A servo control method of bolt tightening robot for power transmission lines

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Abstract. This paper discusses a control method of bolt tightening robot automatically search and tighten. Because of the influence of the wind in the search process, so this paper adopt the servo system to determine the position of the target to complete the bolt docking[1]. Due to the bolt by weathering, corrosion, etc have different situation, so for different years of bolt, the fastening work done by corresponding torque control.

1. Introduction
With the continuous development of the power grid, compact towers and multi-loop line towers have been widely used. The distance between the cross arm and the phase is getting smaller and smaller, which brings new problems to the safety of manual live working, and there is a serious shortage of technical personnel. Carrying out maintenance greatly restricts the timely and effective conduct of live work and affects the reliability of power supply.[2]

This paper has carried on the related research and exploration in the following aspects:

Location of the variables in the position servo system is uncertainty, so it is difficult to establish the exact mathematical model. Under the disturbance of wind, video cameras and bolt roll motion will occur. So the least square method is used to predict the trajectory of the camera[3]. The relationship between x, z and t obtained by the Generalized Hough Transform calibrate the coordinate into the actual position.

(2) In this paper, a controller is developed to handle the torque control problem of automatically tightening bolts after the docking work. According to the characteristics of the mechanical bolt/nut connection, the process is divided into four stages, and the fuzzy logic controller is required to have the professional knowledge of bolt tightening and the ability to detect errors. The four-stage fuzzy logic controller is designed to solve the system's highly nonlinear and error conditions. An infrared detector is added to detect the life of bolts in the high-voltage line and complete the corresponding torque control.

The rest of the paper is organized as follows. Section II presents in detail the basic structure of the robot Section III presents the position servo system of bolt fastening robot. Section IV presents the bolt fastening of torque control. Section V presents the conclusion of the paper.
2. The basic structure of the robot

2.1. The basic structure of the bolt tightening robot

As shown in Figure 1, the proposed bolt-tightening robot consists of a main body, two walking wheels with corresponding locking clips, an equipotential wheel, two arms and a bolt-tightening unit.

The walking wheel is connected to the two arms to drive the main body to move back and forth along the power transmission line. The locking clamp is fixed at the connection point of the arm and the wheel. If the robot falls from the pipeline, the clamp will squeeze the pipeline to ensure the stability of the robot. The equipotential wheel is installed near the walking wheel to keep the robot at the same potential as the power transmission line.

![Figure 1. The basic structure of the bolt tightening robot.](image)

2.2. Improvements for our robot

Aiming at the bolt tightening task on the power transmission lines, we designed a bolt tightening unit which consists of a mechanical arm with multi-degree-of-freedom (DOF) and the endmost bolt tightening performer for our robot. The multi-DOF arm has three joints which locate at the both ends and the center of the arm. By three joints’ collaboratively working, the multi-DOF arm can take the endmost performer to anywhere we want.

The endmost tightening performer is made up of pipe spanners, close focusing cameras, micro-driving motors and several support mechanisms. The two close focusing cameras are installed at the right center of pipe spanners’ tail end as shown in Fig.2.

![Figure 2. Details of the endmost bolt tightening performer.](image)

3. The position servo system of bolt fastening robot

3.1. The track prediction of cameras

Due to the wind disturbance the mechanical arm, the movement has the characteristics of nonlinear, therefore, in this paper, using the least square method to forecast the movement of mechanical arm[4].

Known information on a set of discrete points, begin square distance of the curve \( z = \delta(x_i) \), make it on the whole, as far as possible approximation to the original data, the formula as:

\[
\delta_i = \varphi(x_i) - z \quad (t = 1,2, \ldots, \mu)
\]
Referred to $\delta_i$ as the fitted curve $\phi(x)$ eviation in node $x_i$. In order to make $\phi(x)$ reflect the change trend of the given data, the absolute value of the deviation $|\delta_i|$ may be required as small as possible. To minimize the sum of the squares of the deviation principle was used to ensure the absolute value $|\delta_i|$ of each deviation. This principle is called the least squares principle.

Due to mechanical arm do roll motion, therefore,

$$X = b_0 + b_1t + b_2t^2$$

(2-2) is the trajectory estimation curve function of the camera, and on the basis of the $t$ seconds before the camera the actual trajectory coordinate $x(t_k)(k = 1,2, ... , N)$ the type can be calculated by the corresponding estimates, so in the $N$ point estimates of variance for:

$$\|\phi\|^2 = \sum_{i=1}^{N} [x(t_i) - b_0 - b_1t - b_2t^2]^2$$

(2-3)

Using the least squares method is as follows:

$$\begin{bmatrix} N \sum_{i=1}^{N} t_i & \sum_{i=1}^{N} t_i^2 & \sum_{i=1}^{N} t_i^3 \\ \sum_{i=1}^{N} t_i & \sum_{i=1}^{N} t_i^2 & \sum_{i=1}^{N} t_i^3 \\ \sum_{i=1}^{N} t_i & \sum_{i=1}^{N} t_i^2 & \sum_{i=1}^{N} t_i^3 \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^{N} x(t_i) \\ \sum_{i=1}^{N} x(t_i)^2 \\ \sum_{i=1}^{N} x(t_i)^3 \end{bmatrix}$$

(2-4)

$$\begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = \frac{1}{4} \begin{bmatrix} c_0 \sum_{i=1}^{N} x(t_i) + c_1 \sum_{i=1}^{N} x(t_i)^2 + c_2 \sum_{i=1}^{N} x(t_i)^3 \\ c_0 \sum_{i=1}^{N} x(t_i) + c_1 \sum_{i=1}^{N} x(t_i)^2 + c_2 \sum_{i=1}^{N} x(t_i)^3 \\ c_0 \sum_{i=1}^{N} x(t_i) + c_1 \sum_{i=1}^{N} x(t_i)^2 + c_2 \sum_{i=1}^{N} x(t_i)^3 \end{bmatrix}$$

(2-5)

(2-5) into (2-3), minimum variance can be obtained under the meaning of the $N$ point best square approximation of general solution, namely square prediction algorithm based on least squares track equation. The coordinates of the next moment camera position:

$$X = b_0 + b_1t + b_2t^2$$

(2-6)

Deciding by $N$ track points at the $t_k$ second, $X(t_{k+1}/t_k)$ is the coefficient which will be used to estimate the position of the object at $t_{k+1}$ second[5]. As shown in figure 3.

3.2. The track prediction of bolt

Assume that the camera fixed, bolt do roll motion[6]. But when the camera also do motion of roll, bolt relative to the camera trajectory for small waves, according to the method of least square fitting curve figure as follows:
By a curve fitting, the bolts do small amplitude curve movement under wind disturbance. Considering the Hough Transform has stronger robustness applied to low signal-to-noise ratio, this paper use the Generalized Hough Transform to estimate the target trajectory[7]. Considering the characteristic of the object movement, the target can be thought of maintained a uniformly accelerated motion under the condition of the weak wind, so the quadratic curve equation can be used in the movement of target trajectory. Target prediction position according to the time as shown in formula (1) (2).

\[ x = a_1 t^2 + b_1 t + c_1 \]  
\[ z = a_2 t^2 + b_2 t + c_2 \]  

The formula \((x, z)\) indicates the predicted position of the target at different times; \(a_1, a_2, b_1, b_2, c_1, c_2\) denote prediction curve equation coefficients x-axis and z-axis direction of change over time. As shown in equation (1), the unknown coefficients \(a_1, b_1, c_1\), variables \(x, t\), converted into the parameter space corresponding to the three variables, which turned into three-dimensional problem. To determine the parabola in rectangular coordinates, obtain the intersection points of three curved surfaces in the parameter space to simplify the calculation, and establish a ternary system of equations by any one of the \(x\) coordinate values in three different times in the rectangular coordinate system, such as

\[ x_i = a_1 t_i^2 + b_1 t_i + c_1 \]  
\[ x_j = a_1 t_j^2 + b_1 t_j + c_1 \]  
\[ x_k = a_1 t_k^2 + b_1 t_k + c_1 \]

Solutions of equations (3), the equations of variable \(a_1, b_1, c_1\) value, its value in the corresponding parameter space \(a, b, c\). Specified herein recorded once every 200ms bolt moving image of the \(x\)-coordinate of the target forecast, the abscissa indicates the number of frames in a continuous sequence of images changes, ordinate is the target \(x, z\) coordinate values. Predicted results below(Fig5,Fig6):

![Figure 5. X position forecast trajectory.](image-url)
The Hough transform prediction predicts the quadratic curve through probability and statistics, obtained in the parameter space of the concentrated distribution of the quadratic curve coefficients. The total number of data points given for trajectory prediction is \( m \), and the error of the larger data point is \( p \). After the hough transform obtain \( C_m^3 \) quadratic curve equation, the number of effective equation is \( C_{m-p}^3 \).

Finally, coordinate calibration to predict the trajectory at the next moment when the robot arm and the bolt overlap, sending to the robot arm controller to complete the bolt connection.

4. The bolt fastening of torque control

There are thread friction and end friction during bolt tightening. The friction coefficient only reflects the friction between the contact surfaces, while the torque coefficient reflects the friction performance of the bolt thread connection. Experiments to measure the torque coefficients of different bolts are conducive to controlling the torque. [8-10].

Bolt fastening process can be divided into the following four stages:

(1) The first stage: Bolt / nut alignment: The controller is provide a slow start, in order to avoid the damage by that the nut sticking to the thread of the bolt, and the bolt torque level were maintained in a low range of specific relative angular position.

(2) The second stage: The bolt and nut threads are in contact with each other. At this point, it is required to apply a small value of torque to overcome the friction caused by the contact between the two threads.

(3) The third stage: The nut runs smoothly until the arrival of the flange and a maximum and the most stable friction level appear. Monitoring the angular displacement of the nut is very important in this stage, which helps to estimate the effective length of the bolt.

(4) The forth stage: Once the nut has reached the final part of the flange tightening process will begin when the bolt is tightening. Turning the nut during this part of the tightening process generates the desired clamping force between the flange and the nut.

5. Conclusion

This paper puts forward how to realize the track prediction for docking with the bolt under wind disturbance, the paper not only combines with least square method to predict the target trajectory, but also use the generalized hough transform combined with the composite tracking model, and finally realizes the estimate of the target location. Upon completion of the docking, a torque controller is used to handle automatic screw tightening problems.

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