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An Embodiment of Stereo Vision System for Mobile Robot for Real-time Measuring Distance and Object Tracking

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Abstract

All these days, the active stereo vision system which can detect the certain object and measure the distance from the object through the camera's image have been studied. In the stereo vision system, it is the key point to search the certain object through the image and to track the object by controlling the motor which supports the camera based on the searched object information. Also, as the human being can estimate the distance from the object by using two eyes, the distance from the certain object can be estimated by using two cameras in the stereo vision system. When the certain object is located on the corner of image plane in the stereo vision system where the existing camera is fixed, an error occurs due to a lens's distortion, so reliability goes down. However, the cross stereo vision system always places the object in the middle of image and places the object in the middle of low distortion lens, so it can increase reliability of information gained from the system as its advantage. This paper is intended to implement the stereo vision system which can track the object and can measure the distance from the object in real time by applying the trigonometric measurement method and the robot kinematics to the cross-visual stereo vision system which is fabricate to be applied to the mobile robot and by distributing the controller's load, and to evaluate the performance by applying the mobile robot under an indoor lighting environment.

Keywords : stereo vision, mobile robot, tracking object, measuring distance

1. Introduction

A research on the active stereo vision system which ensures the certain object tracking and distance measuring has been continued for a long time. The ultimate goal of the stereo vision system is to implement the human's visual function. For it, the certain object from inputted imagery information must be detected or recognized.[1] Also, as the human being can estimate the distance from the object by using two eyes, the distance between the robot installed in the stereo vision system and the certain object must be known. Through the latest hardware's high speed, high intensity, and miniaturization, the consecutive imagery data can be processed in real-time. Also, the camera provides more information, since the informationization era when the large quantity of data is rapidly and accurately processed. Stereo vision technology is very useful to gain information. Detecting the certain object in the right and left image must be firstly detected. When the object is detected and matched, the distance information can be calculated by trigonometric measurement method [2]. Stereo matching is the most primary problem in the field of computer vision. Many algorithms have been proposed, but it is very difficult to do the accurate matching up to now.[3]

In this paper, Chapter 2 describes the kinematics of stereo vision system. Chapter 3 describes the algorithm about the distance measurement, and Chapter 4 describes the method to recognize the object and to detect the object by using two cameras. Chapter 5 shows the results of the experiment derived by methods proposed in this paper. Finally, Chapter 6 describes the results.

2. Coordinates

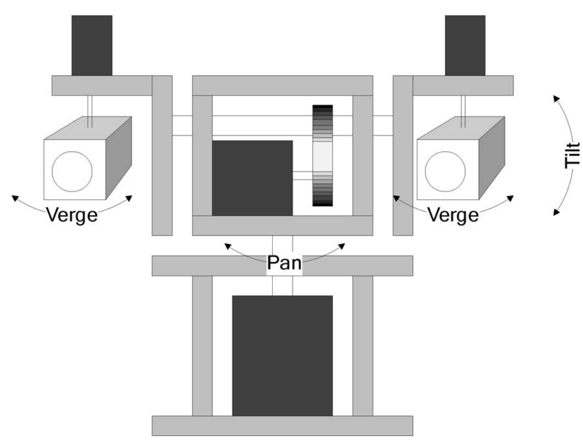

Fig. 1 Stereo Vision System

The kinematics of the stereo vision system to be implemented in this paper is described in the above Figure 1. In order to estimate variables required for

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solving the kinematics, the modeling can be done like Figure 2. By using the modeling variables, the camera's reference coordinate system can be calculated.

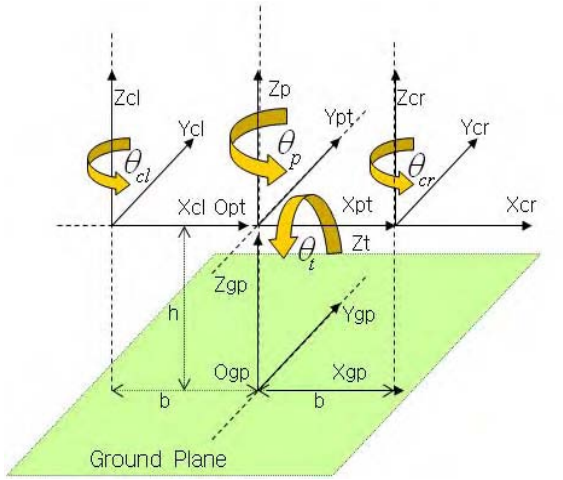

Fig. 2 Coordinates Plane

In Figure 2,

Ogh : a center of absolute coordinate axis
Opt : a center of Pan-Tilt coordinate axis
Zp : a rotation axis of Pan
Zt : a rotation axis of Tilt
Zcl,Zcr : a rotation axis of right and left camera
h : a height from a plane
b : a distance from the center to camera
θcl,θcr : a rotation angle of left and right camera
θp : a rotation angle of Pan
θt : a rotation angle of Tilt

By using the above parameters, the below Formula 2.1 and Formula 2.2 can be expressed with the matrix.

$$F_{cl} = R(Z,\theta_{cl}) * T(b,0,0) * R(X,\theta_t) * R(Z,\theta_p) * T(0,0,-h) * F_g \quad (2.1)$$

$$F_{cr} = R(Z,\theta_{cr}) * T(-b,0,0) * R(X,\theta_t) * R(Z,\theta_p) * T(0,0,-h) * F_g \quad (2.2)$$

Where,
Fcl is left camera's local coordinate and Fcr is right camera's local coordinate, and Fg is Global Coordinate.

The camera's coordinate system on the global coordinate system can be calculated by using the above formula.

3. Measuring Distance

The human's vision can estimate the distance from the object as two eyes compare the object in the different points. By using it, the stereo vision system can measure the distance from the certain object through using two cameras' distance and the camera's angle. Figure 3 shows the structure for measuring the distance from the object..

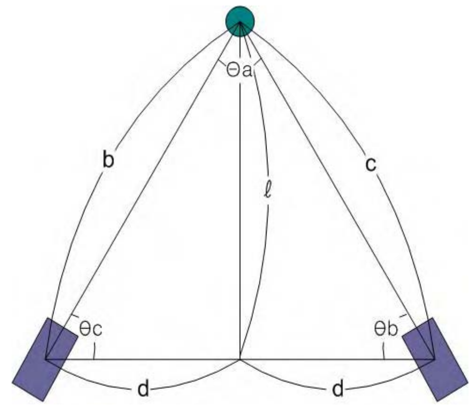

Fig. 3 Trigonometry

In the above Figure 3,

d : a distance from the center of camera (know)
b,c : a distance between the camera and the object (unknown)
ℓ : a distance between the center and the object (unknown)
Θb, Θc :an angle of camera (know)
Θa : an angle of camera's cross point (know)

When the distance between cameras is 2d like the above Figure 3, the distance from the camera to the center is d. Also, the angle of camera looking at the object is θb, θc. The distance (d) from the camera and the center and the angle of the camera (θb, θc) can be known. When one side's length and the angles of both ends are known, the distance from the camera and the object and the distance between the center and the object can be calculated by using the law of sine and the second law of cosines. The law of sine is shown in the Formula 3.1 and the second law of cosines is shown in the Formula 3.2.

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C} \quad (3.1)$$

$$a^2 = b^2 + c^2 - 2bc \cdot \cos A \quad (3.2)$$

Because the angles of both ends are known, the remaining angle(θa) can be known. The distance from each camera to the object (b, c) can be calculated by using the law of sine as shown in the Formula 3.3.

$$\frac{b}{\sin\theta_b} = \frac{c}{\sin\theta_c} = \frac{2d}{\sin\theta_a} \quad (3.3)$$

In the above Formula 3.3, b and c can be calculated. When b and c is known, the distance from the center of robot to the object (ℓ) can be calculated by using the Formula 3.1. The formula to calculate ℓ is shown in the Formula 3.4 or Formula 3.5.

$$\ell^2 = c^2 + d^2 - 2cd \cdot \cos\theta_b \qquad (3.4)$$

$$\ell^2 = b^2 + d^2 - 2bd \cdot \cos\theta_c \qquad (3.5)$$

When one of both Formula 3.4 and Formula 3.5 is selected and then the square is removed, the distance from the center of the camera to the certain object can be calculated.

4. Tracking Object

The sensor which can give the largest quantity of information as the single sensor is just the vision sensor. By processing the image gained by using this vision sensor, the stereo vision system is operated. The vision control system is largely divided into two things according to the position of camera. One is the eye-in-hand system that the camera is installed in the robot's End-effector or the mobile robot, and another is the static camera system that fixes the camera in the working space. In this paper, the eye-in-hand that the camera always is moved by the certain object will be used. In implementing this system, the image can be obtained per sampling time from the camera, and the position information of object to be tracked can be received from the image. Also, the certain object is detected through the image from the camera, and then the object is shown in one point of the image plane. By using the coordinates of this point on the image plane, the camera's rotation angle is calculated.
The image processing used in the experiment for this paper is intended to distinguish the position of the object colored in the certain color in the color image. The object is detected from already-setting CID(Color ID) in the inputted imagery information. For the rapid image processing, CID method using the LUT(Look Up Table) is used [4]. CID is implemented by applying the dotted scan-line method and the centric coordinates of desired object is known. The controller which is used in this paper is controlled with dual-loop architecture like following figure 4. As a hierarchical architecture, The dual-loop architecture is make a trajectory, and as a low controller, tracking input data from vision system to ensure system safety. [5]

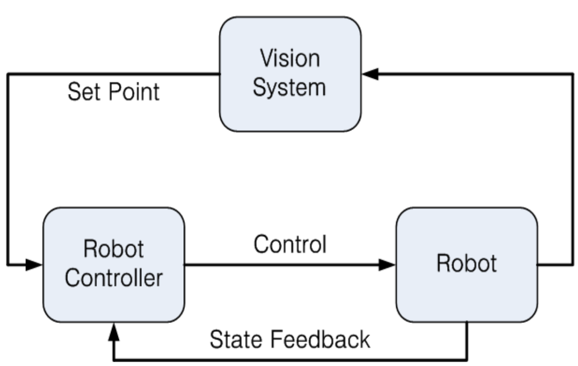

Fig. 4 Dual-loop Visual Servo

If CCD camera is used as the vision sensor, the camera lens model is required to show the projection on CCD image plane of the object for mapping the working space to the sensor space. [5] In this paper, the perspective projection was used as the method which projected one spatial point in the image plane. Figure 5 describes the movement of image coordinates by the movement of object on the image plane to detect the certain object.

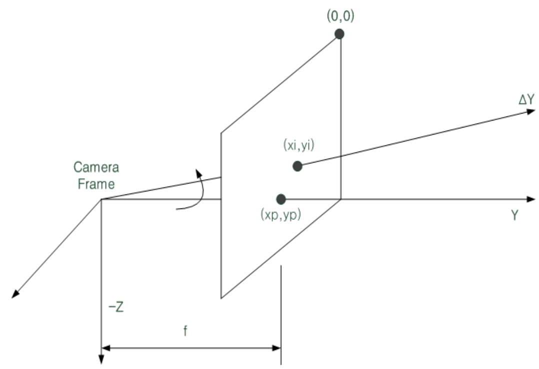

Fig. 5 Camera Model

In Figure 5,

ΔY : Y Axis of the camera moved by rotating Z Axis to the center
xp : Previous x coordinate of the certain object on the image plane
xi : Moved x coordinate of the certain object on the image plane
yp : Previous y coordinate of the certain object on the image plane
yi : Moved y coordinate of the certain object on the image plane
f : A distance between the camera and the certain object

From the camera model, the angle of rotation to move the position of the object on the image plane to the center of image plane can be calculated, by using the inverse kinematics. For the pixel on the image plane, the camera's moving angle is followed.

$$\theta_c = \tan^{-1}\left(\frac{N_p * x_{size}}{f}\right) \qquad (4.1)$$

$$\theta_c = \tan^{-1}\left(\frac{N_p * y_{size}}{f}\right) \qquad (4.2)$$

Where,

Np is the number of pixels, and Xsize, ysize is the size per X and Y pixel on the image plane.

In order to implement the object tracking using the stereo vision, the object's tracking path must be generated by using the image processing system which can process the image from the camera and data supplied from the image processing system. The motor controller is required to move the camera to this path. If these components are well connected, the object can be tracked in real time.

5. Experiment Result

When the position is voluntarily specified to the space of simulation positioned in the right side of panel in Figure 6, PC calculates the angle and makes the command with the sub-controller. Sub-controller controls the motor by receiving the command, and recognizes the present status with data received from the motor.

Fig. 6 Simulation Program

Among data positioned in the middle of the above figure's panel, the above data show data received from the motor by controlling the motor actually, and the below data show data calculated by simulation. There is very small error in the simulation data and the actual data. It is the error arisen by the motor's gear and encoder's resolution.

Fig. 7 Experiment and Measuring Distance

By using Win32-based VFW library, images from two USB cameras were delivered to the screen and then the center of orange ball was searched in delivered two images.

Images were searched by giving the orange ball's coloring range in RGB area with the Dot Scan method.
The following describes the formula to search the center of orange ball.

$$N_{px} = P_{cx} - P_{bx} \qquad (5.1)$$

$$N_{py} = P_{cy} - P_{by} \qquad (5.2)$$

Where,

Npx, Npy is the number of pixels between center to orange ball, Pcx, Pcy is center coordinate of axis X, Y in the vision, Pbx, Pby is orange ball's X, Y coordinate.

When the central coordinate of orange ball from each camera installed on the right and left is delivered to the stereo vision system, the stereo vision system controls the driving part to moving each orange ball's position to the center of image through the following formula.

$$P = \frac{\theta_c}{Res} \qquad (5.3)$$

Where,

P is control position of each motors, θc is the angle to rotate, Res is angle resolution of each actuators.

Because it delivers two images at the speed of 15 frame, and controls the driving part, the control command delivery was delayed.

6. Conclusion

The stereo vision system which searches the center through the certain object's coloring area and tracks the object by using two cameras, was implemented.
It uses two USB cameras and executes the image processing. Time delayed in the serial process which delivered the commands to the driving part, but there was not big problem in the actual tracking. However, the research which minimizes the error of time occurred in the driving part's operation timing and the image processing by using the estimation method such as Kalman Filter and Traffic Controller must be executed for the stereo vision system which will require the precision tracking in the future.

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