Research on Robot Pose Control Technology Based on Kinematics Analysis Model

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Abstract. In order to improve the attitude stability of the robot, proposes an attitude control method of robot based on kinematics analysis model, solve the robot walking posture transformation, grasping and controlling the motion planning problem of robot kinematics. In Cartesian space analytical model, using three axis accelerometer, magnetometer and the three axis gyroscope for the combination of attitude measurement, the gyroscope data from Calman filter, using the four element method for robot attitude angle, according to the centroid of the moving parts of the robot corresponding to obtain stability inertia parameters, using random sampling RRT motion planning method, accurate operation to any position control of space robot, to ensure the end effector along a prescribed trajectory the implementation of attitude control. The accurate positioning of the experiment is taken using MT-R robot as the research object, the test robot. The simulation results show that the proposed method has better robustness, and higher positioning accuracy, and it improves the reliability and safety of robot operation.

1. Introduction
With the development of artificial intelligence technology, control performance and intelligence of various types of robot are improved, people design all kinds of industrial robots instead of people to work, improve the working efficiency of the robot in the crawl and walk. The movement and stability of the attitude and position accuracy requirements, the need for attitude control of the robot, improve the accuracy and robustness of the robot control, attitude control technology of robot, it has great significance in the optimization design of the robot and improves the intelligence degree of the robot [1].

Attitude stability of robot control system is the core unit of the whole robot of artificial intelligence, attitude control system of the robot is mainly composed of attitude sensing system of robot, driver and actuator system, unit subsystem control center attitude control system, wherein the sensing system refers to the sensing device to obtain information from the outside world for the control system composed of perception the original is the sensor, it is like the human foot and realize the useful information of the external input by sensing devices for the central nervous system that control heart unit processing robot control system, to provide guidance for the implementation of the control execution unit[2]. The output mechanism of robot control system controlled by gyro, relay, solenoid valve and actuator motor etc.
which, by the motor terminal output, intelligent operation and control of electromechanical equipment. With the intelligent degree is not Continuous improvement of quality control and control precision of the robot control system highlights the importance of traditional methods include fuzzy control, neural network control, rough set theory, the sliding mode control algorithm, various control methods have advantages and disadvantages for the application object of different emphases. Disadvantages of the conventional sliding mode control algorithm has steady-state error boundary layer method to suppress chattering, and the neural network fuzzy control method for the robot to reach the stage is not robust[3,4].

To overcome the drawbacks of traditional methods, in order to improve the attitude stability of the robot, this paper proposes an attitude control method of robot based on kinematics analysis model, solve the robot walking posture transformation, grasping and controlling the motion planning problem. By using three axis accelerometer, magnetometer and three axis gyroscope integrated attitude measurement, the gyroscope data from Colman filtering according to the centroid of the moving parts of the robot corresponding to obtain stability inertia parameters, actuator to control the robot to run any accurate space location, ensure the end effector along a prescribed trajectory, realize the accurate positioning of the attitude control. Finally, simulation experiments show the method improves superior performance of control quality.

2. Analytic model of robot kinematics parameters

2.1. Robot kinematics model

Kinematics analysis model of robot is constructed in three-dimensional space, the robot is fixed on the lower extremity with respect to the inertial reference system $\Sigma_I$ motion available $4 \times 4$ homogeneous coordinate matrix $^I\mathbf{T}_0(\alpha_0, \beta_0, \gamma_0)$ expressed in Cartesian space ($=^I\mathbf{T}_0(\theta_x, \theta_y, \theta_z)$), including 3 translational and $\mathbf{p} = [x, y, z]^T$ constant direction around 3 axes rotation, respectively with yaw angle $\alpha_0$, pitch angle $\beta_0$ and the roll angle $\gamma_0$, yaw angle $\alpha_0$ is rotation angle around the Z axis, the rotation matrix is expressed as $\mathbf{R}_z(\alpha_0)$:

$$
\mathbf{R}_z(\alpha_0) = \begin{bmatrix}
c_{\alpha_0} & -s_{\alpha_0} & 0 \\
s_{\alpha_0} & c_{\alpha_0} & 0 \\
0 & 0 & 1
\end{bmatrix} \equiv \mathbf{R}_z(\theta_z)
$$

Set $\beta_0$ is the rotation angle around the Y axis, whose rotation matrix $\mathbf{R}_y(\beta_0)$ is expressed as:

$$
\mathbf{R}_y(\beta_0) = \begin{bmatrix}
c_{\beta_0} & 0 & s_{\beta_0} \\
0 & 1 & 0 \\
-s_{\beta_0} & 0 & c_{\beta_0}
\end{bmatrix} \equiv \mathbf{R}_y(\theta_y)
$$

Set $\gamma_0$ is the rotation angle around the X axis, whose rotation matrix $\mathbf{R}_x(\gamma_0)$ is expressed as:

$$
\mathbf{R}_x(\gamma_0) = \begin{bmatrix}
1 & 0 & 0 \\
0 & c_{\gamma_0} & -s_{\gamma_0} \\
0 & s_{\gamma_0} & c_{\gamma_0}
\end{bmatrix} \equiv \mathbf{R}_x(\theta_x)
$$
The homogeneous transformation matrix of the terminal effector coordinate system \( \Sigma_e \) relative to the inertial coordinate system \( \Sigma_i \) is:

\[
{^i T}_e(\theta) := T_0(\theta_1, \theta_2, \theta_3) \cdot T_3(q_4)
\] (4)

The forward kinematics formula of the kinematic chain, joint configuration \( \theta \) and terminal effector pose \( p_e \) can be obtained by the robot from the waist to the effector at the end of the arm:

\[
p_e = f(\theta)
\] (5)

2.2. Forward kinematics equation and analysis of robot

The end effector of the robot is located in Cartesian space, the speed is \( \dot{p}_e \cdot \dot{p}_e \in \mathbb{R}^{6 \times 1} \), and the angular position and angular velocity of the joint space are \( \theta \) and \( \dot{\theta} \in \mathbb{R}^{10 \times 1} \) respectively. Then, according to (5) formula, the forward kinematics differential equation of the robot can be obtained:

\[
\dot{p}_e = J(\theta)\dot{\theta}
\] (6)

Wherein, \( J(\theta) \in \mathbb{R}^{6 \times 10} \) is the Jacobi matrix of robot arm. The inverse kinematics solution of redundant kinematic equation (8) is:

\[
\dot{\theta} = J^+ \dot{p}_e + (I - J^+ J) \dot{\xi}
\] (7)

Wherein, \( J^+(\theta) = J^T(JJ^T)^{-1} \) is Moore-Penrose generalized inverse matrix of Jacobi matrix \( J \), the singular value decomposition method; \( I \in \mathbb{R}^{10 \times 10} \) is unit matrix; \( \dot{\xi} \in \mathbb{R}^{10} \) is an arbitrary vector; \( J^+ \dot{p}_e \) is joint velocity solution, also known as the minimum norm solution, the definition of robot action; \((I - J^+ J)\dot{\xi}\) homogeneous solution, action is not generated in the end effector[5].

According to the classical gradient projection method proposed by Liegeois, \( \dot{\xi} \) is replaced by \( k \nabla H(\theta) \), and formula (7) can be rewritten:

\[
\dot{\theta} = J^+ \dot{p}_e + k(I - J^+ J)\nabla H(\theta)
\] (8)

According to damped weighted least squares norm WLN (Weighted Least-Norm), the optimal joint velocity of robot is:

\[
\dot{\theta} = J^+_{WL} \dot{p}_e
\] (9)

Wherein, \( J^+_{WL}(\theta) = W^{-1}J^T[J \cdot W^{-1}J^T]^{-1} \), \( w_j = \begin{cases} 1 & \text{if } \Delta |\partial H(\theta)/\partial \theta_j| > 0 \\ 0 & \text{else} \end{cases} \).
3. Fixed position control law design

3.1. Analysis and optimization of control parameters
This paper proposes an attitude control method of kinematics model of the robot based on the analytical solution, robot walking, attitude transform, grasping and controlling the motion planning problem, using three axis accelerometer, magnetometer and three axis gyroscope integrated attitude measurement, using the accelerometer and magnetometer attitude calculation, the measurement data; the gyro angle estimation as the process data, and then through the Kalan filter to correct the error of attitude angle estimation, finally get the precise attitude, that a real time attitude angle is $\theta^k$. When the robot is in non-accelerated motion, the gyroscope data from Kalan filter, using four element method to calculate the attitude angle $\theta^{oe}$:

$$
\theta^{oe} = \theta^{e} + \varepsilon^{oe}
$$

At the same time, the four element vectors satisfy the differential equation:

$$
\begin{bmatrix}
q_0 \\
q_1 \\
q_2 \\
q_3
\end{bmatrix} = \frac{1}{2} \omega(t)Q(t) = \frac{1}{2} \begin{bmatrix}
0 & -\omega^b_{nx} & -\omega^b_{ny} & -\omega^b_{nz} \\
\omega^b_{nx} & 0 & -\omega^b_{nz} & -\omega^b_{ny} \\
-\omega^b_{ny} & \omega^b_{nz} & 0 & -\omega^b_{nx} \\
-\omega^b_{nz} & -\omega^b_{ny} & \omega^b_{nx} & 0
\end{bmatrix} \begin{bmatrix}
q_0 \\
q_1 \\
q_2 \\
q_3
\end{bmatrix}
$$

According to Lyapunove stability control theory, using Euler angle method to calculate the attitude angle, there is a singularity problem, based on the practical engineering, using the four elements method for solving gyro attitude angle, four elements represent the coordinate transformation matrix such as:

$$
T = C^b_\alpha = \begin{bmatrix}
q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_1q_2 - q_0q_3) & 2(q_1q_3 + q_0q_2) \\
2(q_1q_2 + q_0q_3) & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2(q_2q_3 - q_0q_1) \\
2(q_1q_3 - q_0q_2) & 2(q_2q_3 + q_0q_1) & q_0^2 - q_1^2 - q_2^2 + q_3^2
\end{bmatrix}
$$

At the same time, the four element vectors satisfy the differential equation:

$$
\begin{bmatrix}
q_0 \\
q_1 \\
q_2 \\
q_3
\end{bmatrix} = \frac{1}{2} \omega(t)Q(t) = \frac{1}{2} \begin{bmatrix}
0 & -\omega^b_{nx} & -\omega^b_{ny} & -\omega^b_{nz} \\
\omega^b_{nx} & 0 & -\omega^b_{nz} & -\omega^b_{ny} \\
-\omega^b_{ny} & \omega^b_{nz} & 0 & -\omega^b_{nx} \\
-\omega^b_{nz} & -\omega^b_{ny} & \omega^b_{nx} & 0
\end{bmatrix} \begin{bmatrix}
q_0 \\
q_1 \\
q_2 \\
q_3
\end{bmatrix}
$$

The four orders Runge Kutta method is used to solve the differential equation, and the updated values of the four parameters are calculated. The attitude angles are obtained by substituting Euler angles:

$$
\theta = \arcsin(-T_{31})
$$

To sum up, the stability motion inertia parameters are obtained according to the center of mass corresponding to the moving parts of the robot. The attitude control is carried out by using the random sampling RRT motion planning method [6].

3.2. Attitude positioning control
When the robot is in the state of non-acceleration motion, the attitude angle $\theta^{k}_a$ is calculated:

$$
\theta^{k}_a = \theta^{k}_t + \varepsilon^{k}_a
$$

When the robot is in any position, it is assumed that the acceleration measured on the three axis of the robot coordinate system is:

$$
A_b = [a_x \ a_y \ a_z]^T
$$
Then the coordinate system transformation matrix $A_b = C^b_n A_n$ can be obtained:

$$
[a_x \quad a_y \quad a_z]^T = \begin{bmatrix}
\cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\
\sin\psi\sin\theta\cos\psi - \cos\psi\sin\theta & \cos\psi\cos\psi + \sin\psi\sin\theta\sin\psi & \sin\theta\cos\psi \\
\sin\psi\sin\theta\cos\psi - \cos\psi\sin\psi & \cos\psi\cos\theta\sin\psi - \sin\psi\cos\psi & \cos\psi
\end{bmatrix} \begin{bmatrix}
0 \\
g
\end{bmatrix}
$$

(16)

The $C^b_n$ is the Euler angle matrix of sins, and the elevation angle and the side angle can be calculated:

$$
\begin{align*}
\theta &= \arcsin\left(-\frac{a_y}{g}\right) \\
\gamma &= \arcsin\left(\frac{a_x}{g\cos\theta}\right)
\end{align*}
$$

(17)

In the process of motion, the robot will change its attitude, and there are pitch angles $\theta$ and side angle $\gamma$, which can be used to correct the measurement system:

$$
\begin{cases}
m'_x = m_x\cos\theta + m_y\sin\gamma - m_z\cos\sin\theta \\
m'_y = m_y\cos\gamma + m_z\sin\gamma
\end{cases}
$$

(18)

According to the idea of difference of discrete system, the difference of angle estimation between two adjacent time points can be obtained:

$$
\Delta_\theta = \theta^{k+1}_a - \theta^k_a = (\theta^{k+1}_T - \theta^k_T) + (\epsilon^{k+1}_a - \epsilon^k_a)
$$

(19)

$$
\Delta_\gamma = \theta^{k+1}_g - \theta^k_g = (\theta^{k+1}_T - \theta^k_T) + (\epsilon^{k+1}_g - \epsilon^k_g)
$$

(20)

Subtracting the two formulas, we get the error of the fusion of the two moments:

$$
f = \Delta_\theta - \Delta_\gamma = (\epsilon^{k+1}_a - \epsilon^k_a) - (\epsilon^{k+1}_g - \epsilon^k_g)
$$

(21)

Find covariance:

$$
Cov(f, f) = E[(f - Ef)(f - Ef)^T] = E[(f - Ef)^2] = E\left[\left((\epsilon^{k+1}_a - \epsilon^k_a) - (\epsilon^{k+1}_g - \epsilon^k_g)\right)^2\right]
$$

(22)

Here, the errors of gyroscopes, accelerometers, and magnetometers are independent of the zero mean white noise sequence [7]. According to the above processing, the single tree RRT motion planning cycle is carried out, and the robot is accurately run to any position of the space to ensure that the end effector moves along a predetermined trajectory, and the robot’s pose optimization control is realized.

4. Simulation results and analysis

In order to test the performance of the localization method in robot control in the simulation experiment, the robot dynamics software ADAMS is used to construct a simplified analysis simulation system, MT-R robot experiment by university independent research and development of thought, by the three axis LSM303DLH electronic compass (including accelerometers and magnetometers) and L3G4200D gyro attitude information the sensing module arranged on the robot, using three axis accelerometer, magnetometer and three axis gyroscope integrated attitude measurement sensitivity, three axis gyroscope L3G4200D is 8.75/17.50/70 mdps/digit, the stability of the oscillation amplitude fExtend setting as 0.3, selection of simulation parameters as:
\[ \lambda = 1.744, \lambda_1 = 0.862, \lambda_2 = 3.9753, \alpha = 0.1859, \beta = 3.9508, \] according to the simulation environment and parameters of robot control simulation the construction of robot attitude control simulation software in Visual C++ environment, get the robot's motion picture. The data display and control interface is shown in Figure 1.

![Figure 1. Image data display and control interface of robot motion.](image1)

The vision system based on the above we designed with seven degree of freedom controllers, control is the basic input device of robot teleoperation, hand position information on the one hand detection robot operator, as a control instruction to control the remote manipulator's position and movement, on the other hand, it will be far back and robot arm environmental reproduction information interaction force and acts in the hand of the operator, in the two scenario set 5 seconds delay and without delay, respectively, do 6 experiments, the robot is inserted into the workpiece and placed in the experimental operation of the drawer, the simulation process is shown in Figure 2. In order to control the accuracy of quantitative test, control the convergence curve as shown in Figure 3.

![Figure 2. Experimental process of attitude control in robot operation.](image2)
The simulation results show that the method proposed in this paper has higher accuracy in robot pose control, it has better control robustness, and can perform a certain degree of complexity in operation, and improve the operation accuracy.

5. Conclusion
This paper proposes an attitude control method of kinematics model of the robot based on the analytical solution, robot walking, attitude transform, grasping and controlling the motion planning problem. The kinematics analytical model of robot in Cartesian space, by using three axis accelerometer, magnetometer and three axis gyroscope integrated attitude measurement, the original acquisition of gyroscope the data after Colman filtering according to the centroid of the moving parts of the robot corresponding to obtain stability inertia parameters, using random sampling RRT motion planning method, accurate operation to any position control of space robot, to ensure the end effector along a prescribed trajectory, realize the accurate positioning of the attitude control. The experimental results show that using the method of robust robot attitude control is better, attitude control precision is high, and improve the operation reliability of robot. It has good application value in robot control field.

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