Camera Position Estimation for UAVs Using SolvePnP with Kalman Filter

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***Abstract*— In this paper, we propose an algorithm for obtaining camera coordinates for unmanned aerial vehicles (UAVs) using SolvePnP and Kalman filter (KF). The data and motion of circle can be recognized and tracked through the KF with high accuracy. Then, the recognized circle is used as an image point of the SolvePnP algorithm. The translation and rotation vectors can be extracted from reference of the world coordinate system using the image point. The position of UAVs can be obtained from the extracted information and the results demonstrate that the position can be derived from only camera. The robust performance of the proposed algorithm is demonstrated through experimental results.**

***Keywords*—** *Position estimation, Kalman filter, SolvePnP, UAVs*

I. Introduction

Although the unmanned aerial vehicles (UAVs) were used for military purposes in the past, nowadays, they have become widely used [1]. UAVs have been used in various areas, however, the big drawback is that, unlike a car moving in two-dimensional space, UAVs move in three-dimensional space using only force of the propeller and it is hard to estimate the coordinate values and position of UAVs [2-3].

The coordinate values through the sensor fusion method which fuses the inertial measurement unit (IMU) and the camera when receiving the coordinates of the UAVs and there is a way to know the position of UAVs using only a camera with optical flow algorithm. Given a feature point in the image, the location of the UAVs can be determined through the pixel change in the next image [4-6]. Another way to find out the position of UAVs is posing from orthography and scaling with iteration (POSIT), which is an algorithm that can obtain approximate three-dimensional information and show the corresponding two-dimensional information [7].

In this paper, we propose a novel position estimation method using only camera information. The relation between the world coordinate system and the camera coordinate system is calculated, the necessary parameters are found between the two coordinates, and obtain the position of UAVs using SolvePnP with Kalman filter (KF). The SolvePnP gives the translation vector and rotation vector between the world coordinate system and the camera coordinate system, and thus, the real position can be obtained.

This paper is composed as follows. Section II presents the position estimation using the KF and SolvePnP. Section III shows experimental results using a single camera. In Section IV, concluding remarks are presented.

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II. SolvePnP Algorithm

Fig. 1 represents input and output of SolvePnP. An object point, an image point, a camera matrix and distortion parameters are input, and a translation vector and a rotation vector are output.

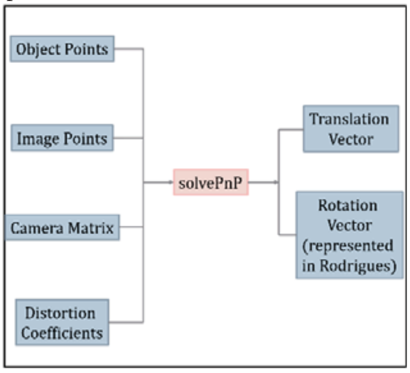

Fig. 1 Input and output of SolvePnP

P_{obj} and P_{img} are set to circle shape with one center point and the other six points. P_{img} is obtained by obtaining the center point and radius information by using the circle extraction and using 7 points. In order to reduce the error P_{img}, SolvePnP is constructed using the KF with constant velocity model. To uniquely determine the rotation in the dimensional space, the rotation axis, the rotation angle, and the viewpoint of the observer are required. At this time, the rotational axis and the observer's point of view can be expressed in the direction of the rotational axis, and the principle is set to right hand sides.

By creating a rotation direction vector using $u = w \times T(w)$, the angle of rotation and the direction of the rotation axis can uniquely determine the rotation in the three-dimensional space.

The rotation matrix **R** can be represented by the rotation angle θ and the rotation axis direction vector **v** as follows:

$$p_{rot} = p\cos\theta + (v\times p)\sin\theta + (v\cdot p)(1-\cos\theta), \tag{1}$$

$$p_{rot} = \left(\cos\theta I + \sin\theta \begin{bmatrix} 0 & -v_z & v_y \\ v_z & 0 & -v_x \\ -v_y & v_x & 0 \end{bmatrix} + (1-\cos\theta)vv^T \right) p, \tag{2}$$

$$R = \cos\theta I + \sin\theta \begin{bmatrix} 0 & -v_z & v_y \\ v_z & 0 & -v_x \\ -v_y & v_x & 0 \end{bmatrix} + (1-\cos\theta)vv^T. \tag{3}$$

SolvePnP returns the rotation vector *[a b c]*, which can be used to calculate the rotation angle and the direction of the rotation vector as follows:

$$\theta = \sqrt{a^2+b^2+c^2}, \qquad v = \begin{bmatrix} v_x & v_y & v_z \end{bmatrix}^T = \begin{bmatrix} a/\theta & b/\theta & c/\theta \end{bmatrix}^T,$$

$$\begin{bmatrix} x & y & z \end{bmatrix}^T = R\begin{bmatrix} X & Y & Z \end{bmatrix}^T + t = 0.$$

To convert the coordinates of the camera coordinate system with the world coordinate system based on *(0, 0, 0)*, we add a negative value to the product of the rotation matrix and the translation matrix. In this way, the position coordinates of the camera can be obtained through the image.

III. Experiment

The camera for the experiment is the Logitech c920 model, and the internal parameters and distortion parameters of this camera has been obtained through the chess board which is taken by various angles using the OpenCV intrinsic function.

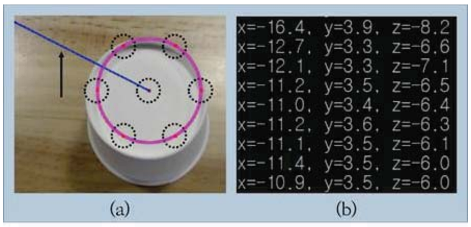

Fig. 2 The application of SolvePnP with KF:
(a) circle detection (b) camera coordinate

Fig. 2. (a) shows how circular tracking occurs. The line pointed by the arrow is a straight line connecting the center of the tracked circle from the fixed point. The dotted circle shows seven points on the image plane. These points can be obtained by SolvePnP using the object points that have been input.

Fig. 2 (b) shows the coordinates of the camera that completed the Rodriguez rotation transformation. As you move in a certain direction, you can see that the value changes constantly in the x direction. Fig. 3 represents the movement of the camera based on the point *(0, 0, 0)* in the world coordinate system. Since there is a process of converting a vector into a matrix, it is possible to check the unstable state due to the noise as the camera moves.

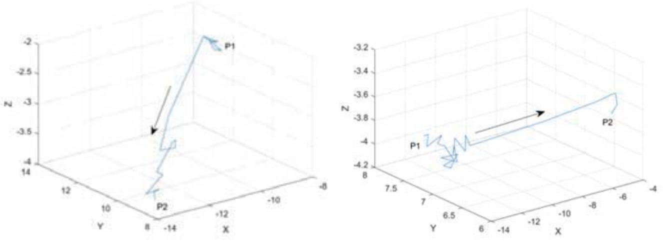

Fig. 3 Camera coordinates change:
(a) diagonal movement (b) straight movement

IV. Conclusion

In this paper, the camera position estimation algorithm is proposed, which can obtain the coordinates using only the single camera. It is possible to obtain an appropriate relationship between the world coordinate system and the camera coordinate system using local coordinate of camera and global coordinate. From the relationship represented with the rotation vector represented in Rodriguez equation, and translation vector and the KF, the estimated position of the camera is obtained. Through experimental result, successful camera position estimation is demonstrated.

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