The Research of Mechanical Arm on Remote Operation System

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Abstract. With the rapid development of the Internet, the combination of Internet technology and robotics has become an important research direction. This paper studies the development status and trends of the domestic and foreign in mechanical arms and remote control and summarizes the problems of the remote control of the robot arm, such as distance, delay, a high degree of freedom and difficulty in controlling. Setting up the remote installation of KUKA mechanical arm, supporting sensors, make up the robot hardware platform, and perform remote operation experiments at any location and at any time through the server/client model. Realizing the trajectory planning on the simulation system, preview the simulation results, confirming the execution effect, and actually running the KUKA manipulator, which has a strong research value and practical value.

1. Introduction

With the emergence and perfection of Web technology, the domain of web-based remote-control robot has become active. The Robotic Telescope developed by Goldberg [1] is a long-range Robotic Telescope that allows users to view space through telescopes over the Internet. The online interactive painting robot "PumaPaint Project", designed by Stein [2], allows any user on the Internet to control a robotic arm to paint on a remote laboratory canvas. "KheOnTheWeb" [3] [4] developed by The Swiss Federal Institute of Technology, is the first web-based autonomous mobile robot system. Users can control the robot through the network to move in the artificial maze and get the required image feedback through the camera. Wang Tai [5] conducted research on the remote control of multi-operator and multi-robot, breaking through the traditional architecture of single-operator and single-robot, and greatly promoted the development of remote-control technology. Doulgeri and Matiakis [6] implemented the demonstration work of path planning and control for remote industrial robots through Web browsers.

This thesis consists of an introduction, Kinematic Modelling, Simulation system, Remote Control Platform, Experiment, and Conclusion. As shown in Fig.1, the user first obtains the access permission of the remote operation experimental system through the network. After verification, the user can control the action of the mechanical arm in the virtual simulation system. Then confirming the safe action results, the handler can request the server to execute the simulation results. After receiving the request, the server sends the related control command flow to the robot platform for controlling the action. At the same time, the feedback information flow (robot status information, video monitoring information, etc.) of the robot platform is sent to the client’s interface. Users can see the corresponding execution results comparing to the virtual simulation system of the client.
2. Kinematic Modelling

The common robot manipulator, which usually has 6 degrees of freedom, comprises shoulder joint, upper arm, elbow joint, lower arm, wrist, and the end-effector. The dynamic modeling of a manipulator robot with N-DOF can be divided into four steps: Direct Kinematics, Inverse Kinematics, Differential Kinematics and Dynamics [7]. Denavit and Hartenberg put forwards to a matrix method to build the attached coordinate system on each link in the joint chains of the robot to describe the relationship of translation or rotation between the contiguous links way back in 1955 [8].

The structure diagram of the manipulator is described in Fig. 2, and the D-H coordinate system of the humanoid robot manipulator could be found in Fig. 3. Table 1 is the D-H parameters table. Direct kinematic and inverse kinematics are the core of the kinematic analysis, which is the following topics.
Table 1. The D-H parameters Table

| Joint | $\alpha_{i-1}$ /° | $a_i$ / m | $\theta_i$ /° | $d_i$ / m | The range of Joints' angle |
|-------|-----------------|-----------|---------------|-----------|---------------------------|
| 1     | 0               | 0         | 90            | 0.415     | $-170^\circ$ ~ $170^\circ$ |
| 2     | 90              | 0.025     | 90            | 0         | $-190^\circ$ ~ $45^\circ$  |
| 3     | 0               | 0.56      | 0             | 0         | $-120^\circ$ ~ $156^\circ$ |
| 4     | 90              | 0.035     | 0             | 0.515     | $-185^\circ$ ~ $185^\circ$ |
| 5     | -90             | 0         | 90            | 0         | $-120^\circ$ ~ $120^\circ$ |
| 6     | -90             | 0         | -90           | 0         | $-350^\circ$ ~ $350^\circ$ |

2.1. Direct Kinematic

According to the link parameters from Table 1, it is simple to deduce the equation, where $(n_x, n_y, n_z)$ is the normal vector, $(o_x, o_y, o_z)$ is the orientation vector, $(a_x, a_y, a_z)$ is the approach vector, $(p_x, p_y, p_z)$ is the end-effector position vector. Its kinematics solution is:

$$
^0T_6 = ^0T_1 ^1T_2 ^2T_3 ^3T_4 ^4T_5 ^5T_6 = \begin{bmatrix} n_x & o_x & a_x & p_x \\
 n_y & o_y & a_y & p_y \\
 n_z & o_z & a_z & p_z \\
 0 & 0 & 0 & 1 \end{bmatrix}
$$  \hspace{1cm} (1)

2.2. Inverse Kinematic

The inverse kinematic analysis is the opposite of the forward kinematic analysis. The corresponding variable of each joint could be found with the given location requirement of the end of the manipulator in the given references coordinate system. The inverse kinematic analysis is done by multiplying inverse matrix on the left side of the above equation and then equalizing the corresponding elements of the equal matrices of both ends [9].

With inverse kinematic solutions, the value of each joint can be determined to place the arm at a desired position and orientation. To decouple the angles, the matrix is routinely multiplied with the individual $^iT_i^{-1}$ matrices. To solve for the angles, it would multiply the two matrices with the $^iT_i^{-1}$ matrices, starting with $^0T_1^{-1}$:

$$
^0T_1^{-1} \times ^0T_6 = ^1T_2 ^2T_3 ^3T_4 ^4T_5 ^5T_6
$$  \hspace{1cm} (2)

From (2, 4) elements, we could get $\theta_i$:

$$
\theta_i = A \tan 2(p_x, -p_y) \text{ or } \theta_i = A \tan 2(-p_x, p_y)
$$  \hspace{1cm} (3)

From (1, 4) and (3, 4) elements, we could obtain $\theta_3$:

$$
d_4s_5 + a_3c_5 = ((c_1p_x - s_1p_y - a_1)^2 + (p_z - d_1)^2 - a_2^2 - a_3^2 - d_4^2) / (2a_3) = k
$$  \hspace{1cm} (4)

$$
\theta_3 = A \tan 2(k, \pm \sqrt{d_4^2 + a_3^2 - k^2}) - A \tan 2(a_3, d_4)
$$  \hspace{1cm} (5)

Then multiply the two matrices with the $^0T_3^{-1}$ matrices.
\[ T_5^{-1} T_6 = T_4 T_5 T_6 \]  

(6)

From (1, 4) and (2, 4) elements, we could acquire ∂₂:

\[
\begin{align*}
\mathbf{s}_{23} &= \left((p_x s_4 + a_1 - p_y c_4)(a_3 + a_2 c_1) - (p_x - d_4)(-d_4 - a_2 s_4)\right) / \left((p_x - d_4)^2 + (p_y s_4 + a_1 - p_y c_4)^2\right) \\
\mathbf{c}_{23} &= \left((p_x - d_4)(a_3 + a_2 c_1) - (p_x s_4 + a_1 - p_y c_4)(-d_4 - a_2 s_4)\right) / \left((p_x - d_4)^2 + (p_y s_4 + a_1 - p_y c_4)^2\right)
\end{align*}
\]

(7)

\[
\theta_2 = \theta_{23} - \theta_3 = A \tan 2(s_{23}, c_{23}) - \theta_3
\]

(8)

From (2, 3) and (3, 3) elements, we could deduce ∂₃:

\[
\theta_3 = A \tan 2(a_y c_{23}, c_{23} + a_z s_{23}, a_z s_{23} + a_x s_{23} c_{23} + (a_y s_1 + a_y c_1)^2)
\]

(9)

From (1, 3) and (3, 3) elements, obtain ∂₄:

\[
\theta_4 = A \tan 2\left(\frac{-(a_z s_1 + a_z c_1)}{a_z c_{23} - a_y c_{23} + a_z s_{23}}, \frac{-(a_z s_{23} + a_z s_{23} s_{23})}{a_z c_{23} - a_y c_{23} + a_z s_{23}}\right)
\]

(10)

From (2, 1) and (2, 2) elements, we could get ∂₆:

\[
\theta_6 = A \tan 2\left(\frac{n_x s_{23} - n_y c_{23} - n_y c_{23}}{c_{23} o_z s_{23} c_{23} - c_{23} o_z c_{23} - c_{23} o_z c_{23}}, \frac{n_x s_{23} c_{23} - n_y c_{23}}{c_{23} o_z s_{23} c_{23} - c_{23} o_z c_{23} - c_{23} o_z c_{23}}\right)
\]

(11)

3. Simulation system

In order to enhance the security of the whole experimental system, the construction of the simulation system is the key point to ensure the safety and reliability of the system.

An accurate and reliable simulation system is designed to realize the virtual operation of the robot. The user can watch the results of the virtual operation, confirm the safety of execution, and then control the physical robot to perform corresponding actions, which is the programming language to build the simulation environment in the left of Fig. 4.

\textbf{Figure 4.} The simulation and a real platform
In the simulation space of the mechanical arm, the posture of the mounting bracket, machine seat and working platform are fixed and invariable, but the posture of each axis of the mechanical arm, the end-effector and the object on the working platform alters according to the control, which is based on the dynamic modeling of the second part.

4. Remote Control Platform
As shown in Fig. 5, the information flow of the system is given. The communication between the server and the robot platform is divided into Universal Serial Bus (USB) and network communication. The remote PC connects to the server via the IP address of the WAN, and the KUKA Robot arm controller, end-effector, torque sensor, the digital camera are connected to the server via LAN, while the analog camera is connected to the server via USB. The server manages all the resources uniformly and transfers the sensor information to the client according to the system design so that the client can control the whole robot platform remotely.

![Figure 5. Overall of the information flow.](image)

5. Experiment
The mechanical arm remote control experiment system takes the KUKA KR10 mechanical arm as the main body, carrying the end manipulator grasping and 6-axis pressure sensor, to provide the operator with the service of remotely operating the mechanical arm. In order to ensure the safety of operation, the simulation function is pre-requisite. The operator can execute the simulation results after being ensured safety. For the exact coordinates of the uncertain grabbing target, the robot arm would be activated after obtaining the accurate coordinate values through traditional image processing.

5.1. Remote control experiment
The whole system adopts the server/client mode. The server could collect the shaft Angle and sensor information of the robot platform, monitors the wan access request at any time, and the remote user can log into the remote operator interface through the special client software by inputting the registered username and password. As shown in Fig. 6, the software will directly display the global image and the part image captured by the manipulator, and users can choose remote control to control the manipulator.
5.2. Simulation experiment

In the simulation mode, in order to enhance the security of the entire experimental system and avoid unexpected results after controlling the mechanical arm action by accident, the construction of the simulation system is the key point to ensure the safety and reliability of the system. As shown in Fig. 7, the remote operator can execute the simulation results after ensuring safety.

5.3. Auto grasp

As shown in Fig. 8, with the high definition of black and white cameras to get the image of the jigsaw board on the working platform, cutting the size of the image to just cover the desk, filtering to reduce the high-frequency noise, we can get the binarization image to proceed contour detection for acquiring the center of the shape. In order to grab the arbitrarily placed tangram, the pixel coordinates of the central position of the target object in the picture are obtained through image processing. Through the transformation matrix of the camera and the calibrated base coordinate system, the configuration of the target object in the base coordinate system be calculated, and then the robot arm should be controlled to grab the specified target object.
6. Conclusion
This research builds the remote operation of KUKA mechanical arm, performing remote operation experiments at any location and at any time through the server/client model. The operator can preview the simulation results, confirm the execution effect, and actually run the KUKA manipulator, which has a strong research value and practical value.

Since the image is gained from a single camera overlooking the ground, only two-dimensional information is acquired after image processing, and no depth information is obtained. The later stage needs to be improved to increase the camera for the depth information providing comprehensive information, and the deep learning method would be considered for image processing to acquire machine intelligence and improve the intelligence level of the system.

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