Research on Laser Positioning Technology of CMOS Triangulation for Precision Surgery

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Abstract

Traditional surgery relies on doctors' experience and human factors.In order to improve the accuracy of operation, this article selected laser as a way to achieve accurate positioning, using the principle of optical triangulation, using the three coordinate measuring arm, using the CMOS sensor, set up an embedded system to obtain and track accurate positioning, in order to help the precise implementation of surgery, based on the principle of optical triangulation, By identifying the lens to collect the reflected light from the object and projecting it to a two-dimensional CMOS array, the profile of the target object is analyzed and processed by the signal processor, and the displacement of the target is measured by detecting the change of the position of the light receiving. Finally, the prototype experiment system is designed, after repeated experiments and calculations. The method is adjusted and the repetition precision is controlled in the 0.3mm.

Keywords

Precision surgery; CMOS sensor; Optical triangulation principle; Embedded system.

1. Introduction

The traditional surgery depends on the experience of the doctor. There are many factors affecting the operation. The operation is easy to cause the patient's knife mouth to be too large and the recovery time is long after the operation. There is a large risk[1, 2]. Precision surgery emphasizes the integration and optimization of modern technology and traditional surgery, focusing on building a new type of surgical mode and technology system[3,4] with low consumption, high efficiency and high quality. Surgical related equipment is a direct tool for doctors to perform operations. Accurate and real-time positioning of surgical instruments is the key to successful operation.

In 1986, Dr. Roberts[5] of the Standford medical school in the United States combined the CT image with the surgical microscope, guided the operation with ultrasonic localization, and was successful in clinical practice. Hei Brun and others use three mesh and binocular machine vision principle to use ordinary light or infrared optical imaging system to realize space positioning. The precision of this kind of positioning instrument is high, but like ultrasonic system, there is the problem of line of sight constraint. Kato has designed an electromagnetic guide, which consists of a three-dimensional magnetic field source, a magnetic field detector, a three-dimensional digital and a computer. The advantage of this device is that the magnetic field detector can be placed anywhere. There are many metal materials in the operation room that affect the distribution of the electromagnetic field. In the fusion display, the navigation system synchronously displays the surgical field seen by endoscopy with the corresponding CT or MRI photos on the screen, and the surgeon can find and deal with the focus more accurately and avoid the damage to the healthy tissue[6].

The operation navigation system establishes the relationship between the patient and the image by registration of the preoperative scanning image and the patient's actual space. In the operation, the space location system is tracked through the space positioning system in the operation, and the corresponding image information is displayed on the monitor. The registration of preoperative images and patient space is the key to the navigation system without frame stereotaxic operation, usually by post marking (Marker) on the skin tissue of the patient, but the accuracy of this method is relatively poor compared with the stereotactic system. The registration of patients and preoperative images based on surface registration can achieve high accuracy, but the registration process is more complex. Ryan can realize the registration[7] by picking up a large number of points on the surface and according to the minimum energy rule. Video calibration (video alignment)[8] and raster scan (laser scanning)[9] can also be used to achieve spatial registration.

In the study of many schemes, it is found that laser has the characteristics of good direction, high brightness, good monochromatic and good coherence, and it is widely used in the design of position tracking system[10,11]. In this paper, the laser is selected as the way to achieve accurate positioning, using the principle of optical triangulation, using the three coordinate measuring arm and using the CMOS sensor to build the embedded system to obtain and track the precise positioning.

2. Application of Optical Triangulation Principle to CMOS Sensor Integration

2.1 Principle Theory of Optical Triangulation

The basic idea of the principle of optical triangulation is to use geometric information in the light of structural light to help provide geometric information in the scene. According to the geometric relationship between the camera, the structure light and the object, the three-dimensional information of the object is determined. As shown in Figure 1, a schematic diagram of the triangle measurement is given.

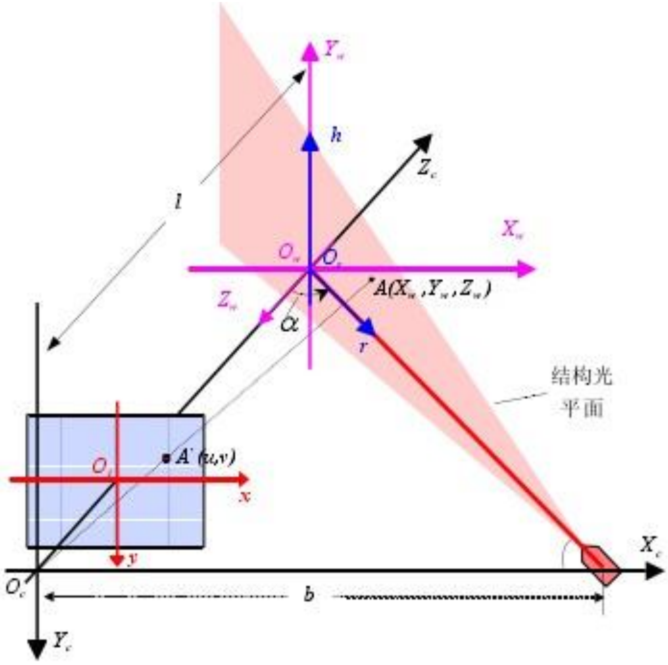


Figure 1. Schematic diagram of triangulation

The angle between the structure light plane and the camera optical axis is angle , and the origin point Ow of the world coordinate system Ow-XwYwZw is located at the intersection point of the camera optical axis and the structural light plane. The Xw axis and the Yw axis are parallel to the Xc axis and the Yc axis of the camera coordinate system, and the Zw and Zc coincide but the direction is opposite. The distance between Ow and Oc is L. The world coordinate system and the camera coordinate system have the following relations:

$$\begin{cases} X_c = X_w \\ Y_c = -Y_w \\ Z_c = l - Z_w \end{cases}$$

The image of A is A '. In the world coordinate system, the equation of line of sight OA' is:

$$\frac{X_w}{x} = -\frac{Y_w}{y} = \frac{l - Z_w}{f}$$

In the world coordinate system, the equation of the structured light plane is:

$$X_w = Z_w tg\alpha$$

Solved:

$$\begin{cases} X_w = \dfrac{xl \cdot tg\alpha}{x + f \cdot tg\alpha} \\ Y_w = \dfrac{-yl \cdot tg\alpha}{x + f \cdot tg\alpha} \\ Z_w = \dfrac{xl}{x + f \cdot tg\alpha} \end{cases}$$

Due to the definition of the right angle coordinate system Op-uv on the digital image, the coordinates of each pixel (U, V) are the number of columns and rows of the pixel in the array of images, and (U, V) is the coordinates of pixels in the digital image coordinate system. Like the physical location on the image plane, the image plane two-dimensional coordinate system Oi-xy, represented by a physical unit, is set up in parallel with the U axis and the V axis. The origin is the intersection of the camera's axis and the image plane, which is generally located in the center of the image, but in the actual case, there will be a small offset and the coordinates in the Op-uv are recorded (U0,). V0). The physical dimensions of each pixel in the direction of the X axis and the Y axis are Sx and Sy, then the coordinates of any pixel in the two coordinate system are expressed in homogeneous coordinates and matrix forms, with the following relation:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} 1/s_x & 0 & u_0 \\ 0 & 1/s_y & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

The inverse relation is:

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} s_x & 0 & -u_0 s_x \\ 0 & s_y & -v_0 s_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix}$$

The corresponding relationship between the pixel points and the world coordinate points can be obtained as follows:

$$\begin{cases} X_w = \dfrac{f_x (u - u_0) l \cdot tg\alpha}{f_x (u - u_0) + tg\alpha} \\ Y_w = \dfrac{-f_y (v - v_0) l \cdot tg\alpha}{f_x (u - u_0) + tg\alpha} \\ Z_w = \dfrac{f_x (u - u_0) l}{f_x (u - u_0) + tg\alpha} \end{cases}$$

2.2 Application Integration with CMOS Sensor

The CMOS sensor applies the measuring principle of triangulation. If the position of the object changes, the position of the light receiving on the CMOS will also change, and the displacement of the target is measured by detecting its change, as shown in Figure 2.

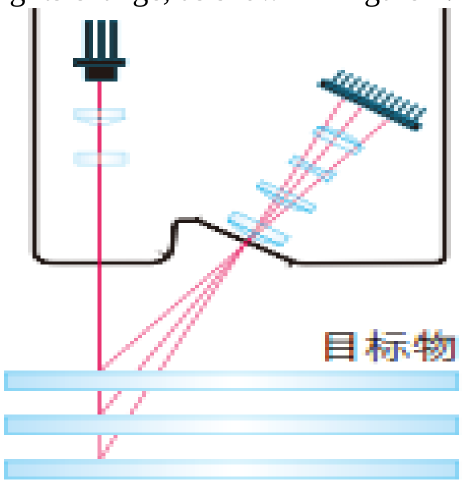


Figure 2. The principle diagram of the application of triangulation for CMOS sensor

Based on the principle of optical triangulation, the light emitted by a semiconductor laser generator is formed by a lens, forming a X plane light screen and forming a contour line on the object. The lens collects the reflected light from the object and projected it to a two-dimensional CMOS array, so the profile of the target object is analyzed and processed by the signal processor. The length of the profile is measured by X axis, and the height of the contour is measured by Z axis.

2.3 Integration of CMOS Sensor Module and Embedded System Platform

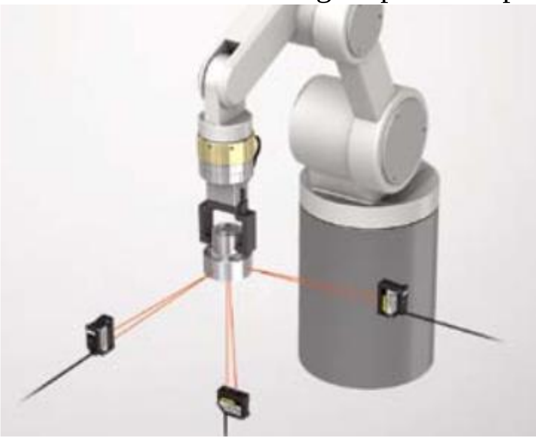
The working principle of the CMOS sensor is to irradiate the pixel array through external light, which produces photoelectric effect and generates corresponding charges in the pixel unit. The row selection logic unit selects the corresponding row pixel unit as required. The image signal in the row pixel unit is transmitted to the corresponding analog signal processing unit and the A/D converter through the signal bus of the respective column, and converted into the digital image signal output. The row selection logic unit can scan the pixel array one by one or interlacing it. The combination of row selection logic unit and column selection logic unit can realize the window extraction function of the image. The main function of the analog signal processing unit is to amplify the signal and improve the signal to noise ratio. In addition, in order to obtain a quality practical camera, the chip must contain various control circuits, such as exposure time control, automatic gain control and so on. In order to make each part of the chip operate according to the prescribed beat, multiple timing control signals must be used. In order to facilitate the application of the camera, it also requires the chip to output some timing signals, such as synchronous signal, line start signal and field start signal.

On the CMOS sensor chip, the digital signal processing circuit is integrated, including AD converter, automatic exposure control, non-uniform compensation, white balance processing, black level control, gamma correction and so on. In order to carry out the fast calculation, the DSP devices with programmable functions are integrated with CMOS devices to form a single chip digital camera and image processing system. Using USB, serial port and other communication protocols, the embedded system platform can be directly connected to the CMOS sensor module for application.

The embedded system is used to connect the CMOS sensor module, the laser emission source module and so on. According to the triangulation principle, the precision positioning experiment is carried out, and the repetition precision can be kept in the 0.3mm.

3. Prototype

As shown in Figure 3, the design algorithm is based on embedded platform integration, synthesis, operation of X, Y, Z three axis CMOS sensor detection data to precisely locate. Repetitive precision is controlled in 0.3mm through repeated experiments and improvements.



(a) Prototype experiment system

(b) Prototype equipment applied to surgical navigation system

Figure 3. prototype equipment

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