Research on obstacle avoidance method of robot manipulator based on binocular vision

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Abstract. Aiming at static obstacles in indoor environment, the six-axis robot manipulator can avoid obstacles successfully through binocular stereo vision system. According to the principle of camera imaging, the camera calibration is completed by using the camera calibration toolbox of MATLAB, and then the three-dimensional coordinates of the feature points of obstacles are obtained by using the Structure from Motion (SFM) algorithm, so as to determine the location of obstacles. In the aspect of path planning, combining the characteristics of binocular visual obstacle recognition, the artificial potential field (APF) method is used to realize the obstacle avoidance. Finally, the simulation and data analysis under the Matlab development environment verify the feasibility of the algorithm in the binocular vision obstacle avoidance system.

1. Introduction
With the development of manipulator technology, the working environment of robot manipulator becomes more and more complex[1][1][2]. Therefore, the autonomous obstacle avoidance function of the manipulator is necessary. The obstacle avoidance planning problem of a robot manipulator is to search a path from the starting point to the ending point without colliding with the intermediate obstacle in the environment with obstacles. The planned path is the trajectory of the manipulator[3]. The use of binocular cameras and computers to simulate the human eyes and brain to obtain information of binocular stereo vision, industrial robot and machine vision fusion is a broad prospect of the field of development. Combining the robot manipulator with the vision system, the external target information is measured by the vision sensor system, and then the feedback signal is transmitted to the robot manipulator to control the relative motion of the robot manipulator and improve the autonomous operation ability of the robot manipulator[4].

2. Related work

2.1. Research on binocular vision system
Using binocular camera and computer to simulate human eyes and brain to obtain stereo vision information is a development trend of machine vision. In this paper, the ultimate goal of using binocular vision system is to obtain the depth distance information between the robot manipulator and the obstacle.
2.1.1. Principle of binocular stereo vision imaging.

The binocular vision system uses two cameras to form two images from different angles according to the principle of stereoscopic imaging of human eyes, and the same point in two images will form very obvious visual difference, the three-dimensional information of the target point can be calculated.

The distance between the two cameras, $C_1$ and $C_2$ is $B$ and the focal length of the camera is $f$ [5]. The space point $P$ is imaged by two cameras: $P_1(X_{left}, Y_{left})$ and $P_2(X_{right}, Y_{right})$. Because the two cameras are placed horizontally, the $Y$ coordinates of the target object in the two images are the same, so we only need to calculate the $X$ coordinates to get the three-dimensional coordinates of point $P$ in space.

![Stereoscopic imaging schematic diagram of binocular vision system.](image)

2.1.2. Principle of distance measurement based on binocular vision system.

Binocular stereo vision ranging is to use two cameras at the same time the left and right images for stereo matching, according to stereo matching disparity map to calculate the distance of the object. Camera calibration and matching of left and right image pairs are the key points of the ranging scheme.

There is a distance between the two cameras in the three-dimensional space, the location will be different, the environment on a target point on the left and right image pixel projection deviation, the deviation is called parallax. According to the special algorithm, the parallax of the left and right image can be calculated, so the distance between the object and the binocular camera in the environment can be obtained.

It can be solved by triangulation distance method:

$$Z = \frac{fT}{d}$$

(1)

The focal length $f$ and baseline distance of two cameras $T$ can be obtained by binocular camera calibration. Therefore, as long as the value of the parallax $d$ is known, the depth distance $Z$ can be obtained.

2.2. Research on obstacle avoidance method of robot manipulator

Obstacle avoidance method of manipulator has always been a hot issue in robot field. In order to solve the problem of obstacle avoidance path planning, researchers at home and abroad can be divided into two categories [6], one is intelligent path planning algorithm, such as genetic algorithm [7], fuzzy logic algorithm [8] and ant colony algorithm [9], the other is traditional path planning algorithm, such as free space method, artificial potential field method and fast search random tree method.

For the obstacle avoidance method of manipulator, this paper selects the artificial potential field method which is widely used. In 1986, Khatri first proposed an artificial potential field algorithm for
robot avoidance. Artificial potential field method is a mature and efficient method, it does not need to use a lot of data in the pre planning space, but real-time detection of environmental information.

3. Image feature extraction and matching

The image processing link is the premise and foundation for the binocular stereo vision system to accurately identify obstacles. This chapter first briefly describes the related image processing technology applied to the two-dimensional images collected by the binocular camera; secondly, in the feature point detection and matching part of the image, the scale parameters are improved, which can effectively solve the problem of poor adaptability to scale changes. The stereo matching is performed on the image pairs collected by the binocular camera, and finally the disparity map obtained by the stereo matching based on the triangular ranging principle accurately obtains the three-dimensional coordinate information of the obstacle, and realizes the obstacle ranging.

3.1. Calibration of binocular stereo vision system

This article uses MATLAB toolbox Stereo Camera Calibrator to calibrate the binocular camera. This method is simple and convenient, and the calibration accuracy is also high, which meets the needs of use. In the calibration process, the black and white grid is used as the calibration plate, and under the condition that the relative position of the fixed binocular camera remains unchanged, images of multiple sets of calibration plates in different poses on different templates are taken. During the calibration process, select the corner of the black grid at the upper left corner of the checkerboard as the origin of the world coordinate system. At the same time, the positive direction of the $X$-axis is horizontal to the right, and the positive direction of the $Y$-axis is vertically downward. Extract the target corner points from the corner points of each picture. After the end, click Calibration to realize the camera calibration and obtain the relevant parameters.

3.2. Stereo matching of image features based on SFM

The reliability of the results of binocular vision ranging depends on the stereo matching of image features. The accuracy of stereo matching directly determines the accuracy of distance measurement, so stereo matching is one of the most critical links in the process of judging binocular visual obstacles.

Structure from Motion (SFM) algorithm is to recover camera motion from at least two pictures taken from different angles, and at the same time recover the target structure, that is, the actual three-dimensional coordinates of the feature points in the target. The SFM algorithm is based on the point cloud generation theory of the two-dimensional view. It first extracts the feature point pairs of the images taken at different angles, and then calculates the relative posture of the camera in the three-dimensional space corresponding to the different images. Finally, through the principle of triangulation, the three-dimensional coordinates of the feature points in the image are calculated by the matched feature points. In this article, a binocular camera is used to obtain two pictures from different angles to achieve the restoration of the target structure.

The SFM algorithm process requires matching point pairs between the left and right images. Therefore, the detection and matching of feature points is a key step that must be performed. First, the feature points with higher accuracy are detected in the image, and then a better matching effect can be obtained. Generally, the SIFT algorithm is often used in SFM to complete feature inspection and matching. The SIFT feature is a local image feature that remains unchanged for rotation, scale scaling, and brightness changes, while maintaining a certain degree of stability for viewing angle changes, occlusion, and noise. Due to the above-mentioned advantages of SIFT, this paper chooses the SIFT algorithm to extract the feature points of the image. The SIFT algorithm is implemented as follows:

- Scale space extreme value detection.
- Key point detection.
- Precisely locate key points.
- Determination of the direction of key points.
- Generate keypoint descriptor.
• Feature point matching.

After the above feature matching process, the following results can be obtained:

![Figure 2 Matching results.](image)

According to the image feature extraction and matching information, combined with the introduction of the binocular vision ranging principle in Section 2 above, the matrix relationship between the rotation and translation of the two cameras under the mathematical model can be obtained, and then the matrix relationship of each feature point on the obstacle image can be solved. The three-dimensional coordinate value, the depth information and disparity data obtained thereby. Combined with triangulation distance method, the actual distance of the obstacle can be measured.

4. Realization of obstacle avoidance method by artificial potential field method

4.1. Hand-eye calibration of robotic manipulator and camera

In the above, through the binocular vision system, we can find the position of the feature point on the obstacle in the camera coordinate system. Next, you need to get the position of the obstacle relative to the base coordinate system of the robot arm, so you need to calibrate the robot arm and the camera by hand and eye, the purpose is to find the transformation relationship between the camera coordinate system and the base coordinate system of the robot arm. The method used in this article is the "Eye-to-hand" situation.

![Figure 3 "Eye-to-hand" hand-eye calibration diagram.](image)

The basic idea of robot hand-eye calibration is to control the robot claw to observe a known calibration reference object in different positions, so as to derive the relationship between the robot end R and the results of multiple observations by the camera. For "Eye-to-hand" hand-eye calibration, first we need to establish a coordinate system, which are: the robot base coordinate system, the robot arm end coordinate system, the calibration board coordinate system, and the camera coordinate system.

according to:

\[
_i^w H \ast_v H_i = _i^w H \ast_v H
\]
\[ ^{w}H \cdot ^{g}H_{j} = ^{w}H_{j} \cdot ^{g}H \]  

(3)

Solve \(^{w}H \cdot ^{g}H_{j}\) represents the homogeneous transformation matrix of the chessboard with respect to the end of the robot. Since the chessboard is fixedly connected to the end of the robot during the entire calibration process, \(^{g}H_{j}\) is a constant matrix.

4.2. Basic principles of artificial potential field method

Artificial potential field method algorithm establishes an artificial potential field including gravitational field and repulsive force field. In the gravitational field, as the distance between the robotic manipulator and the target position decreases, the gravitational force will also decrease. When the manipulator is at the initial position, the gravitational force at the end of the gravitational field is the maximum value during all motions, and the gravitational force direction is from the manipulator to the target position. In the repulsive force field, the repulsive force decreases as the distance between the manipulator and the obstacle increases, and the direction of the repulsive force is from the obstacle to the manipulator. The entire artificial potential field is the superposition of gravitational and repulsive forces [10].

If the current position coordinate of the end of the robot manipulator is \(X\), the target point position coordinate is \(X_{g}\), the distance between the robot manipulator and the obstacle is \(d\), and the radius of the repulsive force field is \(d_{0}\), then the gravitational potential function and the repulsive potential function are defined as:

\[ U_{aat} = \frac{k_{a}}{2} \left| X - X_{g} \right|^2 \]  

(4)

\[ U_{rep} = \begin{cases} k_{r} \left( \frac{1}{d} - \frac{1}{d_{0}} \right)^2, & d \leq d_{0} \\ 0, & d > d_{0} \end{cases} \]  

(5)

\(U_{aat}\) is the gravitational potential function; \(U_{rep}\) is the repulsive potential function; \(k_{a}\) is the constant of gravitation; \(k_{r}\) is the constant of repulsion.

4.3. Experimental environment and results

The robotic manipulator control and teaching system is based on the 64-bit Ubuntu operating system. The robotic manipulator obstacle avoidance simulation experiment uses Matlab R2018b to obtain the obstacle avoidance planning experiment results. Based on the above binocular vision detection data and artificial potential field method, through simulation The path planning effect of the algorithm proposed in this paper is verified, and the two-dimensional and three-dimensional simulation experiments are carried out, and the experiment of path planning of the manipulator is carried out, so that the robot can realize mobile obstacle avoidance. In the obstacle environment, use Matlab simulation to carry out the experiment as shown in Figure 4.
Similarly, use the MatlabRobotic Toolbox to build the robot's kinematics model to complete the three-dimensional path planning. After the robot arm collision detection work, the robot arm's overall obstacle avoidance path planning simulation can be implemented. The overall implementation program results are as follows:

The `link()` and `robot()` functions in the MatlabRobotic Toolbox toolbox are used to build the manipulator object model, and combine D-H parameters to realize the simulation effect of the manipulator. From the simulation results, it can be seen that using the depth data obtained by binocular vision, the obstacle avoidance path planning can be successfully completed by the artificial potential field method, which proves the effectiveness of the method.

5. Conclusion
This thesis focuses on the path planning of static obstacles in the binocular stereo vision system in indoor environments. The system mainly includes: binocular camera image acquisition and parameter calibration, image feature extraction and stereo matching, real-time dynamic obstacle avoidance strategy formulation. It can be applied in fields such as unmanned driving, logistics distribution, security and safety, to promote the development and progress of society.

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