Self-location recognition of rotorcraft by monocular camera mounted on the craft based on solid label

Tetsuya Morisaki[1*], Sigat Sharon Ludai[1], Hisao Emoto[2], Takayuki Okabe[1]

[1]Department of Mechanical & Electrical Engineering, Tokuyama Collage of Technology, Japan,

[2]Department of Environmental Science and Engineering, Yamaguchi University, Japan

Abstract: The inspection of bridges has been made possible with adjacent shooting using a camera on RC rotorcrafts. Then, accurate information of the location and direction of the camera is acquired without GPS signal because the rotorcraft flights under the bridge and the signal is intercepted by the bridge girder. This is the reason we considered P3P solution which is the method of estimating the information using a photograph of geometrical characteristics of 3 feature points placed on established actual coordinate system by the pan-tilt camera mounted on a rotorcraft. In order to evaluate the system, we generated the coordinate error of each feature point in a photograph of three vertexes of an equilateral triangle landmark. From the result, it is understood that there are possibility that the measurement error of the camera location is getting bigger as the angle between the camera and the equilateral triangle landmark is nearing to be parallel to each other. So, to prevent the measurement error from getting bigger, another feature point was added and thus solidifies the equilateral triangle landmark into a tetrahedron landmark to make it impossible to form confronting equilateral triangle no matter which direction the camera is pointing at.

Key-Words: *Tetrahedron Landmark, Self-Location Recognition, Perspective-Three-Point*

1. Introduction

Close visual inspection is needed in bridge maintenance. However, scaffold is needed plus it takes time and money to perform safety measure for the inspectors if close visual inspections from under the bridge is to be performed. With this social background, close-up photography using a camera mounted on a flight vehicle has come to be used. Among that, a RC rotorcraft has special features of being hard to be shed by wind and capable of obtaining payload easily compared to other aircraft with the same volume. Furthermore, capabilities of performing fixed point hovering and rotation flights which are difficult to perform using fixed-wing aircrafts make it an excellence choice when it comes to performing close-up photography. Such self-location information of the aircraft is generally supported by GPS. However, it becomes a problem when situating the flight vehicle under the bridge making the process of accumulating precise self-location information difficult due to the interception of GPS signal by the bridge girder. Therefore, a study about technique of performing self-location recognition of the rotorcraft based on the shooting of a label placed on established actual coordinate system by a camera mounted on it.

Received: 2014/11/15, Accepted: 2014/12/1
*Corresponding author: Tetsuya Morisaki
Email: morisaki@tokuyama.ac.jp

2. P3P (Perspective-Three-Point)

Among the methods of estimating the location and direction of the camera from the geometrical characteristics of the label placed on established actual coordinate system, a method of estimating 3 feature points is called P3P solution. Figure 1 explains the outline of P3P. M_i(i=1~3) refers to 3 feature points in the labeling. Here, ${}^{w}O$ and ${}^{c}O$ are defined by origin of actual coordinate system with the label as baseline and origin of camera coordinate system with the camera as baseline respectively. Eq. 1 which elaborate $\mathbf{q}_i(i\text{=}1\sim3)$ are obtained from the image of the label captured using camera and the camera parameter from the coordinate system of the camera.

$$\mathbf{q}_i = \begin{bmatrix} u_i \cdot u_s \\ v_i \cdot v_s \\ 1 \end{bmatrix} \quad (1)$$

(u_i, v_i) $(i\text{=}1\sim3)$ is the coordinate in the image of $M_i(i\text{=}1\sim3)$, while (u_s, v_s) is a constant obtained from camera calibration. Furthermore, the following equation shows the relationship formed by making $s_i(i\text{=}1\sim3)$ as any real number.

$$\mathbf{p}_i = s_i \mathbf{q}_i,\ i = (1,\ 2,\ 3) \quad (2)$$

Here, a, b, and c are assumed to be the length of each side of the triangle according to $M_i(i\text{=}1\sim3)$ which results to the following equations.

$$\begin{cases} \left| s_1\mathbf{q}_1 - s_2\mathbf{q}_2 \right|^2 = a^2 \\ \left| s_1\mathbf{q}_1 - s_3\mathbf{q}_3 \right|^2 = b^2 \\ \left| s_2\mathbf{q}_2 - s_3\mathbf{q}_3 \right|^2 = c^2 \end{cases} \quad (3)$$

$\mathbf{p}_i(i\text{=}1\sim3)$ from Eq. 2 can be computed by solving system of equations of $s_i(i\text{=}1\sim3)$. Moreover, with $\mathbf{p}_i(i\text{=}1\sim3)$ and the coordinate of $M_i(i\text{=}1\sim3)$ on the actual coordinate system, vector ${}^w\mathbf{r}_c$ which is from ${}^wO$ towards ${}^cO$ is obtained. In other word information on the self-location of the camera is obtained. It should be noted that information about the self-location of the camera is obtainable by solving systems of equations shown in Eq. 3 through a number of solutions [1]. When solving the equation for self-location recognition, there are a few factors that have to be considered and determined such as selection of solution which means self-location from obtained a few possible solutions, calculations where rounding errors are taken into consideration, possible imaginary solution and etc. That is why numerical solution based on Newton-Raphson's method was used to solve $s_i(i\text{=}1\sim3)$.

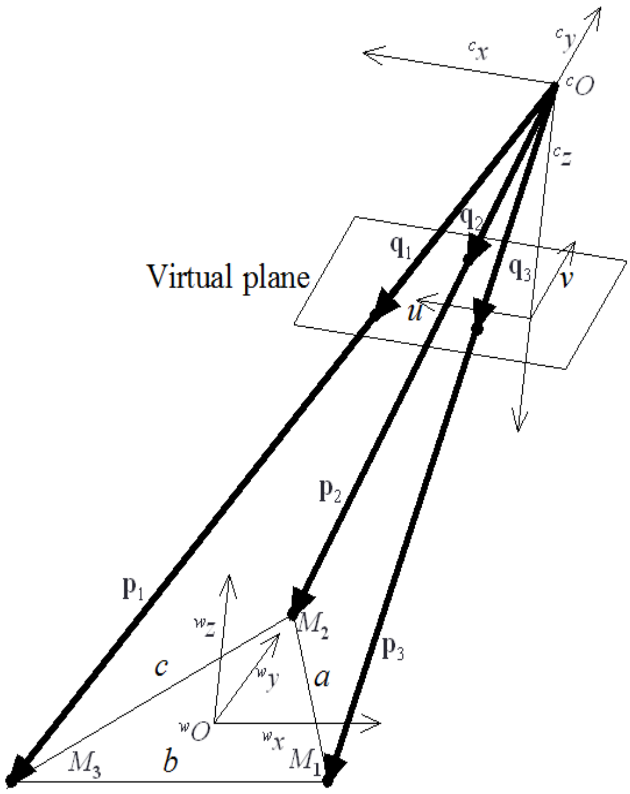


Figure 1 Perspective-Three-Point problem

3. Application of self-location measurement using P3P

(u_i, v_i) $(i\text{=}1\sim3)$ obtained from the image of photographed label includes errors caused by image processing and camera lens system. A simulation where 3 vertexes, $M_i(i\text{=}1\sim3)$ of an equilateral triangle label are assumed as feature points to estimate how this error affects the self-location of the camera was done. In this simulation, assuming the changes in the viewing angle of the camera mounted on the rotorcraft that performed pan-tilt, (u_i, v_i) $(i\text{=}1\sim3)$ is calculated by the positional relationship between ${}^wO$ and, ${}^cO$ and rotation of each axis. Vector ${}^w\mathbf{r}_c$ from ${}^wO$ to ${}^cO$ can be computed by applying (u_i, v_i) $(i\text{=}1\sim3)$ to the previously mentioned P3P method. Although in actual situation, errors of (u_i, v_i) $(i\text{=}1\sim3)$ are included from image processing and camera lens system. Assuming this, the same goes even when adding virtual error (e_{ui}, e_{vi}) $(i\text{=}1\sim3)$ to (u_i, v_i) $(i\text{=}1\sim3)$ and thus solving the vector ${}^w\mathbf{e}_c$ formed from ${}^wO$ to ${}^cO$, vector ${}^w\mathbf{e}_c$ using P3P method as same as ${}^w\mathbf{r}_c$. Then, measurement error E based on virtual error (e_{ui}, e_{vi}) $(i\text{=}1\sim3)$ is defined as shown in Eq. 4.

$$E = \left| {}^{w}\mathbf{r}_c - {}^{w}\mathbf{e}_c \right| \tag{4}$$

E is obtained from a simulation done by assuming an outdoor set up of each side of the equilateral triangle 1000[mm] with the consideration of portability and a common (u_s, v_s) = (0.500×10^{-3}, 0.500×10^{-3}[mm/pixel]) camera. Provided that, the E here is the mean value after repeating the calculation process for 1024 times as random numbers where uniform distribution of virtual error(e_{ui}, e_{vi}) (i=1~3) generated based on normal distribution (average μ=0[pixel], variance σ^2=4[pixel^2]) used by Box-Muller method. θ and φ are defined as shown in Figure 2. Here, the distance L between ${}^{w}O$ and ${}^{c}O$ is defined 10000[mm]. It should be noted that in Newton-Raphson method that the initial value of s_i(i=1~3) is assumed as true value from between the relationship of ${}^{w}O$ and ${}^{c}O$ and the final condition of the interactive calculation as shown in Eq. 5.

$$0.00001 < \sqrt{\sum_{i=1}^{3} s_i^{\,2}} \tag{5}$$

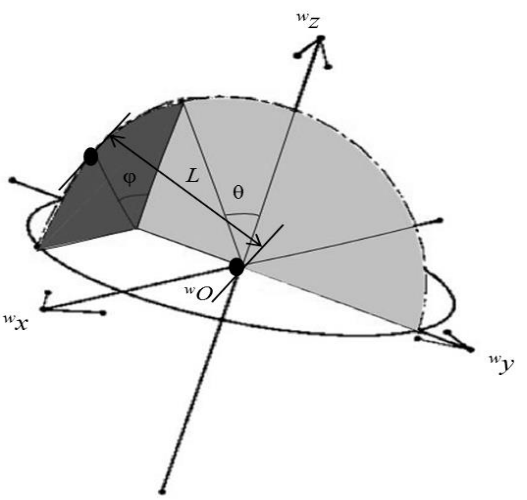


Figure 2 Definitions of θ and φ in the simulation

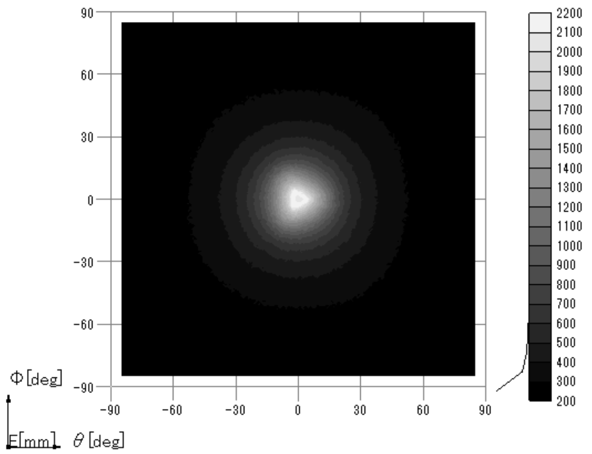


Figure 3 Estimated error distribution using the regular triangle landmark

From the result, it is understood that there are possibility that the measurement error are getting bigger as θ and φ are nearing 0[deg] or in other word, as the angle between the camera and the equilateral triangle landmark are nearing to be parallel to each other. So, to prevent the measurement error from getting bigger, another feature point M_4 on the ${}^{w}z$ axis was added and thus solidifies the equilateral triangle landmark into a tetrahedron landmark shown in Figure 4 to make it impossible to form confronting equilateral triangle no matter which direction the camera is pointing at. The first step is to solve (u_4, v_4) using the same method as (u_i, v_i) (i=1~3). Next step is to calculate the area S_i (i=1~4) [pixel^2] of triangle T_i (i=1~4).

T_1 $\{(u_1+e_{u1}, v_1+e_{v1}),\ (u_2+e_{u2}, v_2+e_{v2}),\ (u_3+e_{u3}, v_3+e_{v3})\}$

T_2 $\{(u_1+e_{u1}, v_1+e_{v1}),\ (u_2+e_{u2}, v_2+e_{v2}),\ (u_4+e_{u4}, v_3+e_{v4})\}$

T_3 $\{(u_1+e_{u1}, v_1+e_{v1}),\ (u_3+e_{u3}, v_3+e_{v3}),\ (u_4+e_{u4}, v_3+e_{v4})\}$

T_4 $\{(u_3+e_{u3}, v_3+e_{v3}),\ (u_2+e_{u2}, v_2+e_{v2}),\ (u_4+e_{u4}, v_3+e_{v4})\}$

Here (e_{u4}, e_{v4}) is another random number produced same as (e_{ui}, e_{vi}) (i=1~3). From the previous calculations, compute the minimum S_{min} from S_i (i=1~4) and then use the triangle made from T_{min} in the measurement. Figure 5(a) is the result from the simulation of the tetrahedron landmark labeled the same as in Figure 3. As the maximum measurement error E is improved to 293[mm] while the minimum is 206[mm] from the previous result shown in Figure 3 and the distribution trend of Figure

5(a) is adjusted to make the difference easier to understand. Note that Figure 5(b) is that the standard deviation is shown when using autonomous navigation onto the rotorcraft.

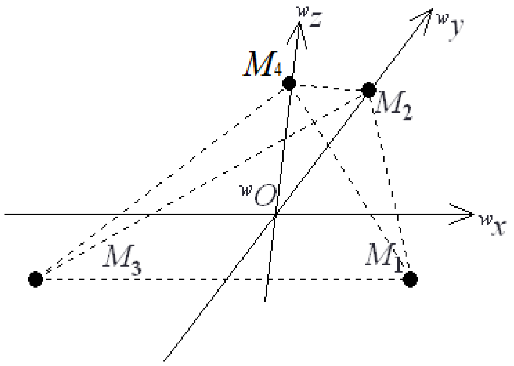
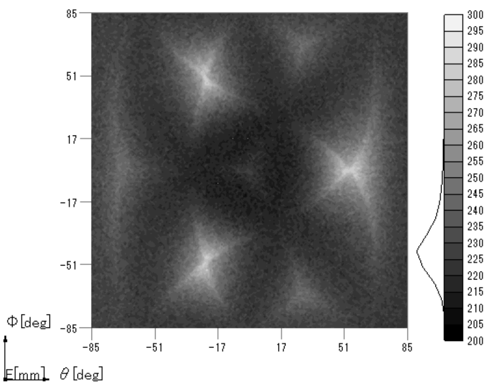
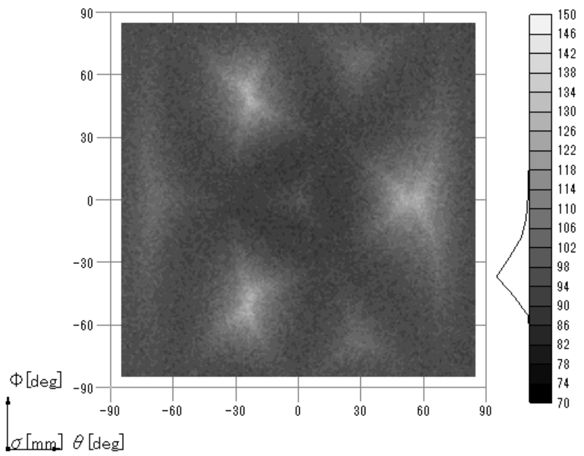


Figure 4　Added feature point M_4 on the ${}^{w}Z$ axis



(a)　Error distribution



(b)　Variance distribution

Figure 5　Estimated error and variance distributions using the regular tetrahedron landmark

4. Conclusion

In this research, an analysis on the simulation where self-location recognition measurement procedure using camera and the solid label were used was conducted. In the future, construction of autonomous navigation system using the rotorcraft by referring to the results from the simulations is expected.

Reference:

[1] Robert M. Haralick, Chung-nan Lee, Karsten OttenBerg and Michael Nolle, “Review and Analysis of Solution of the Three Point Perspective Pose Estimation Problem”, International Journal of Computer Vision, 13, 3, 1994, pp.331-356.