Vision servo positioning control of robot manipulator for distribution line insulation wrapping

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Abstract: Traditional visual servo control based on location needs to convert two-dimensional information into three-dimensional space information, and the conversion process is subject to many interference factors, leading to large control errors. Aim ing at the above problems, the visual servo positioning control of distribution line insulated wrapping robot and manipulator is studied. The position and pose of the manipulator are described and homogeneous transformed so as to calibrate the camera vision system of the manipulator. The image Jacobian matrix is established to realize the visual servo positioning control of the manipulator. Compared with the traditional control method, the experimental verification shows that the control method can reduce the pose error by at least 39.7%, and the control effect is more stable and the reliability is better.

1. Introduction

At present, insulating and wrapping the bare overhead conductor can ensure the safe operation of the line, and it is a common operation mode for operators to operate by elevator truck or pole. But manual operation can only be used in the open area with flat terrain, and the manual operation mode has great limitations, such as high labor intensity, low operation efficiency and unstable operation quality. The distribution line insulation wrapping robot with higher operation efficiency has replaced most of the manual insulation wrapping work, and visual sensing is very important for the insulation wrapping robot, with the help of other sensors, the manipulator moves to the target position according to the visual control command, and then the end effector of the manipulator completes the line insulation protection.

Visual servo positioning control is to control the position and direction of the manipulator and the target through the guidance of visual information collected by mechanical equipment. Traditional position-based visual servo control requires the conversion of two-dimensional image measurement information into three-dimensional spatial information, and the conversion process is affected by the uncertainty of the manipulator model and the error caused by the calibration, resulting in the low positioning accuracy and poor effect of the manipulator. Based on the above analysis content, this paper will study the distribution line insulation wrapping robot manipulator vision servo positioning control.
2. Research on visual servo positioning control of distribution line insulated wrapping robot manipulator

2.1. Description and transformation of insulated wrapping robot and manipulator
The insulated robotic manipulator can be regarded as a series of mechanical devices composed of rod parts connected by joints. In order to realize accurate servo positioning control, the posture of the manipulator is described and homogeneous transformation is processed [4-5]. During the description, the origin of coordinate system \( \{ A \} \) of the insulated manipulator can be placed in the base coordinate system \( \{ O \} \), and the three coordinate components of the origin of coordinate system of the manipulator can be used to form the following position matrix.

\[
\begin{bmatrix}
  x_{oa} \\
y_{oa} \\
z_{oa}
\end{bmatrix} = \begin{bmatrix}
p_x \\
p_y \\
p_z
\end{bmatrix}
\]

(1)

In formula (1), \( x_{oa} \) is the x-axis component of the origin of the coordinate system of the manipulator in the base coordinate system; \( y_{oa} \) is the manipulator coordinate system coordinate origin in the foundation coordinate system y axis direction component; \( z_{oa} \) is the manipulator coordinate system coordinate origin in the foundation coordinate system z-axis direction component.

2.2. Visual system calibration of manipulator
A camera is installed on the end of the robot manipulator to identify the location of the target line. The camera's internal parameter model can describe the relationship between the target circuit and its corresponding imaging points in space. The imaging principle of the camera is pinhole imaging, so the position coordinates of the object in space on the imaging plane are known, and the image points on the digital image can be obtained after magnifying the imaging points of the target [6-7]. Then establish the camera's internal parameter model as shown in the following formula:

\[
\begin{bmatrix}
  x_c/z_c \\
y_c/z_c
\end{bmatrix} = \begin{bmatrix}
x_c \\
y_c
\end{bmatrix} = M_{im} \begin{bmatrix}
  u \\
v
\end{bmatrix}
\]

(2)

In formula (2), \( k_x \) is the amplification factor of the imaging point in the X-axis direction; \( k_y \) is the amplification factor of the imaging point in the Y-axis direction; \( k_z \) is the coupling parameter of magnification imaging coefficients in X and Y directions; \( M_{im} \) is the camera's internal parameter matrix; \( (x_c, y_c, z_c) \) is the coordinate of the distribution circuit in the camera coordinate system; \( (u, v) \) is the point of digital image after amplification and processing. After determining the position of the distribution line in the camera coordinate system, the relative position in space between the distribution line and the camera is observed. Through the transformation relation between camera coordinate system and manipulator coordinate system, the visual system calibration of manipulator is completed.

2.3. Manipulator vision servo positioning control
In the visual servo positioning control of the manipulator, it is necessary to make clear the motion speed of the camera at the end of the manipulator and the characteristic points of the target line, as well as the relationship between the relevant parameters of the corresponding imaging points on the imaging plane. If the number of distribution line feature points is \( N \), according to the binocular
stereo vision principle, the coordinates of distribution line feature points on the image plane of left camera and right camera are \( p_k \left( x_k, y_k \right) \) and \( \tilde{p}_k \left( \tilde{x}_k, \tilde{y}_k \right) \) respectively.

According to the following formula, the linear velocity and rotational angular velocity in the coordinate system of the manipulator are converted to the coordinate system inside the camera:

\[
C_v = \begin{bmatrix}
C_{R_b} & S \left( C_{T_b} \right) \left[ R_b \right] \\
0 & C_{R_b}
\end{bmatrix} \begin{bmatrix}
\dot{v} \\
\dot{\omega}
\end{bmatrix}
\] (3)

In formula (3), the parameters superscript \( B \) are coordinate parameters of manipulator coordinate system; The parameters superscript \( C \) are camera coordinate parameters; \( C_v \) is the linear velocity in manipulator coordinate system and camera coordinate system; \( C_{R_b} \) is the transformation relation matrix when the manipulator coordinates are rotated relative to the camera coordinate system \([8]\). By extending the above process to \( N \) feature points on the distribution line, the image Jacobian matrix is obtained. The manipulator moves to the designated position of the distribution line according to the image Jacobian matrix, and the corresponding operation is performed by the end-effector to complete the servo visual positioning control process of the manipulator. Above, the completion of the distribution line insulation wrapping robot manipulator vision servo positioning control research.

3. Experimental research and analysis

3.1. Experiment content

In order to ensure the validity and authenticity of this experiment, the visual servo positioning control method of the distribution line insulated packaging robot and manipulator studied in this paper is compared with the traditional visual servo control method based on position. Through the comparison experiment, the control effect of the two visual servo positioning control methods can be intuitively compared, and it is judged whether the visual servo positioning control method studied in this paper has practical application value.

3.2. Experimental process

This experiment takes Puma560 manipulator as the control object. The manipulator has six joints, and the specific parameters are shown in Table 1.

| Serial number of manipulator parts | Joint Angle | Joint offset | Connecting rod torsion Angle/° | Initial Angle/° |
|----------------------------------|-------------|--------------|--------------------------------|-----------------|
| 1                                | g1          | 0            | 0                              | 1.682           |
| 2                                | g2          | 0            | 0.4516                         | 0               |
| 3                                | g3          | 0.22         | 0.0257                         | -1.682          |
| 4                                | g4          | 0.512        | 0                              | 1.682           |
| 5                                | g5          | 0            | 0                              | -1.682          |
| 6                                | g6          | 0            | 0                              | 0               |

In order to avoid the interference of visual information acquisition tools on the results of this experiment, a camera with a resolution of 1024×1024 and a focal length of 0.008m was used in the experiment to collect visual information. In the experimental space, the end of the manipulator was set to grab the object position, and the end of the manipulator was moved to the object position under the control of two different methods. The advantages and disadvantages of the two control methods are compared by comparing the convergence of the image pixel characteristic error of the experimental manipulator and the error between the expected pose and the actual pose under the control of two different visual servo control methods.
3.3. Experimental results and analysis
Under the control of two visual servo control methods, the comparison between the end track of manipulator and the desired motion trajectory is shown in Figure 1.

![Figure 1. Comparison of the terminal motion trajectory of the manipulator](image)

Under the control of the two methods, the error values between the expected pose and the actual pose of the manipulator at different motion times are shown in the table below. Combined with Figure 1, the data in Table 2 are analyzed.

| Movement time /s | This paper's method | Traditional method |
|------------------|---------------------|--------------------|
|                  | X       | Y       | Z       | X       | Y       | Z       |
| 0.5              | 0.34    | 0.15    | 0.23    | 0.61    | 0.66    | 0.82    |
| 1.0              | 0.22    | 0.14    | 0.22    | 0.60    | 0.86    | 0.77    |
| 1.5              | 0.31    | 0.12    | 0.26    | 0.66    | 1.01    | 0.77    |
| 2.0              | 0.22    | 0.25    | 0.24    | 0.59    | 0.93    | 0.88    |
| 2.5              | 0.19    | 0.22    | 0.28    | 0.61    | 0.69    | 0.73    |
| 3.0              | 0.32    | 0.11    | 0.22    | 0.71    | 1.02    | 0.84    |
| 3.5              | 0.25    | 0.23    | 0.23    | 0.58    | 0.75    | 0.91    |
| 4.0              | 0.35    | 0.13    | 0.25    | 0.69    | 0.87    | 0.93    |
| 4.5              | 0.28    | 0.25    | 0.30    | 0.58    | 0.73    | 0.85    |
| 5.0              | 0.26    | 0.26    | 0.26    | 0.63    | 0.98    | 0.71    |

It can be seen from the table 2 that the error between the actual pose and the expected pose of the manipulator end in the three directions of X, Y and Z is much smaller than that of the traditional method when the manipulator is controlled by this method. Under the control of the traditional method, the position error of the manipulator in the Y-axis direction is the largest, which indicates that the traditional method has a large error in obtaining the depth position information of the target. The pose error in the z-axis direction is slightly larger than that in the X-axis direction, indicating that the traditional method overcompresses the image height and size during the conversion between space and plane information, increasing the control error. By further calculating the data in the above table, it can be seen that compared with the traditional control method, the control method in this paper can reduce the pose error by at least 39.7%. Combined with the curve information in figure 1, the motion trajectory of the manipulator end under the control of this method is closer to the desired motion trajectory. Based on the above content, the manipulator has a lower posture error under the control of the control method in this paper, and the moving trajectory is closer to the expected trajectory.

In conclusion, the vision servo positioning control of the robot manipulator for distribution line insulation wrapping has high control accuracy and good stability, and the actual application effect is better.
4. Conclusions
Distribution line insulation wrapping robot can replace the construction workers to carry out the work, not only the use is not restricted by conditions, but also can improve the line wrapping efficiency. In order to improve the working precision of distribution line insulated wrapping robot and manipulator, an improvement is made on the basis of the traditional control method. The simulation experiment verifies that the visual servo control method studied in this paper has a high control accuracy, saves a lot of manpower and material resources in practical application, has a high economic benefit, and has a very broad market application prospect.

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