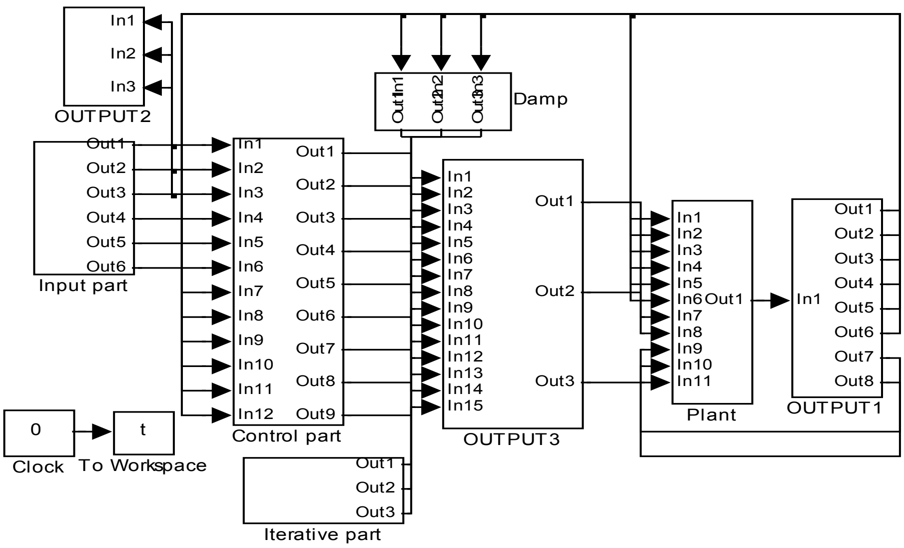


Figure 6. Simulation diagram

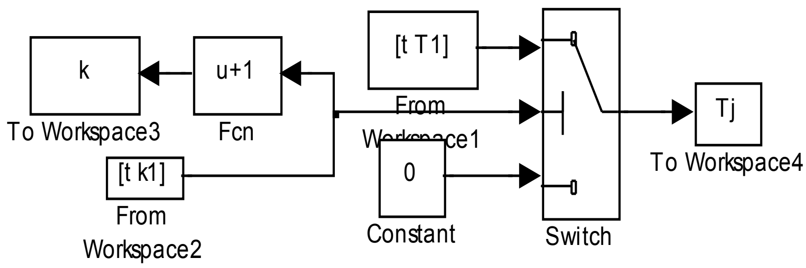
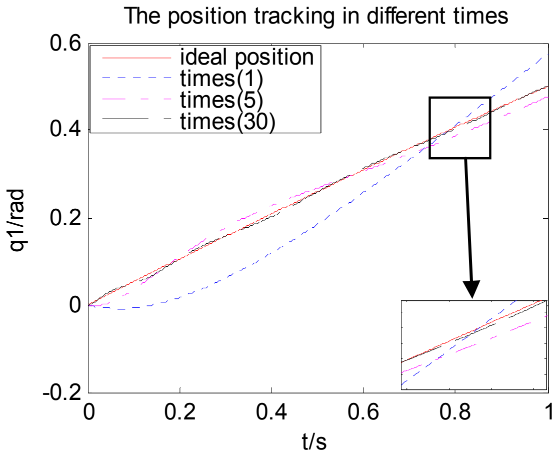


Figure 7. Iterative part

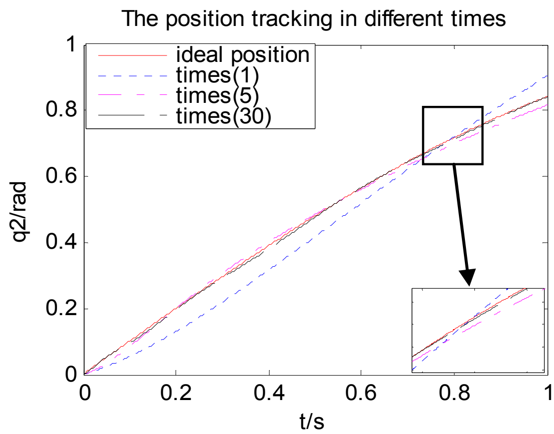
Tracking effect in 1 iteration, 5 iterations, 10 iterations and 30 iterations respectively of three joints are shown in Figure 8. It can be clearly seen that tracking is poor in 1 iteration and the effect gets better and better through multiple iterations. It tracks on a given trajectory basically when the number of iterations reaches to 30 times by a number of simulations.

Change graph of k_p and k_d of three joints in the 30th iteration is shown in Figure 8. It can obviously be seen that k_p and k_d change in the tracking process. It can be seen from Figure 9(a) that variation of k_p is relatively large at the beginning, because the e is relatively large and gradually stabilizes.

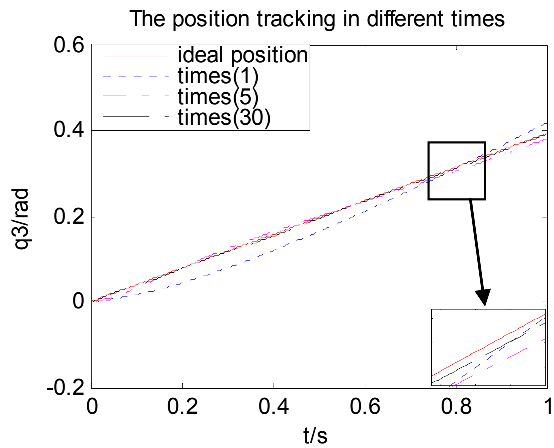
The path tracking effect diagram after 30 iterations is shown in Figure 10. It can be seen that effect in PD iterative self-learning control proposed is better than PD iterative control, and it can tracks the given target trajectory more accurately.



(a) joint 1

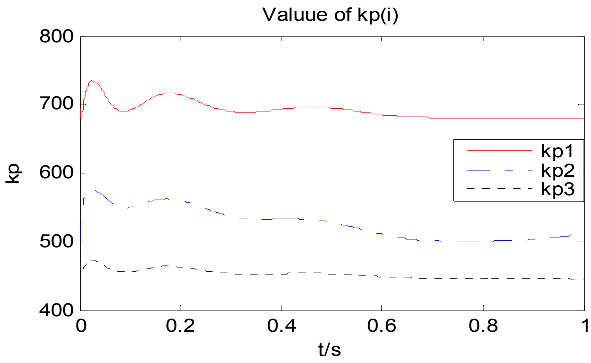


(b) joint 2

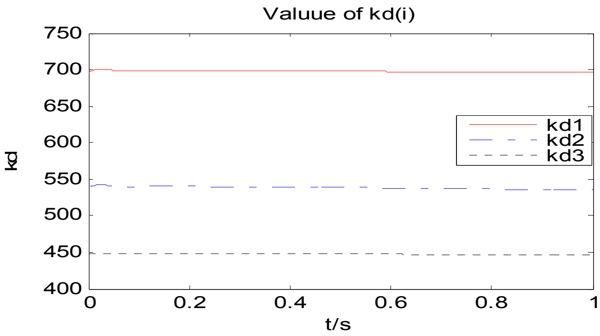


(c) joint 3

Figure 8. Tracking effect diagram of each joint in the different number of iterations

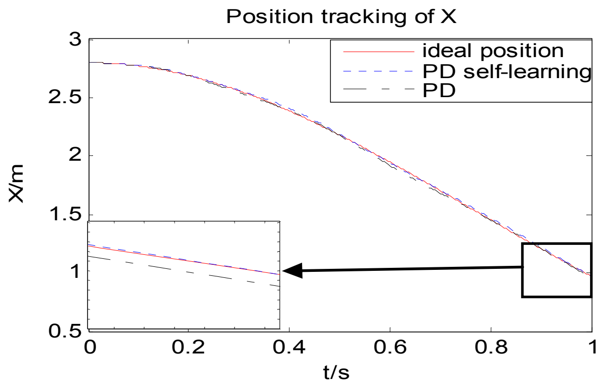


(a)k_p

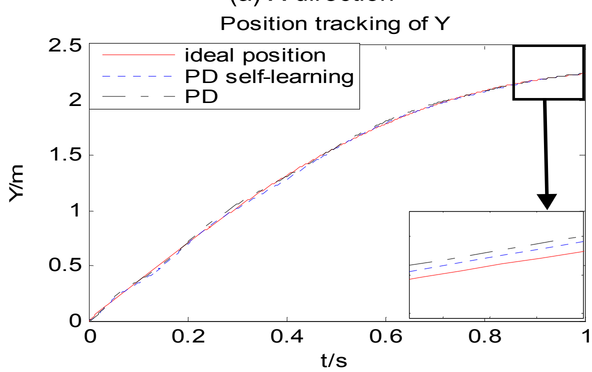


(b) k_d

Figure 9. k_p and k_d of three joints in the 30th iteration



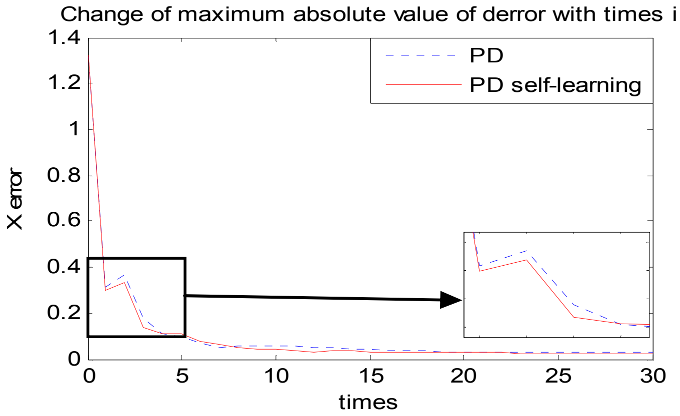
(a) X direction



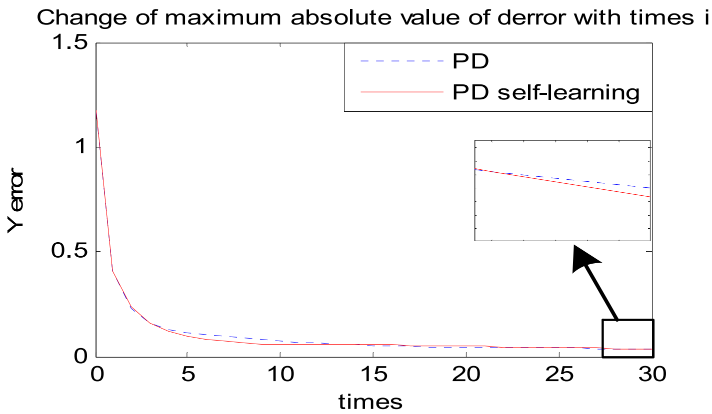
(b) Y direction

Figure 10. Path tracking effect diagram

Error convergence process in 30 iterations is shown in Figure 11. It can be seen that convergence rate in PD iterative self-learning control proposed is better than PD iterative control whether in the X direction or Y direction, as well as the final error value is smaller.



(a) X direction



(b) Y direction

Figure 11. Error convergence process in30 iterations process

5. Conclusion

Iterative control of three-link robot is researched in depth. The basic principle of the PD type iterative learning control is understood firstly. Then a PD type iterative self-learning control algorithm is proposed based on the PD type iterative learning control algorithm. The error $e_{k+1}(t)$ of target value and the actual value of this iteration is introduced into the PD learning gain to make the PD learning gain k_p and k_d become error functions $k_p(e_{k+1}(t))$和 $k_d(e_{k+1}(t))$ and to achieve the effect of self-learning. Simulation analysis of planar 3-link robot trajectory control shows that the proposed algorithm is better than unmodified in speedability and accuracy.

Acknowledgements

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