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An Indoor Autonomous Surveillance Robot via Humanoid Vision System

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Abstract: This paper is devoted to develop a positioning and tracking scheme for a surveillance robot aiming at suspicious target and measuring the distance to the target. The vision of a general camera is too narrow for tracking fast moving targets. In addition, the flexibility of tracking is limited by robot's dynamics. We design a particular humanoid vision system with two pan-tilt servo systems which can be operated collaboratively or independently. The humanoid vision system is fast and flexible for tracking a moving target and measuring the distance. An embedded system is exploited for the humanoid vision system and robot servo control. An image recognition and tracking algorithm has been developed using LabVIEW for the system. Camshift tracking algorithm can recognize and track suspicious targets efficiently. Different from the previous systems, this system is cheap and easy to control.

Keywords: Surveillance robot, Humanoid vision system, Image process, Image tracking.

1 INTRODUCTION

The efficient image positioning and tracking method for an indoor autonomous surveillance robot for security technology has been a very important issue. An excellent surveillance robot must have the ability to recognize and to track suspicious targets. Furthermore, the relative distance between the target and robot is the significant information for the remote observers.

Luo [1] and Chien [2] et al proposed the system architecture of security robot with multiple sensors. Hsia [3] proposed the mobile robot autonomous obstacle avoidance in unknown indoor environment with a scanning laser rangefinder. However, a scanning laser rangefinder cannot identify the suspicious targets. Therefore, this paper is devoted to develop a positioning and tracking scheme for a surveillance robot aiming at a suspicious target and measuring the distance to the target. From many references, we know that the vision system is a good sensor for robots to achieve the surveillance missions in complex indoor environments. However, the vision of a general camera is too narrow for tracking fast moving targets. In addition, the vision systems are usually fixed on robots. Thus the flexibility of tracking is limited by robot's dynamics.

In this paper, we have accomplished three major objectives. Firstly, in order to track and to measure the distance between the robot and the moving target, we designed a particular humanoid vision system with two pan-tilt servo systems. Different from [4] and [5], our system is very cheap and easy to control. These two pan-tilt servo systems can be operated collaboratively or independently. The humanoid vision system is fast and flexible for tracking the moving target and measuring the distance to an intruder or a suspicious person. The robot system is shown in Fig. 1.

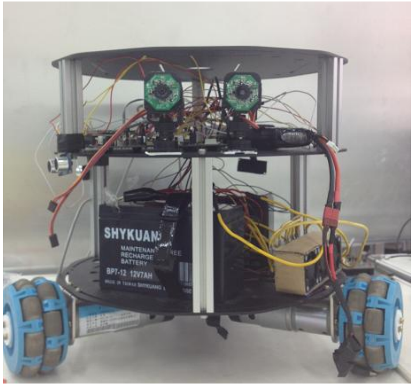


Fig. 1. The surveillance robot system

An embedded system, called PSoC (Programmable System-on-Chip), is exploited for the humanoid vision system and robot servo control. PSoCs integrate memory, analog and digital peripheral functions, and a microcontroller on a single chip. It has good performance for servo control. An image recognition and tracking algorithm has been developed using LabVIEW software for the humanoid vision system. Camshift tracking algorithm can recognize and track suspicious targets efficiently. Based on the triangulation method, the position of the target in a 3D space can be measured by the humanoid vision system. In addition, we have succeeded in designing human-computer interface which makes the operation, data logging and real-time image observation of the robot system possible.

To investigate the performance of the proposed humanoid vision system from a practical point of view, a red target is used for demonstrating the image recognition and tracking algorithm. The Camshift tracking algorithm can not only recognize but also track the suspicious target quickly. Moreover, it shows that the humanoid vision system computes the distance to the target successfully in the experiments. The robot with a humanoid vision system is able to track and recognize the target, and it also can measure the distance to the target in the indoor environment. The practicality of the humanoid vision system has been verified in this paper.

2 TARGET POSITION ESTIMATION VIA HUMANOID VISION SYSTEM

The humanoid vision system is composed by two pan-tilt servo systems. Therefore the two pan-tilt servo systems can drive the cameras to align the target at the same time. The target image will be located in both cameras. The geometric relationship of the humanoid system is shown as **Fig. 2.** Based on the special architecture of the humanoid vision system, the complex pair image matching problem and 3D coordinate computing problem [6] can be simplified significantly. For a real-time robot system, this is a good solution for fast distance measuring.

By analyzing the relationship shown in **Fig. 2,** we can obtain the depth, Z, and the height, H, of the object. From **Fig. 3**, we have

$$\tan\theta_1 = \frac{p}{Z},\ \tan\theta_2 = \frac{D-p}{Z}. \tag{1}$$

From (1), we have

$$\tan\theta_1 Z = p. \tag{2}$$

Substituting (2) into (1), we have

$$\tan\theta_2 = \frac{D-(\tan\theta_1 Z)}{Z}. \tag{3}$$

The Z and H can be obtained as

$$Z = \frac{D}{(\tan\theta_1 + \tan\theta_2)}, \tag{4}$$

$$H = \tan\theta_3 S, \tag{5}$$

where $S = \left[(D-p)^2 + Z^2\right]^{1/2}$. The θ_1, θ_2 and θ_3 are provided by the encoders of the pan-tilt servo systems.

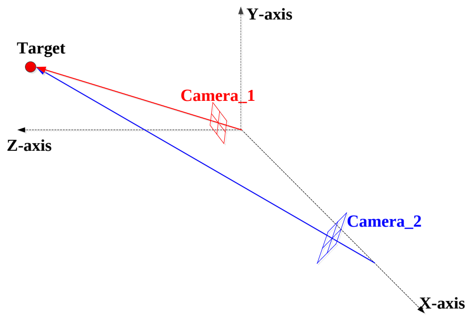


Fig. 2. The geometric relationship of the humanoid visi on system

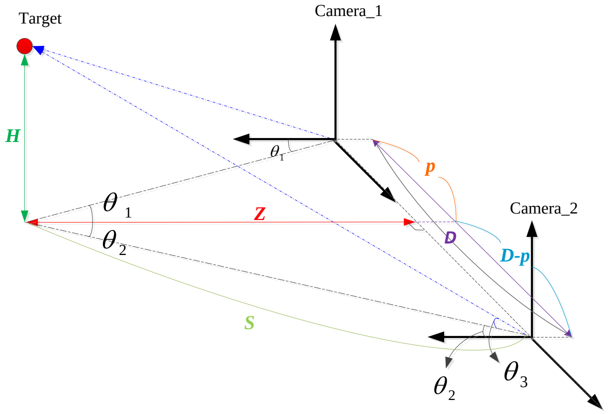


Fig. 3. The target position estimation

3 IMAGE TRACKING METHOD

3.1 HSV Color Model

Color model transformation aims to simplify the image and to segment the object preliminary. In here, HSV (Hue-Saturation-Value) color model is utilized in the image tracking applications [7]. The transformation from RGB to HSV is:

$$V = \max(R,G,B),\ S = \frac{(V-\min(R,G,B))}{V},$$
$$H = \begin{cases} (G-B)*60/S, if\ V = R \\ 180+(B-R)*60/S, if\ V = G. \\ 240+(R-G)*60/S, if\ V = B \end{cases} \tag{6}$$

3.2 CamShift tracking algorithm

The CamShift [8] (Continuously Adaptive Mean Shift) tracking algorithm is a very effective way to track the target.

The steps of CamShift tracking algorithm are:

Step 1 Calculate the HSV color histogram of target and set it to be the template.

Step 2 Calculate the target's color histogram of next image and start to search.

Step 3 Calculate the moving vector V. (If V is divergent, back to Step 1.)

Step 4 Calculate the Bhattacharyya coefficient for finding the best matching block.

Step 5 Record the coordinate of the best matching block from Step 4 as the initial searching position for the next image.

CamShift algorithm has good results for moving target tracking problem. For our application, CamShift algorithm is very quickly and efficiently for tracking and locking the target.

3.3 Moving Vector of the Target

The moving vector of the target is computed by the Camshift tracking algorithm. **Fig. 4** shows the moving vector analysis.

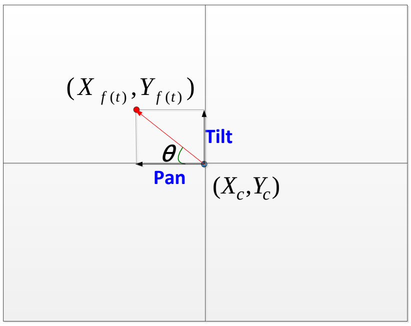


Fig. 4. The moving vector of target

From **Fig. 4**, we have

$$\theta = \tan^{-1}\left(\frac{V_y}{V_x}\right) \tag{7}$$

where $V_x = X_{f(t)} - X_c$, $V_y = Y_{f(t)} - Y_c$. Define

$$|V|^2 = V_x^{\ 2} + V_y^{\ 2}. \tag{8}$$

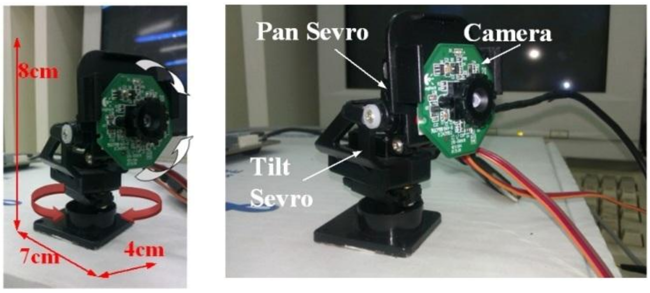
Therefore, the moving vectors along the pan and tilt directions are

$$\begin{cases} Pan = |V| * \cos\theta \\ Tilt = |V| * \sin\theta \end{cases}. \tag{9}$$

4 EXPERIMENTAL RESULTS

4.1 Hardware and Image Display Interface

The humanoid vision system is composed by two pan-tilt servo systems. The pan-tilt camera system is shown as **Fig. 5.** This system is very small and agile. More preferably, this design can be used in pairs or individually. In our application, the distance between the two pan-tilt servo systems is 10cm.



(a) (b)

Fig. 5. Pan-tilt camera system

The controller of the pan-tilt servo systems is a PSoC 5, as shown in **Fig. 6.** The PSoC 5 provides PWM control signals to the servo system and captures the signals of encoders. Moreover, the position of the target is computed by the PSoC 5. The human-computer interface is shown in **Fig. 7.** The real-time image, image processing results and the signals of encoders are displayed on it. In addition, the threshold values of HSV can be adjusted by this interface.

Fig. 6. PSoC 5

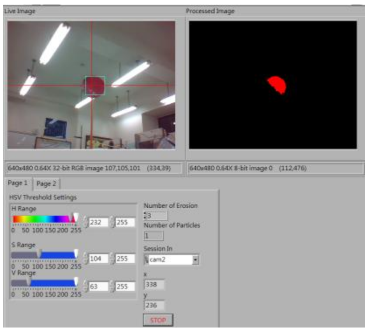


Fig. 7. Image display interface

The tracking results are illustrated as **Fig. 8**. **Figs. 8 (a-L) - (d-L)** and **Figs. 8 (a-R) - (d-R)** are the images captured by the left and the right camera, respectively. The images of target are all located at the centers of captured images.

For further investigating the measurement ranges of the humanoid vision system, we measure the target positions 10 times in each interval. The measurement range is from 0.5m to 6m and the interval is 0.5m. **Fig. 9** shows the average absolute errors of *Z* (depth) and *H* (height), where *Z* and *H* have been described in **Fig. 3**. The acceptable measurement error for our robot is less than 0.2m. In other words, the effective measurement range of the humanoid vision system is 3.5m. This measurement range for indoor surveillance robot is adequate.

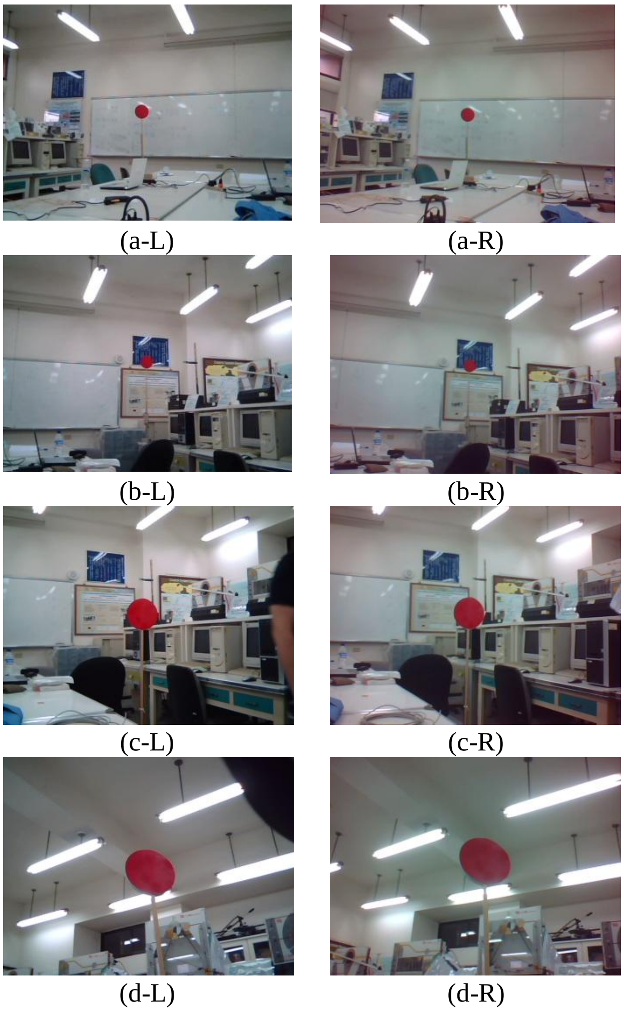


Fig. 8. The image tracking results

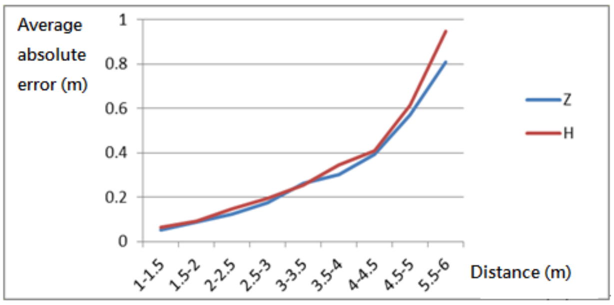


Fig. 9. The target position estimation results

5 CONCLUSION

In this paper, we proposed a particular humanoid vision system for indoor autonomous surveillance robot. The humanoid vision system is composed by two pan-tilt servo systems. Different from other humanoid vision system, our system is very cheap and easy to control.

In experimental results, the Camshift tracking algorithm can not only recognize but also track the suspicious target quickly. The images of target are all located at the center of the captured images. Moreover, it shows that the humanoid vision system computes the distance to the target successfully. The human-computer interface displays the real-time image, image processing results and the signals of encoders.

The robot with humanoid vision system is able to measure the distance of the target. It also can track and recognize the target in the indoor environment. The practicality of humanoid vision system has been verified in this paper.

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