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Tracking Control of Robot's Trajectory Based on DTW-ILC Algorithm

Gu Qun and Hao Xiaohong

School of Electrical and Information Engineering, Lanzhou University of Technology,
Lanzhou, 730050, China

Abstract: When de-icing robot performs the de-icing task, it must cross all kinds of obstacles. The iterative time warping distance learning control algorithm is applied to the ice line robot manipulator trajectory tracking control system, in the implementation of the time, every time to solve the optimal problem is solved using EADTW distance, to optimize the traditional iterative learning control algorithm, the icing line robot manipulator trajectory tracking, solve the disadvantages of the traditional algorithm of real-time. Finally can be verified by simulation, this method can effectively achieve the complete tracking the trajectory of the robot manipulator icing line and has good convergence.

Key words: Power transmission line, de-icing robot, iterative learning control, dynamic time warping, optimization methods

INTRODUCTION

Transmission line icing and snow is always a threat to the safe operation of power and communication network trouble. Often happens in most countries in the world, such as the United States of America, Canada, Russia and other countries. In China, the icing occurs mainly in the southwest, northwest and central china. Transmission line icing is mainly divided into the glaze ice, mixed song, soft rime, frost, snow five types. When the snow and moisture in the air contact, wire is prone to snow phenomenon. If there is a strong wind, the snow is more easily by the wind, wire covered with snow basically does not occur, so the wire covered with snow by the wind speed control, plain or low-lying calm area, wire covered with snow is more common than in mountainous areas. The basic physical process of wire icing is the main winter or early spring season, when the temperature in the $[-5, 0]$ degrees Celsius, wind speed is $3-15 \text{ m sec}^{-1}$. If the weather is fog or rain, we will form a glaze on the wire, then if the temperature rises, the icing process will stop; if the weather suddenly turned cold, will gradually formed ice. Due to the ice cover pole (tower) on both sides of the tension caused by the unbalance of transmission line icing inverted pole (tower) break. When the ice when the action of wind, the ice shedding, then the wire produces self-excited vibration of large amplitude, low frequency. When the dancing time, will make the conductor, insulator, fittings, pole (tower) by the imbalance of impact fatigue damage. When the insulator icing phenomenon, in

a certain temperature, the surface of the insulator icing enable or is the ice bridge, insulation strength decreased, the leakage distance is shortened, thereby causing the ice flashover accident. So the ice damage the safe and stable operation of the transmission line has a great influence, therefore, to study the overhead transmission line deicing technology, has the positive significance and application value to improve the safe operation of power system, has become an important and pressing task. Iterative learning control as a kind of intelligent algorithm for repetitive work control, can achieve good control effect. It is noted that most of the batch processes execute the repeated control tasks in a finite time interval. This repeatability can be utilized to improve system control performance by Iterative Learning Control (ILC) methods (Arimoto *et al.*, 1984; Ahn *et al.*, 2007; Xu, 2011). Tracking control based on icing line robot manipulator trajectory, to improve the traditional robot manipulator trajectory tracking control, iterative time warping distance learning control algorithm (EADTW-ILC) for the control of robot, proposes a learning robot manipulator control algorithm for the tracking control iterative curved distance between based on the. The simulation results can prove, the control method has better adaptability and response speed.

PROBLEM FORMULATION

The mechanical arm model: The following mechanical arm model in the state and output equations:

$$\begin{aligned}\dot{x}_k(t) &= f(x_k(t), u_k(t), t) \\ y_k(t) &= g(x_k(t), u_k(t), t)\end{aligned}\quad (1)$$

The kinetic equation of de-icing line robot arm can be expressed as:

$$\tau(t) = u(t) = D(q(t))\ddot{Q}(t) + H(q(t), \dot{q}(t)) + G(q(t)) \quad (2)$$

$$\tau(t) = [\tau_1, \tau_2]^T, \ddot{Q}(t) = [\ddot{q}_1, \ddot{q}_2]^T$$

$$D(q(t)) = \begin{bmatrix} A & B \\ \frac{1}{3}m_2l^2 + \frac{1}{2}m_2c_2l^2 & \frac{1}{3}m_2l^2 \end{bmatrix}$$

$$A = \frac{1}{3}m_1l^2 + \frac{4}{3}m_2l^2 + m_2c_2l^2$$

$$B = \frac{1}{3}m_2l^2 + \frac{1}{2}m_2c_2l^2$$

$$H(q(t), \dot{q}(t)) = \begin{bmatrix} -\frac{1}{2}m_2s_2l^2\dot{q}_2^2 - m_2s_2l^2\dot{q}_1\dot{q}_2 \\ \frac{1}{2}m_2s_2l^2\dot{q}_1^2 \end{bmatrix}$$

$$G(q(t)) = \begin{bmatrix} \frac{1}{2}m_1lc_1 - \frac{1}{2}m_2lc_{12} - m_2lc_1l^2\dot{q}_2^2 \\ -\frac{1}{2}m_2lc_{12} \end{bmatrix}$$

The number of k operations, $x_k(t)$ is n dimensional state vector, $u_k(t)$ for the r dimension input vector, $y_k(t)$ is m dimensional output vector, l mechanical arm length. m_1, m_2 as the quality of mechanical arm, $\tau(t)$ is a torque vector is applied to the nodes, $D(q(t))$ is the inertia matrix, Each element of the $D(q(t))$ fully reflects the inertia between each link. $H(q(t), \dot{q}(t))$ is the brother's force and the centrifugal force, its influence on component that brother's force and the centrifugal force, $G(q(t))$ is a gravity matrix, the connecting rod of each joint shaft torque.

We know $c_i = \cos(q_i)$, $s_i = \sin(q_i)$, $c_{ij} = \cos(q_i + q_j)$. q_1, q_2 as the node variable, This study selects $m_1 = m_2 = 2\text{kg}$, $l = 0.4\text{ m}$.

ITERATIVE LEARNING CONTROL ALGORITHM FOR CURVED DISTANCE OF TIME(DTW-ILC)

Consider the following discrete time, linear timeinvariant system:

$$\begin{cases} x(t+T_s) = f(x(t), u(t), t) \\ y(t) = g(x(t), u(t), t) \end{cases} \quad (3)$$

where, $t \in [0, T_s, 2T_s, \dots, T_f]$, $T_f = NT_s$. The initial condition $x_k(0) = x_0$, denotes $y_d(t)$ as the desired output trajectory and $y(t)$ as actual output trajectory. Ideally, the ILC controller will iteratively generate a command signal, from trial to trial, such that the $y(t)$ converges to $y_d(t)$.

Defined by the solution of optimization problem:

$$u_{k+1} = f(u_k, u_{k-1}, \dots, u_{k-r}, e_{k+1}, e_k, \dots, e_{k-s}) \quad (4)$$

$$\lim_{k \rightarrow \infty} \|e_k\| = 0 \text{ and } \lim_{k \rightarrow \infty} \|u_k - u^*\| = 0 \quad (5)$$

Where:

$$y_k = [y_k(0), y_k(T_s), y_k(2T_s), \dots, y_k(T_f)]^T \quad (6)$$

$$u_k = [u_k(0), u_k(T_s), u_k(2T_s), \dots, u_k(T_f)]^T \quad (7)$$

$$e_k = [y_d(0) - y_k(0), y_d(T_s) - y_k(T_s), y_d(2T_s) - y_k(2T_s), \dots, y_d(T_f) - y_k(T_f)]^T \quad (8)$$

Consider the system which is described for a linear time invariant model:

$$\begin{cases} x(t+T_s) = Ax(t) + Bu(t) \\ y(t) = Cx(t) \end{cases} \quad (9)$$

Matrix representation $y_k = G_e u_k$.

where, $T_1 = T_f/T_s$.

Consider the following optimization problem:

$$J_{k+1} = \|u_{k+1} - u_k\|^2 + \|e_{k+1}\|^2 \quad (10)$$

where, $e_{k+1} = y_{k+1} - y_d$, $y_{k+1}(t) = [G_e u_{k+1}](t)$, G_e is controlled object:

$$\|e_{k+1}\|^2 \leq J_{k+1}(u_{k+1}) \leq \|e_k\|^2 \quad (11)$$

The algorithm 11 can guarantee the output error is monotone convergence.

When $y_{k+1}(t) = [G_e u_{k+1}](t)$ of the object for linear time invariant systems, optimal input can be directly obtained by:

$$u_{k+1}(t) = u_k(t) + [G_e^* e_{k+1}](t) \quad (12)$$

where, G_e^* is the adjoint operator of G_e . When the object for discrete linear time invariant systems exist as following conclusion:

$$\|e_{k+1}\| \leq \frac{1}{1+\sigma} \|e_k\| \quad (13)$$

where, $\sigma > 0$ is the minimum eigenvalue of G_e . Note that Eq. 13 can show that the algorithm is a geometric convergence.

DTW-ILC PROBLEM DESCRIPTION

Definition 1: For the two time series $X = \{x_1, x_2, \dots, x_m\}$ and $Y = \{y_1, y_2, \dots, y_m\}$, DTW distance can be defined recursively as:

Where:

$$\begin{cases} D_{DTW}(<>, <>) = 0, \\ D_{DTW}(X, <>) = D_{DTW}(<>, X) = \infty \\ D_{DTW}(X, Y) = d(x_1, y_1) + A \\ d(x, y) = \|x - y\|_p \end{cases}$$

$$A = \begin{cases} D_{DTW}(X, \text{Rest}(Y)) \\ D_{DTW}(\text{Rest}(X), Y) \\ D_{DTW}(\text{Rest}(X), \text{Rest}(Y)) \end{cases}$$

where, $\text{Rest}(X) = \{x_2, \dots, x_m\}$, $\text{Rest}(Y) = \{y_2, \dots, y_m\}$.

Definition 2: In the solution of the DTW distance process, gives the error threshold ε , if:

$$D_{DTW}(X, Y) = \sum_{i=1}^m d_i^2 > \varepsilon$$

we Said the effective distance of overflow occurred at k , this position is both an early termination of calculate the distance of the point.

For time series $X = \{x_1, x_2, \dots, x_m\}$ and $Y = \{y_1, y_2, \dots, y_m\}$, DTW calculation of distance: $\text{sum} = 0$, $\text{overflow} = 0$ for $i = 1$ to $i = \text{sum} = D_{DTW}(X, Y)_i$ if $\text{sum} > \varepsilon^2$ then $\text{overflow} = i$:

$$\begin{cases} \text{if overflow} > 0 & \text{There is no overflow} \\ \text{if overflow} < 0 & \text{There is overflow} \end{cases}$$

After each trail, using DTW comparative field method for solving optimization problems (9), the input data and the error data between model output and real output are used to revise plant model and the new plant model will be used in next trail. The model modifying device is designed for non-linear plant and also can be used in linear plant.

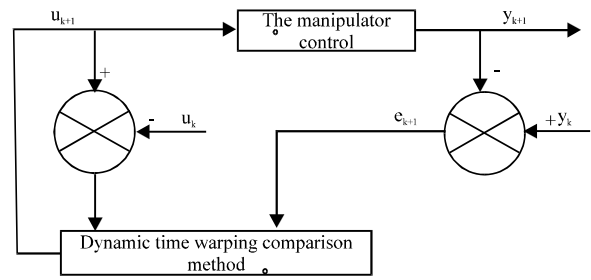


Fig. 1: DTW-ILC control method of operating process

DESIGN OF DEICING ROBOT MANIPULATOR DTW-ILC LINE

For the convergence of the DTW-ILC control method, has been given in the literature (Gu *et al.*, 2013), here is no longer prove. In addition to running process of robot arm control method of DTW-ILC ice line as shown in Fig. 1:

Control thought ice line robot manipulator mainly as follows in this paper. When the control methods except when ice line robot arm control, first calculate the node variables q_1 , q_2 and \ddot{q}_1, \ddot{q}_2 . It calculates the expected trajectory of $u_k(t)$, the implementation of the DTW-ILC algorithm, the first iteration process, According to the kinetic Eq. 1 to calculate the performance index of angular position, velocity, acceleration and the input matrix tracking error of manipulator joints, according to the results of the calculation, can get the input torque, the error value, draw the track, if meet the given boundary conditions, the complete tracking. If you can not meet the definition conditions, continue with the next iteration, until the meet the definition conditions, to stop the iterative learning process, the control process.

SIMULATION

A discrete mathematical model of the controlled object is selected:

$$\begin{cases} x(i+1) = Ax(i) + Bu(i) \\ y(i) = Cx(i) \end{cases} \quad (14)$$

$$A = \begin{bmatrix} 0 & 0 & -0.1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}, B = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}, C = [1 \ 0 \ 0] \quad (15)$$

The sampling period of 0.1 sec, Iterative learning control goal seeking input so that the output of the system track the desired output.

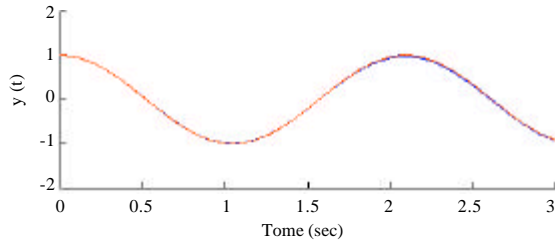


Fig. 2: Output trajectory tracking $y(t)$

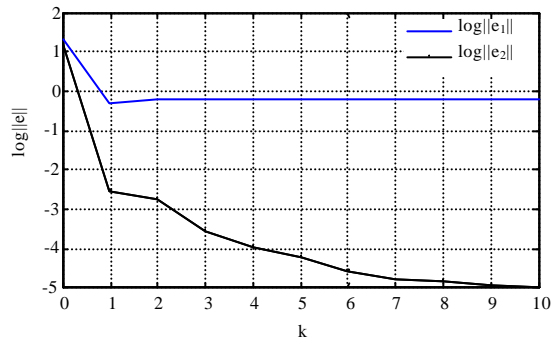


Fig. 3: $\log||e_k(t)||$ convergence curve

$$y_d(i) = 0, \quad i = 1$$

$$y_d(i) = \sin(0.05\pi(i-2)), \quad 2 \leq i \leq 23$$

The constrained input:

$$u_i^{\min} \leq u_i \leq u_i^{\max} \quad i = 1, 2, \dots, 23 \quad (16)$$

Figure 2 and 3, respectively to stop when the control input is limited in the range of $[-1.5, 1.5]$ ($-1.5 \leq u_i \leq 1.5, i = 1, 2, \dots, 23$).

Convergence curve with iteration output tracking error curve and logarithmic form. From the results we can conclude that EADTW-ILC can be used to solve the iterative learning good optimal control problem, which is very good for de-icing line robot manipulator trajectory tracking, the de-icing purpose. Using the monotone

convergence of EADTW-ILC the whole control method can achieve the output tracking error and the convergence speed is very fast.

CONCLUSION

The EADTW-ILC control method used in de-icing line robot manipulator trajectory tracking problem, the problem will only algorithm for robot manipulator ice line in addition to the traditional, an iterative procedure is repeated several times to the desired trajectory to achieve complete tracking, correction system reference model effect. Through the simulation experiment to validate the model and its corresponding algorithm, the results as shown in Fig. 3, shown in Fig. 4, is not only a good line of de-icing robot manipulator trajectory tracking and the algorithm has good convergence.

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