Research on Azimuth Measurement Method of CCD Camera Based on Computer 3D Vision System

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Abstract. In the field of artificial intelligence (AI), three-dimensional (3D) vision system is increasingly used to obtain 3D information of targets. In this paper, a method for measuring the azimuth of CCD camera's apparent axis with high precision applied to 3D vision system is proposed. The azimuth angle of the apparent axis of CCD camera can be easily and accurately measured by using the laser projection transfer method through the horizontal two-dimensional turntable and the linear laser, which provides a method for 3D vision system calibration. This paper introduced the principle of measuring angles of the system, deduced the equation of coordinate transformation of the system, and made systematic error analysis. The results show that the measurement accuracy and reliability of this method meet the needs of 3D vision system calibration, which is much higher than the measurement accuracy and stability of geomagnetic sensors.

Keywords: Artificial intelligence · Three-dimensional vision system · CCD camera · Azimuth measurement

1 Introduction

Since the 21st century, artificial intelligence technology has developed rapidly and has been widely used in medical treatment, security, autopilot, robotics, industrial intelligent manufacturing [1] and other fields. Computer vision [2], as an important branch of artificial intelligence technology, automatically receives and processes the image of a real object through optical devices and non-contact sensors, to obtain the required information or devices for controlling robot or mechanical movement. As one of the hot topics in the field of computer vision, 3D vision system is an important means of 3D perception and measurement of complex environment. Compared with traditional 2D vision system, 3D vision system can perceive and measure shapes-related features, such as object flatness, surface area and volume, etc. 3D vision systems are generally divided into three categories: binocular vision system [3], structured light system [4], and time of flight (TOF) system [5].

CCD camera is the core sensor of binocular vision system and structural light system. The azimuth of CCD camera has a decisive influence on the measurement

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precision of the whole 3D vision system. Therefore, accurate measurement of the azimuth angle of the camera's visual axis can effectively reduce the installation error of the camera's azimuth axis and improve the measurement accuracy of 3D vision system. There are mainly two methods in azimuth measurement: geomagnetic sensor measurement and dual-antenna GPS measurement. Geomagnetic sensor is widely used (such as the traditional compass), but it is greatly affected by the magnetic environment and cannot work normally in some occasions. Dual-antenna GPS needs to measure the position information of the two antennas respectively, and then calculate the azimuth information of the baseline, but it cannot be used because the indoor GPS signal quality does not meet the requirements. In addition, the system takes up a large space (about 2 m of the baseline length). In response to the above needs and problems, this paper presents a method to measure the azimuth angle of light source optical axis or camera optical axis in the room by laser projection method, and carries out precision analysis and test. This paper proposes a method for measuring the azimuth of the apparent axis of CCD camera, which is applied to 3D vision system with high precision. The azimuth of the apparent axis of CCD camera can be easily and accurately measured by using the laser projection transfer method with the cooperation of the horizontal 2D turntable and the linear laser.

2 Angle Measurement Principle

In order to accurate measurement and calibration the azimuth angle of machine vision CCD, laser projection transfer method is used in this paper (see Fig. 1).

First of all, the base of the 2D turntable is fixed above the reference object, and the linear laser A is fixed on the pitch axis of the turntable, which requires to be perpendicular to the azimuth axis of the turntable. The projection plane A on which the laser from the linear laser A located is parallel to the pitch axis of the turntable. The linear laser A select the 532 nm semiconductor laser.

Secondly, the CCD mounting plate is fixed on the tripod. The CCD and linear laser B is fixed on the CCD mounting plate. It is required that the projection plane B where the laser from linear laser B located is parallel to the CCD visual axis, and the linear laser B select the 650 nm semiconductor laser.

Thirdly, set up the tripod to ensure the level of the cloud platform. Turn on the linear laser A, and generate a red light on the horizontal ground, that is the projection line A of plane A on the horizontal ground. Turn on the linear laser B, and a green light is generated on the horizontal ground, that is the projection line B of plane B on the horizontal ground.

Finally, adjust the azimuth axis of the turntable to make the projection line B (green light) parallel to the projection line A (red light); Adjust the pitch axis of the turntable to make the projection line A coincide with the projection line B. In this case, the angle value output by the azimuth axis angle encoder of the turntable is the azimuth angle of the CCD visual axis.

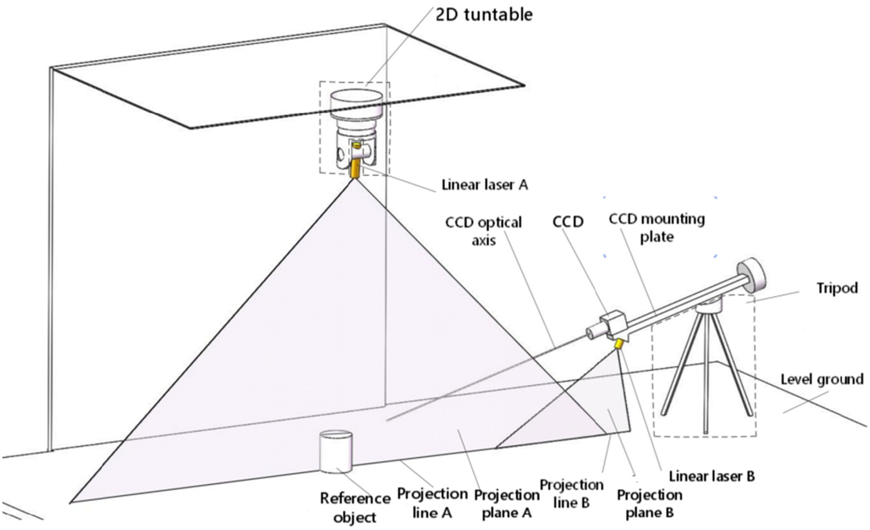

Fig. 1. System diagram.

3 Transformation of Coordinates

Let the coordinate system of the 2D turntable be $OX_1Y_1Z_1$, and the turntable be hung upside down in the room. $OX_3Y_3Z_3$ is the CCD coordinate system. In order to realize the transformation from 2D rotary coordinate system to CCD coordinate system, the transition coordinate system is established. The coordinate system definition is shown in the Fig. 2.

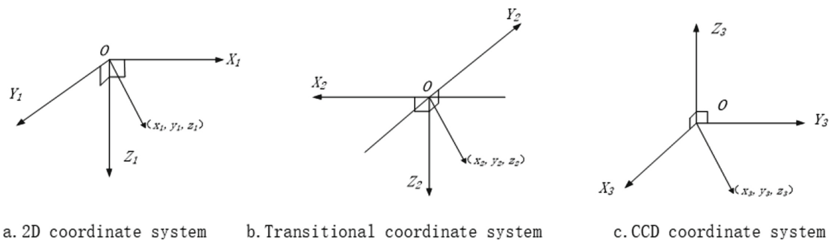

Fig. 2. Transformation coordinate system.

The vector measured by the 2D turntable needs to be converted to the CCD coordinate system through multiple coordinate transformations to obtain the azimuth Angle parameters for CCD modeling. Suppose the coordinate of the particle in $OX_1Y_1Z_1$ is (x_1, y_1, z_1), rotate 180° about the z_1 axis to obtain the coordinate system

$OX_2Y_2Z_2$, which is (x_2, y_2, z_2), and then rotate 180° about the y_2 axis to obtain the coordinate system $OX_3Y_3Z_3$ and the coordinate of the particle is (x_3, y_3, z_3).The coordinate transformation matrix model is established.

$$\begin{cases} x_2 = x_1 C_{x_2x_1} + y_1 C_{x_2y_1} + z_1 C_{x_2z_1} \\ y_2 = x_1 C_{y_2x_1} + y_1 C_{y_2y_1} + z_1 C_{y_2z_1} \\ z_2 = x_1 C_{z_2x_1} + y_1 C_{z_2y_1} + z_1 C_{z_2z_1} \end{cases} \tag{1}$$

Let me write it as a matrix operation.

$$\begin{matrix} x_2 \\ y_2 \\ z_2 \end{matrix} = \begin{bmatrix} C_{x_2x_1} & C_{x_2y_1} & C_{x_2z_1} \\ C_{y_2x_1} & C_{y_2y_1} & C_{y_2z_1} \\ C_{z_2x_1} & C_{z_2y_1} & C_{z_2z_1} \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} \tag{2}$$

In both formulas, C_{i1j2} (i = x, y, z; j = x, y, z) is the cosine of the projection of x1, y1, z1 onto the coordinate axis $OX_2Y_2Z_2$.

$$\mathbf{r}^2 = \begin{bmatrix} x_2 \\ y_2 \\ z_2 \end{bmatrix}, \mathbf{r}^1 = \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix}, C_1^2 \begin{bmatrix} C_{x_2x_1} & C_{x_2y_1} & C_{x_2z_1} \\ C_{y_2x_1} & C_{y_2y_1} & C_{y_2z_1} \\ C_{z_2x_1} & C_{z_2y_1} & C_{z_2z_1} \end{bmatrix} \tag{3}$$

The above equation has been simplified.

$$\mathbf{r}^2 = C_1^2 \mathbf{r}^1 \tag{4}$$

Where r_1 is the projection of the r vector onto the x_2 axis, r_1 is the projection of the r vector onto the x_1 axis. C_1^2 is the transformation direction cosine matrix.

Then the coordinate system $OX_1Y_1Z_1$ rotates about the Z axis, and the cosine conversion matrix to the direction of the coordinate system $OX_2Y_2Z_2$ is:

$$C_1^2 = \begin{bmatrix} cos\alpha & sin\alpha & 0 \\ -sin\alpha & cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{5}$$

The cosine transformation matrix in the direction of frame $OX_2Y_2Z_2$, which is rotated about the Y-axis, to frame $OX_3Y_3Z_3$ is:

$$C_2^3 = \begin{bmatrix} cos\beta & 0 & -sin\beta \\ 0 & 1 & 0 \\ sin\beta & 0 & cos\beta \end{bmatrix} \tag{5}$$

The conversion matrix from coordinate $OX_1Y_1Z_1$ to coordinate $OX_3Y_3Z_3$ is:

$$C_1^3 = C_2^3 C_1^2 \tag{6}$$

Let r^3 be the final converted vector of the coordinate system $OX_3Y_3Z_3$, and the coordinate transformation equation is obtained.

$$r^3 = C_1^3 r^1 \tag{7}$$

Substitute in the rotation Angle, which is represented by matrix operation.

$$\begin{bmatrix} x_3 \\ y_3 \\ z_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} \tag{8}$$

Arrange to get:

$$\begin{bmatrix} x_3 \\ y_3 \\ z_3 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} x_1 \\ y_1 \\ z_1 \end{bmatrix} = \begin{bmatrix} x_1 \\ -y_1 \\ -z_1 \end{bmatrix} \tag{9}$$

After deriving the coordinate transformation, the azimuth and the pitch Angle are respectively:

$$\alpha = -\mathrm{arctan}\frac{x_1}{y_1} \tag{10}$$

$$\beta = -arctan\frac{z_1}{\sqrt[2]{x_1^2 + y_1^2}} \tag{11}$$

4 Error Analysis

4.1 Installation Error

If the azimuth axis deflects α angle around the X axis, the angle error of projection on the XOY plane was analyzed.

According to the parametric equation of the circle in the space coordinate system:

$$\begin{cases} x(\theta) = c_x + r(a_x cos\theta + b_x sin\theta) \\ y(\theta) = c_y + r(a_y cos\theta + b_y sin\theta) \\ z(\theta) = c_z + r(a_z cos\theta + b_z sin\theta) \end{cases} \tag{12}$$

Where, C(c_x, c_y, c_z) is the center of the circle, r is the radius of the circle, vector $a = (a_x, a_y, a_z)$ and vector $b = (b_x, b_y, b_z)$ are orthogonal unit vectors on the plane of the circle.

To simplify the calculation, considering that the center of the circle $C(c_x, c_y, c_z)$ is the origin of coordinates $(0, 0, 0)$, the radius $r = 1$. Let's think about the rotation angle α of the circle $x^2 + y^2 = 1$ around the X-axis, so the normal vector $n = (0, -\sin\alpha, \cos\alpha)$ of the circle, the two orthogonal vectors perpendicular to the normal vector can be expressed as vector $a = (1, 0, 0)$ and vector $b = (0, cos\alpha, \sin\alpha)$. Therefore, the circle considered here is shown in Fig. 3. The parametric equation is specifically expressed as:

$$\begin{cases} x(\theta) = cos\theta \\ y(\theta) = cos\alpha \cdot sin\theta \\ z(\theta) = \sin\alpha \cdot sin\theta \end{cases} \tag{13}$$

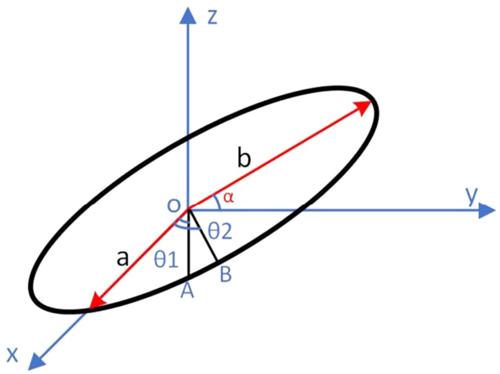

Fig. 3. Azimuth axis installation error model.

The initial angle θ_1 is defined as the included angle between the initial measurement angle pointing ($\overrightarrow{OA}$) and the rotation axis (X axis) of the installation rotation error angle α, and the measurement angle θ_2 is defined as the included angle between the secondary measurement angle pointing ($\overrightarrow{OB}$) and the rotation axis (X axis) of the installation rotation error angle α. Therefore, the coordinates of point A can be expressed as $A(\cos\theta_1, \cos\alpha\sin\theta_1, \sin\alpha \cdot \sin\theta_1)$, the coordinates of point B as $B(cos\theta_2, \cos\alpha\sin\theta_2, \sin\alpha \bullet sin\theta_2)$, and the projection of points A and B on the XOY plane as $A'(cos\theta_1, \cos\alpha\sin\theta_1, 0)$ and $B'(cos\theta_2, \cos\alpha\sin\theta_2, 0)$. According to the included angle formula of vectors, the included angle of vector $\overrightarrow{OA}$ and $\overrightarrow{OB}$ is $\varphi = \cos^{-1}\left(\frac{\overrightarrow{OA} \cdot \overrightarrow{OB}}{\left|\overrightarrow{OA}\right| \cdot \left|\overrightarrow{OB}\right|}\right) = \theta_2 - \theta_1$, and the included Angle of vector $\overrightarrow{OA'}$ and $\overrightarrow{OB'}$ is φ', which can be expressed as:

$$
\begin{aligned}
\varphi' &= \cos^{-1}\left(\frac{\overrightarrow{OA'}\cdot\overrightarrow{OB'}}{\left|\overrightarrow{OA'}\right|\cdot\left|\overrightarrow{OB'}\right|}\right) \\
&= \cos^{-1}\left[\frac{cos\theta_1 cos\theta_2 + (\cos\alpha)^2\sin\theta_1\sin\theta_2}{\sqrt{(cos\theta_1)^2 + (\cos\alpha)^2(\sin\theta_1)^2}\cdot\sqrt{(cos\theta_2)^2 + (\cos\alpha)^2(\sin\theta_2)^2}}\right]
\end{aligned}
\tag{14}
$$

Based on the above error model, when $\alpha = 1$ mrad, the initial angle $\theta_1 \in (0, \pi)$ and the code rotation $\varphi \in (0, \pi)$, the value range of angle measurement error was analyzed. The numerical analysis results are shown as Fig. 4.

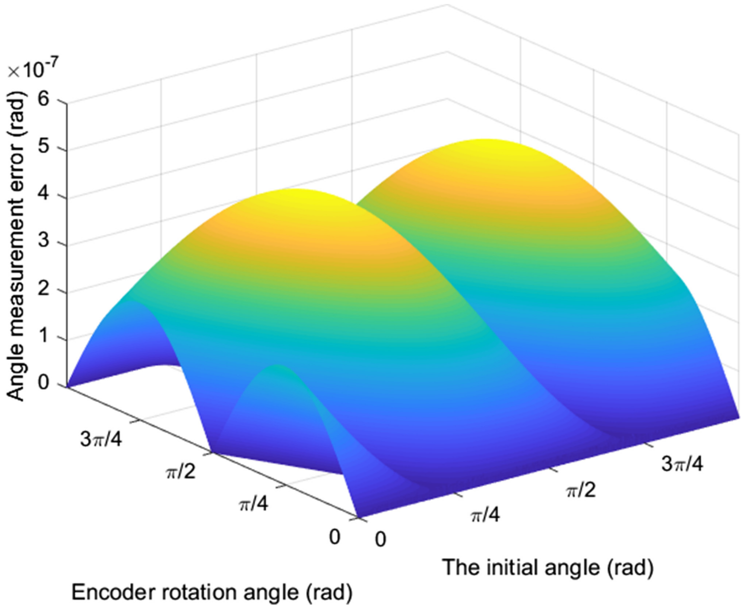

Fig. 4. Angle measurement error analysis.

When there is 1mrad installation error in the azimuth axis and horizontal plane of the turntable, the actual angular measurement error is between 0 μrad to 0.5 μrad. When the initial azimuth angle was $\pi/4$ or $3\pi/4$ and the azimuth displacement was $\pi/2$, the angular error δ_1 was the maximum, with a maximum of 0.5 rad.

Analyze the relationship between the maximum error value of angle measurement 1 mad and the installation error Angle under the conditions of 1 mard–100 mrad, and the results are shown in Fig. 5.

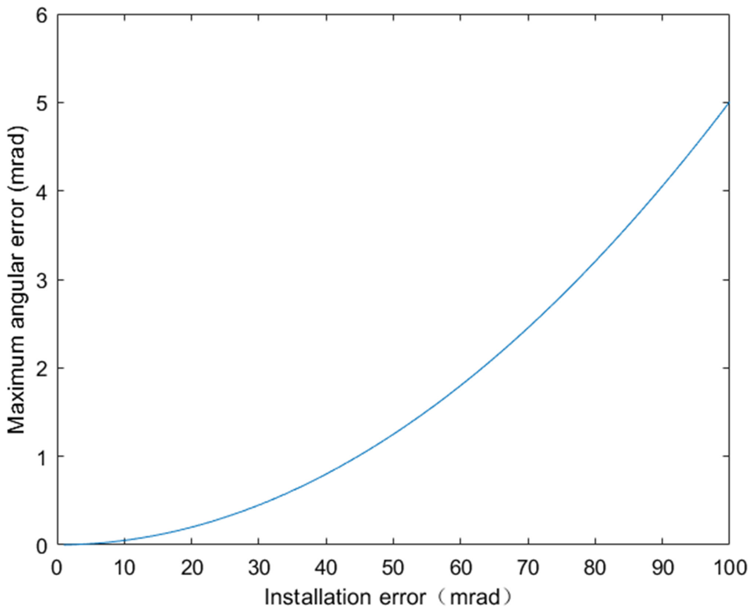

Fig. 5. Relationship between maximum Angle measurement error and installation error.

4.2 Measurement Error

It is assumed that the linear laser projection on the turntable is L_1, the linear laser projection on the CCD is L_2, the coincidence part is L_3, and the Angle between L_1 and L_2 is α.

Let the human eye resolution be a, and it can be seen from the Fig. 6 that the included Angle between L_1 and L_2 is the measurement error Angle of line projection.

$$\delta = 2tan^{-1}\frac{a}{L_3} \tag{15}$$

According to Rayleigh criterion, the resolution limit Angle of human eyes is:

$$\theta = 1.22 \cdot \frac{\lambda}{D} \tag{16}$$

Where D is the pupil size of the human eye, and λ is the working wavelength of light. When D = 3 mm, then the limit resolution Angle of human eyes θ is 0.264 mrad. Therefore, when the observation distance is 0.5 m, the human eye resolution limit distance B is 0.132 mm. In this paper, we take the human eye resolution distance A under normal conditions as:

$$a = n \cdot b(n = 1.5) = 0.198 \approx 0.2\,\text{mm} \tag{17}$$

Based on the above error model, the human eye resolution a is 0.2 mm respectively, and the curve of coincidence length L3 and measurement error Angle δ is established as Fig. 6.

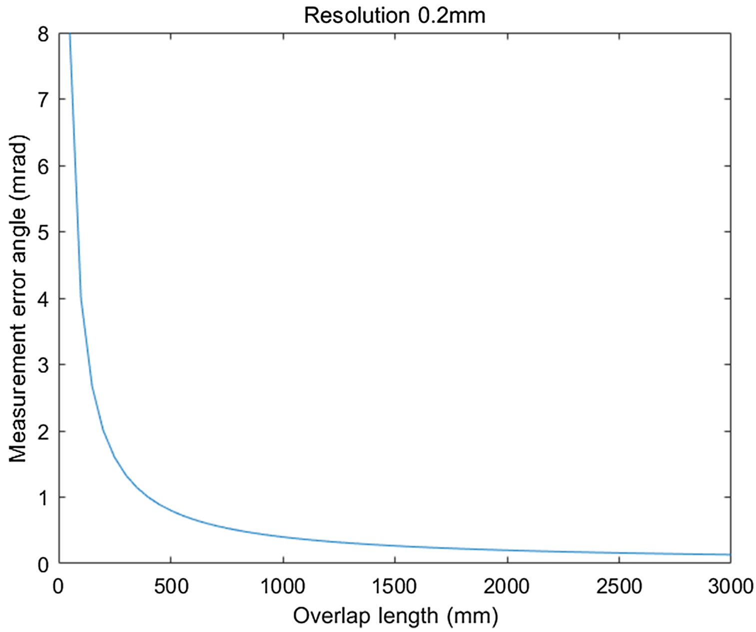

Fig. 6. Measurement error angle.

It can be concluded that the measurement error angle decreases with the increase of coincidence length and resolution. When the human eye resolution is 0.2 mm and coincidence length is 3 m, the error angle δ is 0.13 mrad. Therefore, the thinner the projection line, the clearer the boundary, the more obvious the contrast, the larger the coincidence area, and the smaller the measurement error angle.

5 Conclusion

In this paper, the linear laser alignment measurement method is applied to the 3D vision system, the projection characteristics and measurement methods of the two-dimensional platform are systematically analyzed, and the measurement mathematical model is obtained through coordinate transformation. Of two-dimensional horizontal rotary table with CCD camera produces in the process of laser projection alignment error factors are analyzed and the simulation, the main error is divided into the installation error and measurement error, the overall error is less than 0.13 mrad, the device has simple and reliable, the advantages of high precision and reliability, to improve the measurement precision of 3D-vision system has important significance.

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