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Vision-Based Localization of a Quad-rotor System

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Abstract : This paper presents the localization of a quad-rotor system using a camera for indoor application. To localize the quad-rotor system with a camera, several practical issues are addressed. Firstly, radially distorted images by a convex lens should be corrected. Secondly, markers are used to detect the position and the heading angle of the system. Lastly, position with respect to different heights should be calibrated. Experimental studies confirm the localization based on a vision system.

Keywords :Quad-rotors, position control, calibration, vision system.

1. Introduction

Recently, interests in autonomous systems are enormously increased. Autonomous systems require three major techniques, localization, path planning, and control to perform specified tasks. Among them, localization is the most important technique for autonomous systems to perform tasks in designated areas. Almost all of research on autonomous systems are related with how to recognize whereabouts of the system.

A localization technique is required for not only mobile robots but also unmanned aerial vehicles to accomplish missions. In the outdoor environment, localization can be done by GPS with ease. More accurate localization can be achieved with the help of other inertial sensors. For indoor applications, indoor GPS can be used with the help of mapping techniques.

Quad-rotor systems have been paid attention by control and robotics research communities [1-11]. Various control algorithms have been introduced and tested by simulation as well as experimental studies.

For indoor applications, accurate positioning devices are used for positioning quad-rotor systems. Although those positioning sensors are quite expensive, excellent flying demonstration of formation control of quad-rotor systems has been presented by University of Pennsylvania. Pingpong playing quad-rotor systems have been introduced by ETH. Building a tower with blocks by quad-rotor systems has been demonstrated as well. All of applications use expensive positioning sensors.

In the meanwhile, low cost sensors such as a camera system are also used for localization of quad-rotor systems [10,11]. Quad-rotor systems are equipped with a camera to detect objects or lines on the ground by detecting markers for the posture. Relying upon images, quad-rotor systems can navigate and vision-based trajectory tracking tasks are performed.

Since the expensive sensor is not available in many cases, a single camera is used as a global sensor to locate the quad-rotor system. The concept of vision-based control tasks is described in Fig. 1.

In this configuration, several problematic issues are addressed. Firstly, a camera lens is convex so that images are radially distorted by a convex lens and their solutions should be provided. Secondly, the position and the heading angle of the system should be detected by using markers. Lastly, images can be different with respect to different heights. Position with respect to different heights should be compensated.

In this paper, aforementioned problems are addressed and their solutions are proposed. Experimental studies of calibrating the position of a quad-rotor system are presented.

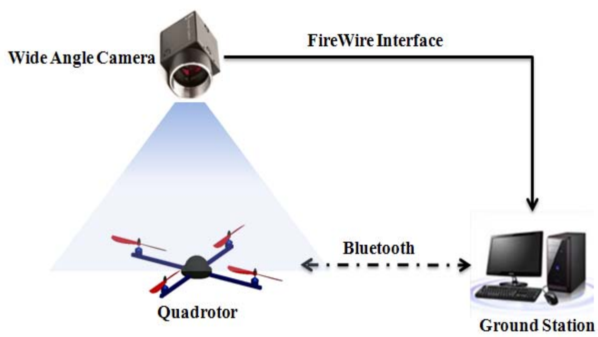

Fig.1 Concept of force control of quad-rotor

2. Camera Calibration

There are two image distortions of a camera, radial distortion and tangential distortion. Usually radial distortion is a major factor to distort the images. Therefore, here we present a method to compensate for radial distortion of a camera.

There is a focal distance, f, between the center of camera plane and the center of the image plane as shown in Fig. 2.

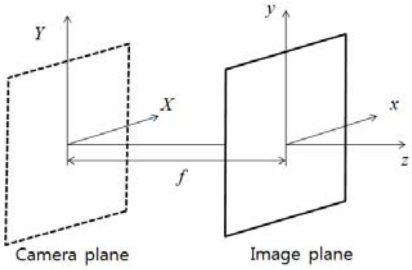

Fig. 2 Camera and image planes

Due to the convexity of a lens, images are distorted as shown in Fig. 3. As the image is far from the center, the distorted rate becomes larger.

Fig. 3 Example of radial distortion

Offsets deviated from z axis in Fig. 1 can be corrected by the following gain matrix, K.

$$K = \begin{bmatrix} m_x & 0 & 0 \\ 0 & m_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} f & 0 & p_x \\ 0 & f & p_y \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} \alpha_x & 0 & x_0 \\ 0 & \alpha_y & y_0 \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

where m_x, m_y are the numbers of pixels per the distance (mm).

The equations for the radial distortion can be described as

$$x_d = x(1 + k_1 r^2 + k_2 r^4 + k_3 r^6 + k_4 r^8 + \cdots) \quad (2)$$

$$y_d = y(1 + k_1 r^2 + k_2 r^4 + k_3 r^6 + k_4 r^8 + \cdots)$$

where r is the radius of a circle measured in the image and k_1, k_2, k_3, k_4 are distorted coefficients.

To find coefficients, test samples are used as shown in Fig. 4.

Fig. 4 Several samples for finding distorted coefficients

After calculations using Open CV, correction matrix, K is found to be

$$K = \begin{bmatrix} 228.7752 & 0 & 333.0775 \\ 0 & 204.2680 & 240.7386 \\ 0 & 0 & 1 \end{bmatrix}$$

Distortion coefficients are found to be $k_1 = -0.266588, k_2 = 0.047068, k_3 = 0.010296$, and $k_4 = -0.005979$.

After correction, we have calibrated images as shown in Fig. 5 (b).

(a) Before (b) After

Fig. 5 Calibration

3. Marker-Based Localization

Since we are relying upon a vision to localize the quad-rotor system, two different colors, red and yellow circles are used to determine the location. Two colored circles are attached to the center and the front of the quad-rotor system. Based on the color information by a camera, we can determine the position, heading angle and even height of the quad-rotor system as shown in Fig. 6.

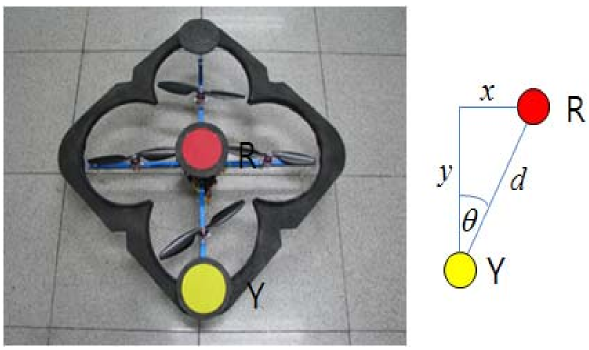

Fig. 6 Detection by Marker

The heading angle and the distance can be calculated by

$$\theta = \tan^{-1}\left(\frac{x}{y}\right), d = \sqrt{x^2 + y^2} \tag{3}$$

Fig. 7 shows the pattern matching between floor tiles and pixels in the camera plane. Since the floor tiles have a regular shape, those tiles can be used as the reference. Each tile block has the size of 0.4 x 0.4 *m*.

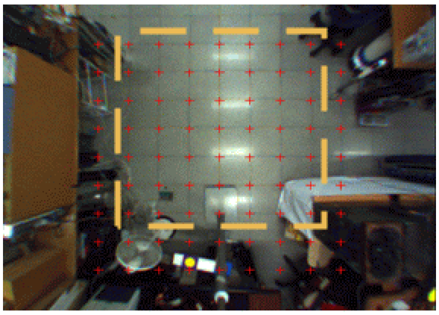

Fig. 7 Position correction by floor pattern

When the quad-rotor system is flying not on the ground, then position can be corrected by the linear relationship as shown in Fig. 8.

$$ah = bH \tag{4}$$

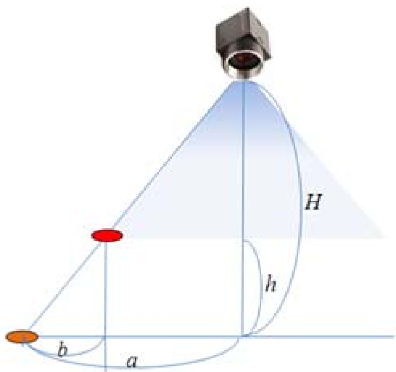

Fig. 8 Position correction by linear relationship

Fig. 9 shows the final GUI window that shows the image captured by a camera. We see that the image has been calibrated by correcting distortions.

Fig. 9 GUI Window

4. Conclusion

In this paper, a camera sensor is used as a global sensor instead of using expensive positioning sensors. Calibration methods using a camera for localization of a quad-rotor system are presented. Based on camera images, position, heading angle, and height are estimated. The estimated error is approximately $\pm 2cm$, which is somewhat large. This error occurs due to the resolution of the camera.

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