Optimal Control Method of Robot End Position and Orientation Based on Dynamic Tracking Measurement

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Abstract. In order to improve the accuracy of robot pose positioning and control, this paper proposed a dynamic tracking measurement robot pose optimization control method based on the actual measurement of D-H parameters of the robot, the parameters is taken with feedback compensation of the robot, according to the geometrical parameters obtained by robot pose tracking measurement, improved multi sensor information fusion the extended Kalan filter method, with continuous self-optimal regression, using the geometric relationship between joint axes for kinematic parameters in the model, link model parameters obtained can timely feedback to the robot, the implementation of parameter correction and compensation, finally we can get the optimal attitude angle, realize the robot pose optimization control experiments were performed. 6R dynamic tracking control of robot joint robot with independent research and development is taken as experimental subject, the simulation results show that the control method improves robot positioning accuracy, and it has the advantages of versatility, simplicity, ease of operation and so on.

1. Introductions

With the development of industrial automation, robot is widely used in production, robot is an important product of the development of artificial intelligence technology, and robot is the automatic implementation of the robotic device. It can accept human command, they can run preprogrammed procedures, and it can also be based on artificial intelligence technology developed by the principle of the programmer action. Its mission is to assist or replace human work, such as industry, construction industry, or dangerous work. The robot actuators can be divided into Cartesian, cylindrical coordinate, polar coordinate type and other types of joint coordinate type. For anthropomorphic considerations, often the relevant parts of the robot the body are known as the base, waist, arm, wrist, hand (gripper or end effector) and walking part (for mobile robot)[1].

The robot control system uses a centralized control method, the robot control by a microcomputer, the other is decentralized (level) control, which uses multiple computers to share the robot, such as when using, two computers together to complete the robot control, the host often used for system management, communication, calculation of kinematics and dynamics, and send commands to the lower level computer information; as a junior from the machine, the joints corresponding to a CPU, for interpolation

and servo control processing, to achieve a given movement, and feedback the information to the host. According to the different operational mission requirements, the robot control mode can be divided into the position control and continuous trajectory control and force control. The stability of the robot control system is the core unit of the whole robot of artificial intelligence, robot walking and working process, need to enter For the arm grasp and rotate around the arm and walking and other movements, these actions are controlled by instructions sent to the execution unit, the execution unit operates stably operation according to the control instruction set, the higher the robot stability control accuracy requirements, to improve the quality control of intelligent robot control has become the current focus[2-4].

Generally speaking, high repeat precision of the robot, but the absolute accuracy is low, causing great impact on the robot performance. For calibration of robots, precision can reach several millimeters, so in many applications of robot control. The robot must be accurately calibrated accurate calibration based on accurate control of end effector on the robot pose control is modeling, measurement, integrated process parameter identification and error compensation of several steps, the purpose is to reduce the error of the geometric parameters of the robot, the robot geometry parameter error, said that the kinematics model, the geometric parameters of the nominal value and the deviation between the real value [5].

At present the main position control method of robot kinematics at the end of the circumference point method and kinematics loop method. The former is the abstract joint axis robot into a linear space, a method of kinematic parameters of the model by using the geometric relationship between the joint axes. The kinematics loop method is using position measurement device for obtaining the robot the method of joint parameters obtained by robot kinematics equations of robot are solved. By the end of the robot pose control is a multi-variable nonlinear control system, using the circumference point method and kinematics control loop method prone to error and performance tracking instability. Aiming at the above problems, this paper proposes a dynamic tracking measurement robot pose optimization control method based on the actual parameters of D-H first measuring robot, using the geometric relationship between the joint axis calculate model of kinematic parameters, the parameters of link model can timely feedback to the robot the implementation, parameter correction and compensation, which can obtain the optimal attitude angle, realize the robot pose optimization control. 6R type joint robot finally adopts a self-developed robot dynamic tracking control experiments show the superior performance of this control method.

2. Robot kinematics model and optimization of motion parameters

2.1. Construction of robot kinematics model
In this paper, the research object is the robot of 6R industrial robot independent research and development, the robot has 6 degrees of freedom, and all revolute joints. The first three joint Axis1, Axis2, Axis3 control the robot wrist position, and then the three joints of Axis4, Axis5, Axis6 control the robot wrist posture. The robot the joint structure is composed of rotary body (waist joint), arm (shoulder), arm (elbow), wrist (wrist) and other parts. The robot linkage can be seen as an open kinematic chain, which is composed of a series of connecting rod through a rotating joint series of open chain end. The fixed on the base, the other end is free, the joint is driven by the drive, the relative movement of the joint lead connecting rod, and the gripper arrival pose is required. In order to study the relationship between the positions of each link, in each connecting rod is fixedly connected with a seat [6]. The relationship between these coordinate systems is described. The kinematic parameter model of the robot is obtained by using the coordinate system method proposed by Denair and Hardenberg, as shown in Table 1.

Table 1. Kinematic parameters table of robot theory.

i	q_i(rad)	α_i(rad)	a_i(mm)	d_i(mm)	Joint constraint
1	q_1	$-\pi/2$	l_s	0	$[-\pi/2, \pi/2]$
2	$q_2-\pi/2$	$-\pi/2$	0	0	$[-\pi/2, \pi/2]$
3	$q_3+\pi/2$	$\pi/2$	0	l_u	$[-23\pi/18,\pi/2]$
4	q_4	$-\pi/2$	0	0	$[0,29\pi/36]$
5	q_5	$\pi/2$	0	l_f	$[0,35\pi/18]$
6	$q_6+\pi/2$	$-\pi/2$	0	0	$[-\pi/4, \pi/4]$
7	q_7	$\pi/2$	l_h	0	$[-\pi/4, \pi/4]$

The motion planning problem of industrial robots studied in this paper is defined as:

Given the robot initial configuration $\boldsymbol{\theta}_{start} \in \mathbf{C}_{free}$ (C- free space), object pose $\mathbf{p}_{obj}$ and feasible grasp the set $\mathbf{g}_c$, and the target configuration $\boldsymbol{\theta}_{goal}$ is unknown, finding a collision in the C- space, avoiding the continuous path mapping singular and satisfy the joint constraint conditions: $\tau:[0,1] \to \mathbf{C}_{free}$, $\tau[1] = \boldsymbol{\theta}_{goal}$, $(\mathbf{p}_{obj}, \mathbf{g}_c) \to \mathbf{f}(\boldsymbol{\theta}_{goal})$. The robot link transformation formula is

$$^{i-1}T_i = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -d_i s\alpha_{i-1} \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & d_i c\alpha_{i-1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (1)$$

In the formula: s means the sine of the angle θ, and C represents the cosine of the angle θ

The transform matrix of manipulator is obtained by multiplying each link: $^0_6T = {}^0_1T\, {}^1_2T\, {}^2_3T\, {}^3_4T\, {}^4_5T\, {}^5_6T$.

It is the position and orientation matrix of the end effector of the robot. The actual D-H parameters of the robot are measured, and the parameters feedback compensation of the robot is carried out.

Set $\mathbf{q}_1 = \begin{bmatrix} q_1, & ..., & q_7 \end{bmatrix}^T$, $\sin q_i$ and $\cos q_i$ were recorded as s_{q_i} and c_{q_i}, and is denoted as s_i and c_i, then the coordinate system between i and i-1 homogeneous matrix can be expressed as $^{i-1}\mathbf{T}_i(q_i)$:

$$^{i-1}\mathbf{T}_i(q_i) = \begin{bmatrix} c_i & -c_{\alpha_i} s_i & s_{\alpha_i} s_i & a_i c_i \\ s_i & c_{\alpha_i} c_i & s_{\alpha_i} c_i & a_i s_i \\ 0 & s_{\alpha_i} & c_{\alpha_i} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (2)$$

As above, the robot base coordinate system and the TCP coordinate system are established, and the actual robot motion parameters of the identification are fed back to the established coordinate model to calculate the robot motion parameters.

2.2. Optimization of geometric parameters of robot end position

According to the geometric parameters of robot pose, according to the geometric parameters of the robot can get the robot pose, use P^n to express the theoretical position under the base coordinate system of robot end flange center, using P^r to represent the actual end effector, $_\Delta P$ said the positioning error of robot pose:

$$P^n = F(a, d, \alpha, \theta) \qquad (3)$$

$$P^r = F(a + \Delta a, d + \Delta d, \alpha + \Delta\alpha, \theta + \Delta\theta) \tag{4}$$

Positioning error can be obtained:

$$\Delta P = P^r - P^n \tag{5}$$

According to the model of link parameters in the robot control system developed by ourselves, the TCP position error at the end of the robot is considered only at the present stage.

A hybrid system using deterministic model set $M = \{m_i \mid i = 1, 2, \cdots, m\}$ is proposed, and the discrete form of the state equation and the observation equation of the robot end position is:

$$\begin{aligned} x(k+1) &= \Phi_i(k)x(k) + w_i(k) \quad i = 1, 2, \cdots, m \\ z(k) &= H_i(k)x(k) + v_i(k) \qquad i = 1, 2, \cdots, m \end{aligned} \tag{6}$$

Among them, $w_i(k)$ and $v_i(k)$ are state noise and observation noise, the covariance matrixes are $Q_i(k)$ and $R_i(k)$ respectively.

The initial state of known m robot pose geometric model for $x^i(0) = \hat{x}^i(0)$, the initial model with probability $u_i(0) = P(m_i(0)/z(0))$, the transfer model with Markov process priors, the transtion-probablity matrix for $[P_{ij}]$, P_{ij} said the probability model of m_i is transferred to m_j. From the time $k-1$ start to k for the moment, the geometric model of robot $m_j(j = 1, 2, \cdots m) \quad \forall m_j \in M$, there:

Predictive probability of terminal pose model is:

$$\bar{c}_j = \sum_i^m P_{ij} u_i(k-1) \tag{7}$$

Transfer probability of terminal pose model is:

$$\begin{aligned} u_{i/j}(k-1/k-1) &= P(m_i(k-1)/m_j(k), z^{k-1}) \\ &= \frac{1}{\bar{c}_j} P_{ij} u_i(k-1) \end{aligned} \tag{8}$$

The name of the geometrical parameters of the robot and the true value of the deviation, with Δai, Δdi, $\Delta\alpha i$, $\Delta\theta$ represent the length of the link rod bias, bias, torsion angle deviation and joint angle errors, which the Δai and the Δdi is due to machining precision and assembly robot rod length the alpha error; $\Delta\theta i$ is between adjacent axis parallelism and Perpendicularity Error Caused by angle; the theta I is due to the robot assembly process, zero bias and zero nominal model angle of optical encoder in the rotary joint zero does not coincide with the carrier when in any attitude, measurement if the carrier coordinates three axis acceleration:

$$A_b = [a_x \quad a_y \quad a_z]^T \tag{9}$$

The coordinate system is transformed into matrix $A_b = C_n^b A_n$, and the real attitude angle at certain time is θ_T^k.

3. Dynamic tracking measurement and robot optimization control

3.1. Improved extended Kalman filter

This paper presents a dynamic tracking measurement robot pose optimization control method based on the improved tracking and measuring method of multisensory data fusion extended Kalan filter to the end position, the end position for the measurement model $m_j(j = 1, 2, \cdots m)$ $\forall m_j \in M$, using $\hat{x}^{0j}(k-1/k-1)$ and $P^{0j}(k-1/k-1)$ as input into the filter model based on m_j (with Kalan filter), then obtain the state estimation $\hat{x}^j(k/k)$ and covariance estimation $P^j(k/k)$.

The likelihood function of the model $m_j(j = 1, 2, \cdots m)$ $\forall m_j \in M$ is computed for k moment:

$$\begin{aligned}
\Lambda_j(k) &= P(z(k)/m_j(k), z^{k-1}) \\
&= P(z(k)/m_j(k), \hat{x}^{0j}(k-1/k-1), P^{0j}(k-1/k-1)) \\
&= N((z^j(k) - z^j(k/k-1)) \,|\, 0, S^j(k))
\end{aligned} \tag{10}$$

Here, $\Lambda_j(k)$ obeys the normal distribution that the mean value is 0 and variance is $S^j(k)$, and the $S^j(k)$ is the information covariance matrix.

The acquired raw data is processed by Kalman filtering [7], and the correction probability of the dynamic tracking model $m_j(j = 1, 2, \cdots m)$ $\forall m_j \in M$ is obtained:

$$\begin{aligned}
u_j(k) &= P(m_j(k)/z^k) \\
&= \frac{1}{c} P(z(k)/m_j(k), z^{k-1}) P(m_j(k)/z^{k-1}) \\
&= \frac{1}{c} \Lambda_j(k) \overline{c}_j
\end{aligned} \tag{11}$$

When the robot carrier is located in any position, the magnetic field along the x axis and the y axis, m_x and m_y are calculated, and the magnetic heading angle H_m is calculated:

$$\psi_m = arctan(\frac{m_y}{m_x}) \tag{12}$$

In the formula, m_x and m_y are the magnetic field on the OX_b axis, OY_b axis component; ψ_m axis magnetic heading angle relative to the robot, $\Delta\psi$ is the true north and magnetic north (magnetic declination angle); ψ is the final requirements of carrier OX_b relative to the north axis heading angle. According to the results of tracking and measuring robot end pose, after continuous optimal autoregressive, using the geometric relationship between the calculated joint axis kinematics parameters of the model, using the improved multi sensor information fusion method extended Kalman filter, through the complementary to improve the precision of attitude angles.

3.2. Robot end position optimization control

The robot joint coordinate system gets involved in the robot base coordinate system, the dynamic tracking system with high accuracy, found in the process of measurement, planar first joint independent rotating joint formed by the motor axis where the first round to replace joint robot structure with high precision of the plane, which can construct the robot base coordinate system establish, in principle is the robot initial zero state, normal to the first joint plane as the Z axis direction of the base coordinate system, second normal joint plane as the base coordinates of the X axis, and Y direction is automatically generated in accordance with the right-hand rule: $Y = Z \times X$. coordinates by using the method of single joint robot can move independently each joint circle, according to Carle filter theory to estimate the

actual attitude of $k-1$ moment angle should be based on the SFF's attitude angle prediction, in the machine On the basis of human kinematics model, this paper adopts the circle point method to measure the robot's actual link parameters model, and obtains the following steps of dynamic tracking, measurement and control of robot end position:

(1) To control the robot first joint exercise alone, this point marks using binocular vision system dynamic tracking of the end effector of a robot, obtain three-dimensional coordinates of targets relative to the camera coordinate system, so that these coordinates can be composed of first joints of the circle, and then we can get the actual joint motor axis, and can calculate the fitting error of circle joint.

(2) Tracking the point coordinates of other joints independently by using the same method, and measuring the coordinates of the tracking points on several end effector as much as possible, so as to improve the accuracy of the subsequent data processing.

(3) Single joint coordinate data and tracking were determined by fitting joint motor axis and the track circle construction, so as to form the actual space robot D-H parameter model, get the robot actual geometric parameters, finally compared with the geometrical parameters of the robot model.

(4) The use of dynamic tracking principle, control the position of the robot to run arbitrary space measuring robot TCP to three-dimensional coordinates of target, compared with the theory of three-dimensional coordinates, using formula $f = \Delta_a - \Delta_g = \left(\varepsilon_a^{k+1} - \varepsilon_a^k\right) - \left(\varepsilon_g^{k+1} - \varepsilon_g^k\right)$ can get the positioning error, thus verifying the precision of robot localization and robot kinematics model updating.

With the above processing, the model parameters of the link can be fed back to the robot in time, and the parameters are corrected and compensated. Finally, the optimal attitude angle can be obtained, and the robot position and attitude optimization control can be realized.

4. Simulation experiment and result analysis

In order to test performance of the control method in the application performance of dynamic tracking measurement and robot end pose control, simulation is taken, experiment takes independent research and development of 6R industrial robot as the research object, first let the robot do the corresponding movement, the collected original data corresponding sensors, including accelerometer, magnetometer and gyroscope the data set. The sampling period is 0.02 s, the Kalan filter cycle is 0.02s. The original data is taken to calculate the corresponding data. The attitude angle gyroscope data as the forecasting data, as a reference sample, transport tracking system of robot TCP using binocular vision dynamic, arbitrary position coordinate measurement at TCP space, using the principle of dynamic measurement the use of independent research and development of robot tracking, binocular vision dynamic tracking system for calibration of robot pose The values of the robot motion parameters obtained during the tracking control are shown in Figure 1, and the experimental results in the X direction are given only because of the similarity of the simulation.
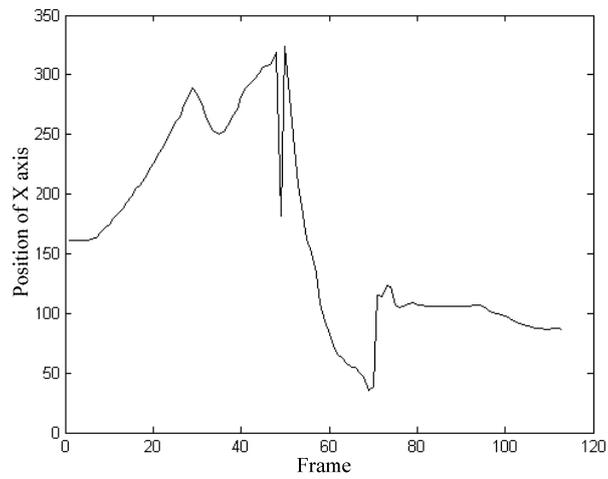
(a) Position
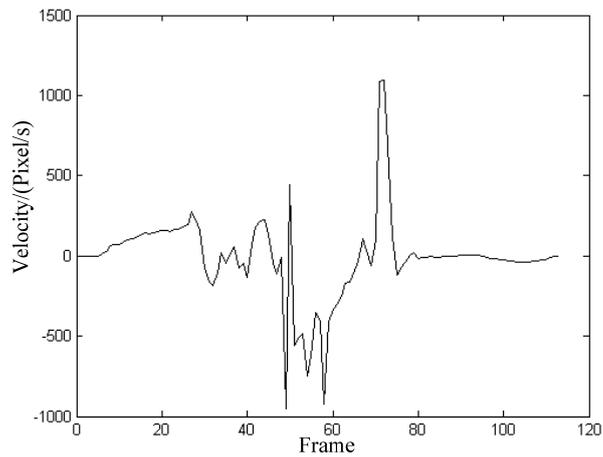
(b) Velocity
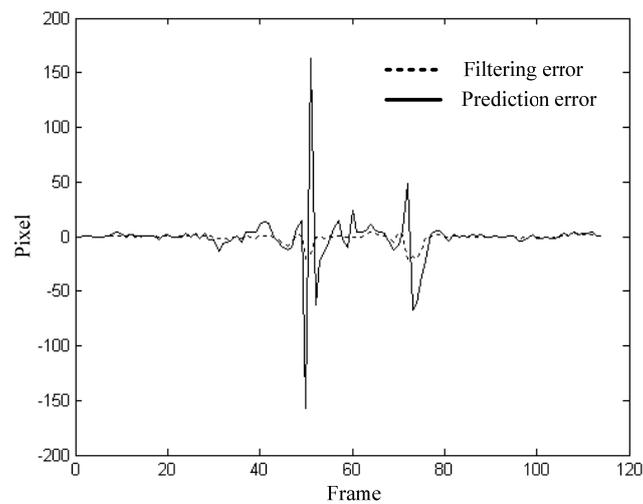
(c) Filtering and prediction of position error

Fig. 1. Parametric output results of end position control of X axial robot.

Figure 1 analysis results shows that, using this method of robot pose control, it can accurately reflect the robot motion maneuvering situation, position error filter small position error prediction obtained with smaller fluctuations in the tracking process. The robot joint end pose measurement errors are presented in Table 2.

Table 2. Fitting error of joint circle.

Number	S(mm)	L(mm)	U(mm)	R(mm)	B(mm)
1	0.056	0.022	0.015	0.073	0.014
2	0.057	0.018	0.013	0.059	0.023
3	0.065	0.033	0.012	0.067	0.023
4	0.046	0.035	0.023	0.078	0.026
5	0.057	0.036	0.024	0.089	0.036
6	0.068	0.034	0.016	0.094	0.035
7	0.065	0.022	0.016	0.083	0.033
8	0.036	0.016	0.015	0.076	0.042
9	0.054	0.021	0.014	0.074	0.023
10	0.056	0.023	0.015	0.094	0.027
Mean value	0.055	0.026	0.017	0.078	0.032

From the positioning error compensation data can be seen, after the robot positioning accuracy has improved significantly, the average error compensation of robot positioning accuracy is 3.997mm, the standard deviation is 0.189; the average error compensation after the positioning accuracy is 1.067mm, the standard deviation is 0.104, the average positioning error is increased by 3.7 times, the average error is increased by 1.8 times using this method, the robot pose control, and improve the localization accuracy, the utility model has the advantages of versatility, timing, easy operation, etc., it can accurately reflect the motion features of the robot.

5. Conclusion
This paper studies the robot dynamic tracking and pose optimization control problem, and a method of robot end position optimization control based on dynamic tracking measurement and improved Kalan filter is proposed. The parameters of feedback compensation of the robot, according to the geometric parameters of robot pose, with improved tracking and measuring multi sensor information fusion method of extended Kalan filter to the end position, after continuous optimal autoregressive, using the geometric relationship between joint axes for kinematic parameters in the model, the parameters of link model can timely feedback to the robot, the implementation of parameter correction and compensation, can get the optimal attitude angle, realize the robot position attitude control optimization. The results show that this method for high precision robot pose control, universal It has the advantages of simplicity, ease of operation and accuracy. It can accurately reflect the movement and motion characteristics of robot movement. It has advantages in robot accuracy measurement and control.

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