INTELLIGENT TWO-AXIS DUAL-CCD IMAGE-SERVO SHOOTING PLATFORM DESIGN

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Abstract

In this research, we propose a two-axis dual-CCD image-servo shooting platform as a development principal basis, which adopts dynamic target tracking method and image processing technique to search, detect and identify the intruding target and execute a continuous tracking action. Herein, we use the architecture of dual-CCD cameras as the basis of the stereo vision construction to find the actual 3D spatial coordinate of target through eliminating the radial and horizontal offsets of camera by using camera calibration technique. Based on the geometric relation and the pixel difference between the dual-CCD images, we can calculate the precise spatial coordinate of target in the dual-CCD coordinate. From the experimental results, the precision of target hitting in dynamic target tracking mode can be promoted to 5mm.

Keywords: *Dynamic Tracking, 3D Spatial Positioning, Image Servo Shooting Platform*

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1. INTRODUCTION

Due to the high cost of the shooting range buildup, it is not adequate to financial effect obviously for the important modern shooting training. On the other hand, dynamic image processing and intelligent control technologies grow rapidly. If these technologies can be applied to build a fully intelligent and automatic training simulator, then we can realize all the shooting training simulation tasks to get higher economic benefit. In this research, the intelligent indoor shooting and training simulator includes three parts: intelligent target robot, smart shooting training simulator, and cloud monitoring system.

The developing objective of this platform is to setup the capabilities of target searching, locking, positioning, tracking, shooting and scoring in real time. There are four topics which we focus on as follows:

A. To design a two-axis dual-CCD image-servo platform mechanism.
B. To discuss and realize how to search and track a moving target accurately by using image processing technique.
C. To calculate 3D spatial coordinate of a moving target in real time by using two-axis dual-CCD image-servo platform system and complete the precise positioning of dynamic target.
D. To design the image servo control loop with the two-axis dual-CCD shooting platform and intelligent target robot.

2. DESIGN OF SHOOTING TRAINING SIMULATOR

This shooting training simulator includes three parts: two-axis dual-CCD image-servo shooting platform, laser shooting module, real-time monitoring.

Two-axis dual-CCD image-servo platform is equipped with two cameras and two servo motors. Two cameras are used as a major external feedback sensor which can provide continuous image information to image processing module for target identification, locking, positioning and tracking tasks in real time.

Two-axis servo motors are driven by axis servo controller SSC-32, which controls the two-axis rotations. As the target is locked and positioned in the image plane, the platform system will be driven to align, track and shoot to the target with laser light. The results of real-time positioning and shooting will be displayed on the monitor in client side.

2.1 System Architecture

The real-time monitoring system is implemented in client side for human machine interaction. In the server side, using the image processing and positioning technique, the target coordinate (X,Y,Z) expressed in the dual-CCD coordinate system can be calculated and transformed into the rotation angles of two axes. And use the servo commands of SSC-32 servo controller [1], the shooting platform can be driven to aim to the target on the shooting line and the firing action is done.

The SSC-32 controller is operated under the SSC-32 commands of PC server through RS-232 or Bluetooth wireless module, and then the SSC-32 controller sends the corresponding PWM (Pulse Width Modulation) control signal to drive the servo motor. The overall system diagram is shown in Figure 1.

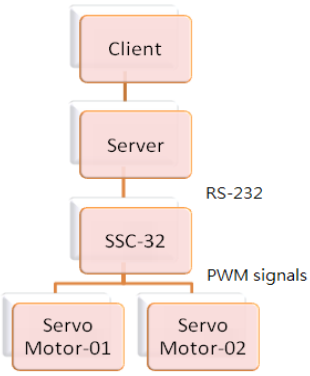

Fig 1: System architecture block diagram

2.2 Hardware Architecture

From Figure 2, we know that the shooting platform includes two servo motors for the driving of azimuth angle and elevation angle and two CCD cameras for the positioning of target. Based on two-axis rotations, we can rotate the platform to aim at the target and then emit the laser light. Laser emitting module is installed on the central point of the left-right camera axis.

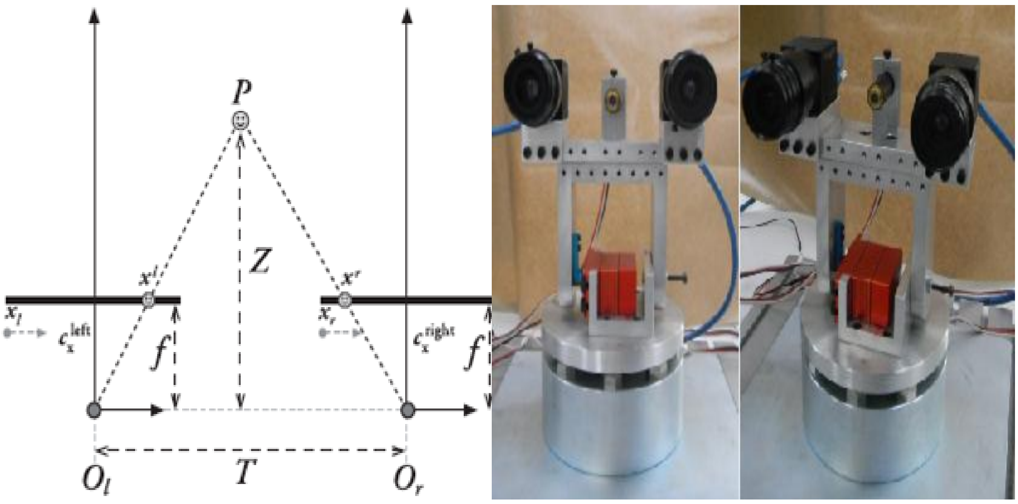

Fig 2: Geometry relation for dual cameras and two-axis shooting platform

2.3 Software Architecture

Software is developed by using Microsoft's C# programming, which is the main development platform based on .NET framework, a high-level object-oriented programming language. In this research, we use EMGU CV [3, 4] as the principal image capture and processing tool.

As the above statement, we use the Lynx motion SSC-32 servo controller, which provides a RS232 port and Bluetooth wireless transmission module. This controller can control up to 32 axes servo motors and promoted to the highest resolution of 1us. In this research, the serial communication baud rate is set to 115200 and the required PWM (Pulse Width Modulation) command is sent to control the servo motor.

3. ARCHITECTURE OF TRACKING AND RECOGNIZING SYSTEM

In this study, the attitude of the motor-driven platform determines the dual-CCD captured image area, and the image is transferred to PC terminal by USB 3.0 interface, after the target image is detected dynamically in PC terminal, we start to run the tracking task and calculate the target position in image space. Then we convert the spatial coordinate of target position into the corresponding two-axis rotation angles, which are the required motor-driven angles of SSC-32 servo commands. Two processes must be done in the PC side. One is dynamic image searching-tracking of target, the other is spatial coordinate positioning as shown in the following:

3.1 Dynamic Image Target Searching and Tracking

When the image is sent to the PC side, template is constructed by using Hough circle-testing method of image processing technique, and then use the template to search the target on the left image and right images until the target is searched. After the target is searched and locked, the target spatial position can be calculated and expressed in the dual-CCD coordinate system, and then the target is locked and tracked dynamically.

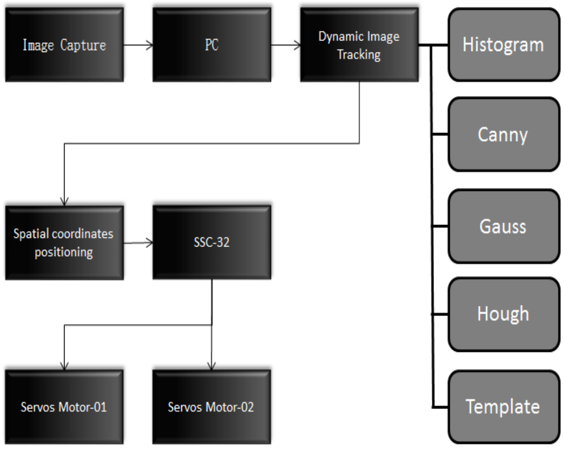

Fig 3: Target positioning and tracking flowchart

3.2 Spatial Coordinate Positioning

The coordinate of the target mass center in the left and right image planes can be calculated separately. Using the coordinates of left-right target images, the target spatial coordinate (X, Y, Z) can be constructed by geometry relation and coordinate transformation. The processing flow is shown in the above figure.

4. THEORETICAL DISCUSSION

4.1 Perspective Projection

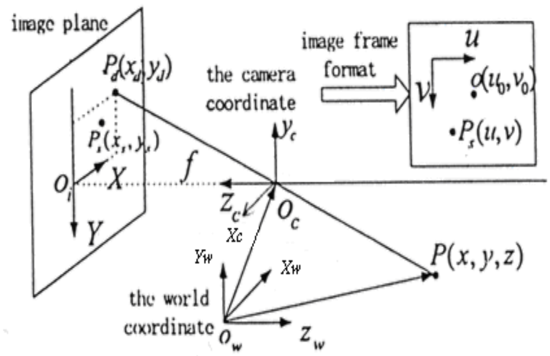

Fig 4: Perspective projection

Perspective projection is a projection which projects the object from three-dimensional (3D) camera coordinate system into two-dimensional image coordinate system. This transformation is known as the pinhole imaging principle. The projection is shown in Figure 4. The coordinate (X_c, Y_c, Z_c) is the coordinate of target point P in the 3D camera coordinate system. Where Z_c-axis is the camera optical axis, f is the focal length of the camera, (x_d, y_d) is the coordinate of target P in the image coordinate system. Assume there is no lens distortion, the relation between the screen coordinate (u, v) and the 3D camera coordinate system can be straightforwardly derived.

4.2 Spatial Positioning

The basic architecture of a 3D spatial positioning system is constructed by adopting two or more than two cameras to abstract synchronizing image information, and then using the different sight-angle projections of the same object to convert the plane image captured by individual camera to 3D image with depth information. The key point is how to construct the spatial coordinate of object for a feature-matching pair of images.

For two plane images, we can find out the corresponding feature points of the same object from the pair of images, the difference between the pixels of the feature points in the dual-CCD image planes is called disparity. It is the key to calculate the object depth for the 3D spatial positioning system.

For the coordinate (X, Y, Z) of a point in space, we can get the left and right images by using perspective projection method. The corresponding coordinates (x_1, y_1) and (x_2, y_2) in the left and right images. The 3D spatial coordinate of target can be calculated from the 3D positioning coordinate system shown in Figure 5. Where, the dual-CCD coordinate system is defined as the world coordinate system.

Using trigonometric relation, we can obtain Equation (1) from the left image plane:

$$x / z = x_1 / f \tag{1}$$

And Equation (2) can be got from the right image plane:

$$(x - L) / z = x_2 / f \tag{2}$$

L is the baseline length. Merging the two equations, we can get Equation (3).

$$z = Lf / (x_1 - x_2) = Lf / d \tag{3}$$

Where, $d = x_1 - x_2$ is disparity between the reference line, L is the distance between the parallel central axes of the two cameras, the focal length f is the focal distance of the image lens. In this system, f=12mm, L=100mm. So, the depth value z can be calculated from Equation (3).

By using translation and rotation, two homogeneous equations can be obtained through the left and right camera conversion formula. Then the 3D spatial coordinates (X_w, Y_w, Z_w) will be solved as following Equation (4).

$$X_w = \frac{L(x_1+x_2)}{2(x_1-x_2)}, Y_w = -\frac{Ly_1}{x_1-x_2} = -\frac{Ly_2}{x_1-x_2}, Z_w = \frac{fL}{x_1-x_2} \qquad (4)$$

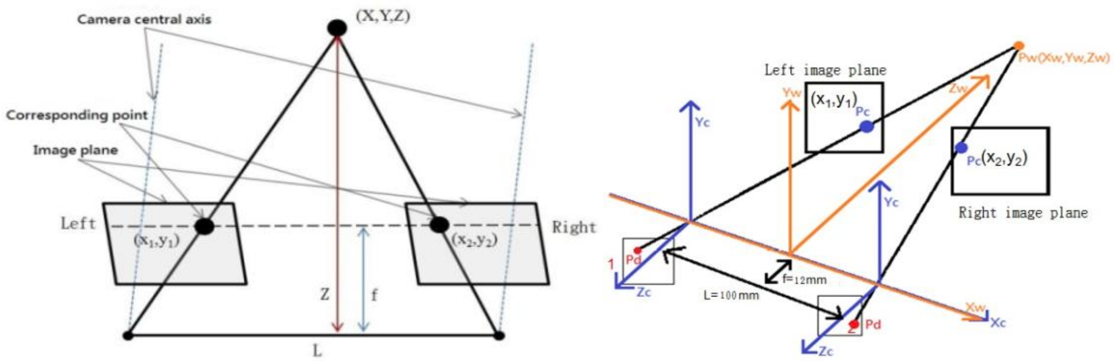

Fig 5: Schematic diagram and coordinate system of 3D positioning

4.3 Three-dimensional Positioning Parameter Correction

The central point of the camera image will produce some bias due to the lens based on the camera calibration theorem, so that the imaging central location doesn't locate in the central point of the ideal image plane. And owing to the curved lens, the light is refracted through the lens will cause image distortion, so it needs to be fixed based on the distortion value for the intrinsic parameter calculation of the spatial coordinate estimation. The intrinsic parameter correction is divided into two stages:

First stage: Fix the offset and distortion of the central point in the ideal camera image plane and the image positions of the left and right cameras.

In general, target proceeds equidistant moving, the change value of pixels in the camera image plane is fixed. But in fact there exists a distortion caused by lens, the change value of pixel coordinate in the image plane is not equal to that in the ideal case.

Therefore, for the equidistant moving, if the changed value of the ideal coordinates is divided by the change value of the actual coordinates, we can obtain a scale factor. If this scale factor is multiplied by the measured image coordinates processed through image processing, then we can adjust the measured image coordinates to that in ideal situation. In this research, we have calculated the scale factors of the left and right cameras respectively and fixed the relational bias and distortion.

When the target object is located on the central axis of the camera, the coordinate of mass center in the image plane must be zero, so the x-direction and y-direction compensation offsets in image coordinate value which already is multiplied by scale factor are reduced to zero. Thus we can correct the image plane center and the optical axis deviation of the actual center.

Second stage: The second stage adjustment is mainly to correct depth Z_w-value. Adjust the relation proportionally between the value $(x_1 - x_2)$ of the measured varying depth Z_w-value and the value $(x_1 - x_2)$ of the ideal Z_w-value.

Z_w-value can be calculated by Equation (5), where the focal length f and the central-axis distance L of dual-camera are constant, and the pixel difference $(x_1 - x_2)$ in the formula is the most important impact factor for the estimation of Z_w-value. In ideal case, the $(x_1 - x_2)$ value will decrease steadily and linearly based on the distance between the target and the camera. Also in the first stage, the revised estimated value of $(x_1 - x_2)$ decreases steadily and linearly. Therefore, it will exist a proportional relation between the estimated $(x_1 - x_2)$ and the ideal value $(x_1 - x_2)$.

For this system, the experimental range is selected from 1500mm to 2500mm. When target object is located at Z_w =1500mm in the camera coordinate system, the ideal parallax $(x_1 - x_2)$ should be 200 pixels, and when Z_w=2500mm, the ideal parallax $(x_1 - x_2)$ should be 120 pixels. Assume $x_1^{''}$ is the parallax value for the estimated value Z_w=1500mm and $x_2^{''}$ is the parallax value for the estimated value Z_w =2500mm. Based on the proportional relation, we have

$$x_1^{''} / 200 = x_2^{''} / 120 \qquad (5)$$

As shown in Figure 6, irrespective of any condition in the same stereo vision system, the relative disparity is the same at the same moving distance, that means the difference of $(x_1 - x_2)$ at Z_w=1500mm and Z_w=2500mm is constant. The difference value in this system is 82.89 pixels, as shown in the following equation:

$$x_1^{''} - x_2^{''} = 82.89 \qquad (6)$$

From the simultaneous equation, the two variables of x_1'' and x_2'' can be solved. And then the corrected visual difference of the depth 2500mm at the first stage can be reduced to x_2''; Using the scaling factor, we can synthesize the estimated Z_w-value into the ideal Z_w-value. Also, substituting this (x_1'' - x_2'') value to the formula of Y-axis equation, we will complete properly the calibration procedure.

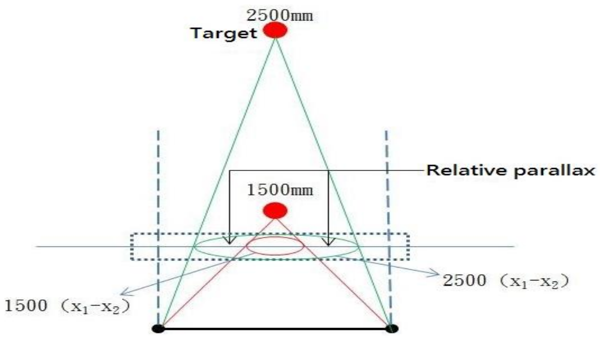

Fig 6: Relative disparity

4.4 Servo Control

In this target tracking system, we utilize image servo control to get the spatial 3D position by using dual-camera as an external smart sensor.

Servo motor is controlled by SSC32 control board with PWM control signal. This system adopts GWS servo motor, its scaling factor between the rotation angle and the pulse width is 9 us/degree, means the servo motor rotates 1 degree when the pulse width increases 9us.This factor is used as a proportional controller parameter adjustment scale, the output should be in proportion to the corresponding pulse width.

Adding the concept of image-servo outer loop feedback controller, the calculated 3D spatial coordinate information is used as the primary feedback signal, and using the pulse width increasing or decreasing type with 50Hz to approximate the mass center of target and make the feedback error to minimum.

5. EXPERIMENTAL RESULT AND DISCUSSION

Experimental verification of this paper is divided into two parts: one is 3D positioning, measurement and error analysis. Another is the actual testing of the target tracking and aiming capabilities. For 3D positioning, we have done the measurements of the X-axis and Z-axis depth respectively according to the proposed 3D spatial positioning method, the range of X-axis measurement is from the-100mm to +100 mm, one data is measured per 5mm and total 41 data are obtained; Z-axis depth is measured in the world coordinate system from 1500mm to 2500mm, one data is measured per 10mm and total 101 data are obtained.

From the shown measurement data, the average error between the X-axis measurement data and the desired standard value is 0.19mm, the maximum error is 0.47mm, this measurement results show that the proposed method of positioning for the X-axis is accurate and the error is less than 5mm. And the average error of Z-axis measurement data is 3.47mm, the maximum error is 10mm.From the result data of Table I, we can find out the error increases significantly behind the distance of 2000mm, and the measured value appears repeated phenomenon. The error source is presumably due to the scaling adjustment of the proposed correction method for Z-axis, so after the uniform scaling adjustment at some distance, the measured data is not just fall in the vicinity of the standard value. As for the duplicated phenomenon of the measured value, mainly due to the distance too far away and make the image moving distance relative small on screen for the 10mm depth change. So the system does not detect its changes and leads to the same measurement result, which is also the main source of measurement error. If the CCD resolution increases or the distance L between the dual-camera lengths, this repeated phenomenon problem can be solved.

This system is designed for the purpose of building automation shooting training range, and can interact with the intelligent target robot, so we plan 0-5 grade training courses for 6 kinds of different conditions, which present the interaction situation between the shooting training platform and the intelligent target robot as described in the following:

Grade 0: This is a basic shooting training class which will place the target at fixed point and drive the shooting simulation system for target tracking and shooting.

Grade 1: The main purpose of this grade is to demonstrate the shooting capability for target hiding and showing. The shooting simulation system needs to be designed as it doesn't take any tracking and shooting action until the target appears as shown in the following figures.

Grade 2: Target small angle shaking: The shooting simulation system needs to be designed to track and shoot target based on the shaking angle of target rotation.

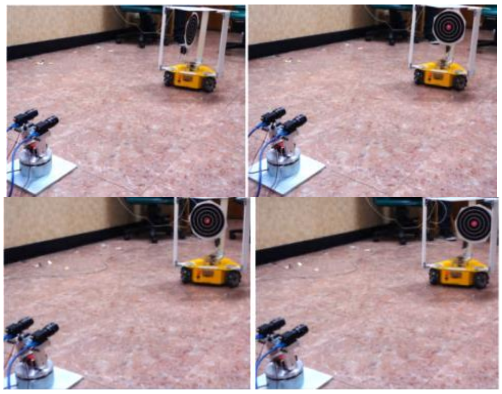

Fig: 7 Static target looming mode and static target shaking mode

Grade 3: Target moving around: The shooting simulation system needs to be designed to track, lock and shoot target continuously based on the forward-backward and left-right moving of target.

Grade 4: Hiding and showing in moving target: The shooting simulation system needs to be designed to calculate the target position and proceed with a tracking-shooting task before the moving target hiding.
Grade 5: Target is moving from left to right and take a small angle shaking in target moving.

6. CONCLUSIONS

This article uses Hough transform and Template matching method to develop and construct three-dimensional dynamic positioning and tracking system. Hough transform is updated once every 30 milliseconds and the target image is saved as a template. The template matching method is updated once every 15 milliseconds, and then we can compare the left and right images to find out the corresponding feature points. Using these feature points, the 3D spatial coordinate can be calculated.

According to experimental results, through the Hough circle transform and template matching methods, the searched target in the image searching mode is almost the locked target accurately. Even the scene of target changes, we still can find out correctly the target by using the assistance of histogram equalization and then identify the target.

In the three-dimensional spatial positioning part, the spatial positioning and correction method in this paper has been validated. The experimental result shows that the measurement is correct. But if the distortion of the selected camera lens and the offsets of lens center are serious, then the errors will increase relatively. The resolution is also a problem needs to be overcome, if we can find out the relationship of dual-camera distance and the resolution of lens, then the same depth problem of the working distance will be solved.

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