Human Acupoint Positioning System Based on Binocular Vision

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Abstract. To realize accurate positioning and recognition of human acupoints in medical treatment, the automatic human acupoints recognition system based on computer binocular vision technology is considered by us. We studied a camera calibration method by plane calibration lattice. To verify and accurately locate human acupoints in medical treatment, the method adopted the principle of binocular vision technology to collect different images of human body limbs to obtain three-dimensional coordinates of space, and the positioning errors of each marker point measured by binocular vision calculation and three-dimensional coordinate measuring instrument are compared. The results show that the system can assist medical personnel to complete the human acupoints recognition and positioning, and respond to the needs of the clinical application.

1. Introduction

As a traditional medical method, acupuncture and moxibustion are widely used in the treatment of various diseases. However, this type of treatment requires a relatively high level of skills and experience of the practitioners, which are mainly reflected in the accuracy of acupoint positioning. The acupoint localization method by the same body size given in homeopathic books mainly depends on the doctor's experience, which is relatively difficult to implement. According to the investigation, at present, all hospitals are still treating patients with various methods of artificial acupuncture and moxibustion by experienced traditional Chinese medicine doctors, they need to pay a lot of physical labour, so it is of great practical value to develop automatic acupoint detection locator which can replace traditional Chinese medicine in clinical application.

At present, stereo vision products used for navigation and positioning in medical surgery mainly include Clarion Technology Inc's active visible light optical locator (¹)(MT) and Canada's Northern Digital Inc's Passive Polaris Spectra (²)(PPS), as well as the Stealthstation Tria TM Plus(STP) operation navigation system of Medtronic Inc (³). There are also some instruments simulating massage manipulation in the market, such as various massagers and massage chairs that use electromagnetic force to vibrate. However, there is still a shortage of instruments that can detect and locate acupoints by machines instead of human beings.

This paper proposes an acupoint locator based on binocular vision (⁴), which can illuminate the accurate positioning of human acupoints. The working process of the working system of the locator is to conduct target positioning and stereo calibration based on the principle of computer binocular vision technology. After camera calibration, different images of human limbs are collected by obtaining data of the registration point to obtain three-dimensional coordinates. Finally, the accurate positioning method of human acupoints is realized.
2. System composition
As shown in Figure 1, the binocular vision acupoint locator system consists of the support frame 3, camera 2, calibration plate 4, computer 5 and infrared transmitter 6. Camera 2 consists of left and right parts, the two cameras are located on the left and right ends of the support frame and are connected by a drive universal hinge. The camera can adjust the shooting angle and position freely with the driver control. Camera 2 is connected to the computer 5. The support frame 3 is a gantry structure that can be moved freely according to clinical requirements.

3. Systematic measurement process
The measurement process of the system is as follows: As shown in figure 2, a planar checkerboard camera calibration method is adopted for the camera, through which the internal and external parameters of the camera are obtained. Then, using the Roberts gradient operator to segment the image, identify the center of the marker and calculate its three-dimensional coordinates; Finally, position verification is carried out by comparing the position deviation of each mark point measured by binocular vision measurement and three-dimensional coordinate measurement instrument. Through the above method to achieve accurate positioning of the target position.

As shown in Figure 3, using a parallel binocular vision model. The internal parameters of the two cameras are equal. They are parallel to each other along the axis of light, and the distance along the X axis is l. As shown in Figure 4, the principle of parallel binocular vision measurement was adopted. Where the C1 coordinate system isO1x1y1z1, The C2 coordinate system isO2x2y2z2, If the coordinates of the space point P are in the C1 coordinate system is(x1,y1,z1), Then in the C2 coordinate system is(x1-1,y1,z1). Therefore, according to its geometric relationship, the coordinate value of the point can be solved as

\[ x_1 = \frac{l(u_1-u_0)}{u_1-u_2}, \]
\[ y_1 = \frac{l\alpha_x (v_1-v_0)}{\alpha_y (u_1-u_2)}, \]
\[ z_1 = \frac{l\alpha_z}{u_1-u_2}, \]

Equations \( u_0, v_0, \alpha_x \) are the internal parameters of the camera. \( (u_1,v_1) \) and \( (u_2,v_2) \) image coordinates of P1 and P2 respectively. So by P1 and P2 image coordinates \( (u_1,v_1) \) and \( (u_2,v_2) \), The three-dimensional coordinate \( (x_1,y_1,z_1) \) of the spatial point P can be solved.
4. Camera installation and calibration

4.1. Camera installation
The two cameras are mounted on the gantry support by a universal hinge. The angle and position of the camera are adjusted by controlling the angle of the universal hinge. The image information captured by the camera is transmitted back to the computer through the acquisition card.

4.2. Camera calibration
The solution idea of camera calibration parameter\(^5\) by the calibration principle of zhang zhengyou's calibration method\(^6\) as follows: Set the coordinates of the 3D point on the plane of the checkerboard to \(Q = [x, y, z]^T\). The coordinate of the two-dimensional point on the image plane is \(sq = [u, v]^T\). The corresponding homogeneous coordinates are \(\hat{Q} = [x, y, z, 1]^T\) and \(\hat{q} = [u, v, 1]^T\): Since the camera imaging model uses a small hole imaging model, the relationship between image point \(q\) and target space point \(Q\) is expressed by:

\[
s\hat{q} = M_1[R, t]\hat{Q}
\]

(1)

\(s\) is an arbitrary non-zero constant factor. \(M_1\) is the camera's internal parameter matrix, then:

\[
M_1 = \begin{bmatrix}
\alpha_x & r & u_0 \\
0 & \alpha_y & v_0 \\
0 & 0 & 1
\end{bmatrix}
\]

(2)

The coordinates of the main point of the image in the inner parameter matrix \(M_1\) are \((u_0, v_0)\), the parameters \(\alpha_x\) and \(\alpha_y\) are the scale factors of the u-axis and the v-axis of the image pixel coordinate, respectively, and \(r\) is the non-vertical factor between the two coordinate axes; Let \(z = 0\), that is, the target plane is located on the XY plane of the world coordinate system. The ith column of the rotation matrix \(R\) is \(r_i\), and the equation (1) has:

\[
s\hat{q} = H\hat{Z}
\]

(3)

Let \(Z\) denote the point on the target plane, then \(Z = [x, y]^T\). \(\hat{Z} = [x, y, 1]^T\), there is a transformation matrix \(H\) between the point \(Z\) on the target plane and the corresponding image point \(m\):

\[
s\hat{q} = H\hat{Z}
\]

(4)

Type in the \(H = \lambda M_1[r_1, r_2, t]\) is a 3 × 3 matrix and is a constant factor. Order, there are:

\[
\begin{bmatrix}
h_1 \\
h_2 \\
h_3
\end{bmatrix} = \lambda M_1[r_1, r_2, t]
\]

(5)

t is the translation vector. \(r_1, r_2\) is the direction vector of the two coordinate axes in the world coordinate system on the image plane, \(t\) is not located on the plane formed by \(r_1\) and \(r_2\) since \(r_1\) and \(r_2\) are orthogonal, therefore \(\det([r_1, r_2, t]) \neq 0\). And because of \(\det([M_1]) \neq 0\), so \(\det[H] \neq 0\).

The method of solving the transformation matrix \(H\) is to minimize the parameter difference between the actual image coordinates \(q_i\) and the calculated image coordinates, and the objective function is as follows:

\[
\min \sum \|q_i - \hat{q}_i\|^2
\]

(6)

After solving the transformation matrix \(H\), from the orthogonality of the equation (5) and the rotation matrix \(R\), two basic equations are obtained:

\[
\begin{align*}
h_1^TM_1^TM_1^{-1}h_2 &= 0 \\
h_1^TM_1^TM_1^{-1}h_1 &= h_2^TM_1^TM_1^{-1}h_2
\end{align*}
\]

(7)

Equation (7) is an important constraint on the parameter matrix within the camera. Since a rotation matrix contains 8 degrees of freedom, it contains 3 rotation parameters and 3 translation parameters.

For a quadric surface in three-dimensional space, it is represented by \(x^TBx = 0\), where \(x = (x, y, z, 1)^T\), \(B\) is a 4×4 symmetric matrix. Obviously, multiplying the symmetric matrix \(B\) by any
non-zero scalar still describes the same quadric. Similarly, a quadratic curve on a plane is represented by $\tilde{x}^T B \tilde{x} = 0$, where $\tilde{x} = (x, y, z, 1)^T$. B is a 3x3 symmetric matrix. The projection of the spatial absolute quadratic curve on the image plane is indicated by $M_1^{-1} T M_1^{-1}$. Order:

$$B = M_1^{-T} M_1^{-1} = \begin{pmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{pmatrix} = \begin{bmatrix} \frac{1}{a_x^2} & -\frac{r}{a_x^2 a_y} & \frac{v_{0r} - u_0 a_y}{a_x^2 a_y} \\ -\frac{r}{a_x^2 a_y} & \frac{1}{a_y^2} - \frac{v_{0r} - u_0 a_y}{a_x^2 a_y} & \frac{v_{0r} - u_0 a_y}{a_x^2 a_y} \\ \frac{v_{0r} - u_0 a_y}{a_x^2 a_y} & \frac{v_{0r} - u_0 a_y}{a_x^2 a_y} & 1 \end{bmatrix}$$

(8)

Since the matrix B is a symmetric matrix, it is represented by the following six-dimensional vector:

$$b = [B_{11}, B_{12}, B_{13}, B_{22}, B_{23}, B_{33}]^T$$

(9)

Assume that the i column vector in the transformation matrix H is $h_i = [h_{i1}, h_{i2}, h_{i3}]$, for which:

$$h_i^T B h_i = v_{ij}^T b$$

(10)

In the formula:

$$v_{ij} = [h_{i1} h_{i1}, h_{i1} h_{i1} + h_{i2} h_{i2}, h_{i3} h_{i1} + h_{i1} h_{i3}, h_{i2} h_{i3}, h_{i3} h_{i2}, h_{i3} h_{i3}]$$

(11)

Therefore, the equation (7) is expressed in the form of a homogeneous equation as follows:

$$\begin{bmatrix} v_{i1} \\ v_{i2} \\ (v_{i1} - v_{i2})^T \end{bmatrix} b = 0$$

(12)

Collect n target images, list n equations, then:

$$V_b = 0$$

(13)

In the above formula, V is a matrix of $2n \times 6$. Assuming $n \geq 3$, b solves a unique value. Assuming $n = 2$, plus an additional constraint of $\gamma = 0$. That is B12=0. To this end, 1 is taken as an additional condition of the formula (13). The eigenvector corresponding to the minimum eigenvalue of matrix 2 is the solution of equation (13), or the matrix V is decomposed by singular value decomposition SVD method to find b.

After solving b, the matrix is solved based on the Cholesky matrix decomposition algorithm, and then $M_1$ is obtained by inversion. After finding $M_1$, the outer parameters of each image are obtained. From equation (5):

$$\begin{align*}
    r_1 &= \lambda M_1^{-1} h_1 \\
    r_2 &= \lambda M_1^{-1} h_2 \\
    r_3 &= r_1 \times r_2 \\
    t &= \lambda M_1^{-1} h_3
\end{align*}$$

(14)

In the formula $\lambda = 1/\|M_1^{-1} h_1\| = 1/\|M_1^{-1} h_2\|$.

The distortion of the camera lens cannot be eliminated. To this end, external parameters solved by equation (14) are used as the initial values of the optimized search, and then all accurate parameter values are solved, and the camera calibration is completed. The basic process is shown in Figure 5.

4.3. Image acquisition

Triangulation is used to obtain 3D spatial information when two cameras shoot the same object from the same horizontal position and different angles. Images of the thumb and middle finger of the body and local images of the limbs requiring acupuncture were collected by the camera. The computer...
preprocesses the image taken by the camera to eliminate other interference and then extracts the feature points. Combining the internal and external parameters of the camera, the computer performs feature template matching. To obtain the size of a thumb and middle finger as well as the spatial coordinates of limbs requiring acupuncture and moxibustion, the data of matched templates was obtained by matching algorithm and perspective transformation.

4.4. Target location
According to the traditional Chinese medicine acupuncture point application of the thumb with the body inch and middle finger with the body inch method, the human body is divided into the following parts: head, back, chest and abdomen, upper limbs and lower limbs. Each acupoint of the human body is based on an organ or a characteristic part of the body. The body parts of the four limbs are measured by the thumb one-inch method, that is, the width of the patient's thumb knuckles is taken as an inch to measure the acupoints. Other parts of the body with the middle finger inch method that is the middle finger flexion in the patient's middle finger between the two sections of the inner finger of the horizontal striated head distance as an inch to measure the acupoint; in order to achieve the accurate positioning of acupoints, accurate spatial coordinates of acupoints are obtained from the collected images by the computer calculation and processing. Then the computer sends out the instruction to drive the infrared transmitter to illuminate the human body surface corresponding acupuncture point position.

5. Conclusion
According to the need of acupoint recognition and localization in TCM treatment, this paper proposes an acupoint locator by binocular vision. In the article, the composition, principle and working process of the binocular vision system are analyzed in detail. The application of camera model and theory and binocular vision system in acupoint recognition and localization has been described. The camera calibration method based on the combination of plane checkerboard, and the identification of the center point of the marker and the calculation of 3d coordinates are studied. By analyzing the technical characteristics of binocular vision, the collected images are obtained, and the rapid and low-error identification and positioning of human acupoints are finally realized, which has important application value for the positioning of acupoints in medicine.

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