A Study on Attitude Estimation of UAV Using Image Processing

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Abstract
Recently, researchers are actively addressed to utilize Unmanned Aerial Vehicles (UAV) for military and industry applications. One of these applications is to trace the preceding flight when it is necessary to track the route of the suspicious reconnaissance aircraft in secret, and it is necessary to estimate the attitude of the target flight such as Roll, Yaw, and Pitch angles in each instant. In this paper, we propose a method for estimating in real time the attitude of a target aircraft using the video information that is provide by an external camera of a following aircraft. Various image processing methods such as color space division, template matching, and statistical methods such as linear regression were applied to detect and estimate key points and Euler angles. As a result of comparing the X-plane flight data with the estimated flight data through the simulation experiment, it is shown that the proposed method can be an effective method to estimate the flight attitude information of the previous flight.

Key Words : UAV, Tracking, Flight information, Euler angles, Image processing

1. Introduction
In recent years, attempts have been made to utilize unmanned aerial vehicles for the promotion of military, industrial and commercial fields, and various studies and experiments for commercial applications such as transportation of goods and IoT convergence applications have been actively conducted[1-4]. In
particular, studies to secretly track a particular aircraft or to estimate the motion of surrounding aircrafts in a cluster flight are also considered to be very important military aspects[5]. Above all, estimating the flight attitude of a leading aircraft in military terms is a very important task in covert tracking of the aircraft. In general, calculation of position and attitude data of arbitrary vehicles is done by using information generated from two devices mounted on the vehicle. The two types of information are the speed, position and attitude information generated based on the sensor data from the IMU(Inertial Measurement Unit) embedded the acceleration sensor and the gyro sensor and position information from the GPS (Global Positioning System)[6]. However, it is impossible to utilize IMU and GPS information as above to estimate the flight attitude information of the preceding flight body, but it is necessary to utilize some equipment attached to other follow-up flight vehicles. For this purpose, it is usually preferable to use a high-performance camera and to use image information photographed therefrom[7].

In this paper, we propose a method to estimate the attitude information of the aircraft from the captured image information by using the camera. Image processing algorithms such as color space segmentation, template matching, edge detection, corner detection, and Hough transform, and statistical method like linear regression are applied to estimate the attitude information of the aircraft. Through the simulation experiment, we found that the actual attitude information from the X-Plane and the attitude information from the camera images are close to each other, and that the attitude information of the preceding flight can be efficiently estimated by only the camera image information, image processing, and statistical methods.

2. Aircraft Flight Estimation Process

2.1 Development Environment

Fig. 1 shows the connections of the components that make up the proposed direction estimation system. We used two computers, PC01 and PC02, here, PC1 to run the X-Plane simulator and PC2 to run the Ot IDE to process the algorithm and LabVIEW to show or compare the results obtained through image processing, and UDP protocol was used for the data transmission between two computers.

X-Plane is a sort of flight simulator from Laminar Research, which is packaged with commercial, military, and other experimental aircrafts, as well as scene information on almost all airports on the planet[8]. In
this case, one type of aircraft is selected as the leading flying object, and it is used to extract and estimate Yaw, Roll, and Pitch information, which is the orientation information of the object through flight adjustment.

To design a user interface for displaying flight information, image processing results Qt Creator was used and for image processing, OpenCV library, which is a programming library for computer vision applications, was used. And LabVIEW, which is a system-level design platform and develop environment for a visual programming language from National Instruments, was utilized to graphically show actual flight orientation data and the estimation values at the same time.

2.2 Detection and Estimation Process

Fig. 2 shows the flow diagram for the process of flight attitude estimation. Each one of the image processing techniques used is analyzed in detail in following sections.

The steps of the proposed methodology are described below:

a) Initially the original image is captured from the display of PC01 using a monocular camera and sent to PC02.

b) In PC02, initially the image is passed through color segmentation and template matching modules in order to isolate and detect the exactly position of the aircraft in the frame.

c) Next, a binary version of the image is obtained.

d) Edge detection process is applied.

Fig. 2. Flow diagram of the proposed aircraft attitude estimation method
e) Using the previous resulting image, the virtual horizon detection is performed.
f) Using the resulting image of d) step, the tail line and its central point are obtained.
g) Corner detection process is applied over the binary image for detect LEFT, RIGHT and TOP points.
h) Using the information obtained in e) and g) ROLL angle is calculated.
i) Using the resulting image of the f) step, the distance between the central point of the tail and the main line of the wings is calculated.
j) Using the equation, previously obtained using linear regression, the PITCH angle is calculated.
k) Using the resulting image of the g) step, the distance between the points LEFT–RIGHT is calculated.
l) Using the equation, previously obtained using linear regression, the YAW angle is calculated.

3. Object Detection and Feature Extraction

3.1 Color Space Segmentation

In the proposed method, the first step taken is to separate the aircraft from the background during flight and here, color segmentation method is used. The flight objects used in the experiments are selected from the flight objects provided by the X-Plane simulator, and the colors of the objects can be selected through the setup menu. In order to distinguish from the background provided, a red color type was selected.

To do color segmentation, first the color space is converted from RGB to HSV, then the Hue channel is splitted. From this Hue channel the aircraft is detected. Hue channels are advantageous for detecting objects of a particular color because they are not affected by changes in brightness or tone of the object[9–10]. The color space conversion from RGB to HSV is calculated by the following equation 1.

\[
\begin{align*}
R' &= R/255, \quad G' = G/255, \quad B' = G/255 \\
C_{\text{max}} &= \max(R, G, B), \quad C_{\text{min}} = \min(R, G, B) \\
\Delta &= C_{\text{max}} - C_{\text{min}} \\
H &= \begin{cases} 
60' \times \left( \frac{G' - B'}{\Delta} \right), & C_{\text{max}} = R' \\
60' \times \left( \frac{B' - R'}{\Delta} + 2 \right), & C_{\text{max}} = G' \\
60' \times \left( \frac{R' - G'}{\Delta} + 4 \right), & C_{\text{max}} = B' 
\end{cases} \\
S &= 0, \quad C_{\text{max}} = 0 \\
V &= C_{\text{max}} 
\end{align*}
\] (1)

The color distribution value of the Hue channel is in the range of 0 to 360 degrees, and the value of the yellow system containing green, which is the color of the flying object used in the experiment, lies between 50 and 90. In experiments, we used this range value are used as a threshold of color segmentation.

Fig. 3 shows the results of color segmentation and shows: (a) the original image, (b) the converted HSV color space image, (c) the result image of applying the yellow color filter to the Hue channel, and (d) the binary image.

Fig. 3. Results of detection of the flight using color space segmentation
3.2 Template Matching

The next step is to use this template to detect the area of the object [11]. Template matching is a widely used algorithm in computer vision that is applied to search the same region within a single image using a specific template image as shown in Fig. 4.

![Fig. 4. Static approach for template matching](image)

Based on this template matching technique we detect the desire object from the entire image area by using a small rectangular area containing an object detected through color segmentation process.

In template matching, the similarity measure between the template image and the overlapping region of the input image is made through normalized cross correlation. Normalized cross correlation is an improved method of classical cross correlation. The result is suitable for the proposed system because it has characteristics that is invariant to the brightness variation of the image compared with the conventional cross correlation. The result of the correlation is in the range of $[-1, +1]$. +1 is when two images are coincident with each other, and -1 is when they are completely different from each other.

If the value of template pixel is $T(x, y)$ and the value of the same size window at a specific pixel position $(x, y)$ in the image is $I(x, y)$, the correlation value $R(x, y)$ between them is calculated by the following equation 2.

$$R(x, y) = \sum_{y=0}^{h-1} \sum_{x=0}^{w-1} \left[ T(x, y) - T(x+y, y) \right]^2 \over \sqrt{\sum_{y=0}^{h-1} \sum_{x=0}^{w-1} T(x, y)^2 \sum_{y=0}^{h-1} \sum_{x=0}^{w-1} I(x+y, y)^2}$$

where $T'(x, y) = T(x, y) - T$, $T$ stands for the average value of pixels in the template image and $I'(x, y) = I(x+y, y) - I(x, y)$, $I(x, y)$ stands for the average value of the pixels in the current window of the image.

As shown in Fig. 4, the method of using the fixed initial template throughout the entire process of template matching is called static template matching.

![Fig. 5. Dynamic approach for template matching](image)

But in the proposed system, since the shape of the object changes momentarily according to the flight control, applying the method makes it easy to miss the target. To solve this problem, we used a dynamic template method. In the dynamic template method, the object area detected in the current frame is used as a template in the next frame. Fig. 5 shows the process and Fig. 6 shows the result of effectively detecting an object in every frame using this dynamic template matching scheme.

![Fig. 6. Results of template matching using dynamic approach](image)
3.3 Edge Detection

In order to estimate the attitude information of the preceding flying object, it is necessary to find the length and the corner point of the wing or tail of the flying object and the edge must first be detected. Here we use a Canny Edge Detector with the best performance in the presence of noise[12]. This detector follows the next step.

1) Apply Gaussian filter $K_M$ to smooth in order to remove the noise.

$$K_M = \begin{bmatrix} 2 & 4 & 5 & 4 & 2 \\ 4 & 9 & 12 & 9 & 4 \\ 5 & 12 & 15 & 12 & 5 \\ 4 & 9 & 12 & 9 & 4 \\ 2 & 4 & 5 & 4 & 2 \end{bmatrix}$$

2) Compute the intensity $G$ and direction of the gradient $\Theta$.

$$G_x = \begin{bmatrix} -1 & 0 & +1 \\ -2 & 0 & +2 \\ -1 & 0 & +1 \end{bmatrix}, \quad G_y = \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \end{bmatrix}, \quad G = \sqrt{G_x^2 + G_y^2}, \quad \Theta = \arctan \left( \frac{G_y}{G_x} \right)$$

3) Limit the intensity $G$ using threshold value $th$ to obtain the thresholded intensity $G_{th}$.

$$G_{th} = \begin{cases} G & \text{when } G > th \\ 0 & \text{otherwise} \end{cases}$$

where $th$ is so chosen that all edge elements are kept while most of the noise is suppressed.

4) Suppress non-maxima pixels in the edges in $G_{th}$ obtained above to thin the edge ridges. To do so, check to see whether each non-zero $G_{th}$ is greater than its two neighbors along the gradient direction $\Theta$. If so, keep $G_{th}$ unchanged, otherwise, set it to 0.

5) Remove the weak edges and connect the splitted edges using Hysteresis threshold method. To connect edges, starting at a pixel which is greater than the high threshold and search all surround neighbours. If the neighbour is greater than low threshold, then it will become an edge. The range of threshold is

$$0 < th_{low} < th_{high} < 1.$$
3.5 Virtual Horizon Line Detection

In the X-Plane Simulator, the Roll angle is the angle formed by the artificial horizon and the longitudinal axis of the wings.

Therefore, in order to estimate the Roll angle of the preceding object from a moving image of the following aircraft it is necessary to detect the artificial horizon line. To do this, we apply the Hough transform algorithm[14].

As shown in Fig. 11, Hough transformation is an algorithm that the straight lines passing through all the points existing in the Cartesian coordinate plane can be converted into the polar coordinates composed of the distance $r$ from the origin and the angle $\theta$ between the horizontal axis.

The process of finding the line component in the image through Hough transform is as follows.

1) Perform a Hough transform on all the points in the edge image extracted by the canny edge detector.

2) Calculate the cumulative score for all points created in the Hough Transform plane consisting of the angle and the distance from the origin.

3) Extract angles and distances for points that have more than a certain score.

4) Draw a line on the original image for each of these angles and distances.

5) For the flight area detected by template matching, it is checked whether or not it includes the lines extracted by Hough transform.

6) Determine the lines with lengths that deviate from the flight area as candidates for the virtual horizon line.

7) A line with the maximum length among the lines included in the candidate group is selected and selected as the most appropriate virtual horizon line.

Fig. 12 shows the Virtual Horizon line extracted as a result of the Hough transform.
3.6 Linear Regression

In estimating the attitude information of the flight vehicle, the yaw and pitch angles should be able to measure the correspondence between the changes in flight wing length with respect to the angle provided when flying through the X-Plane simulator. In order to do this, we first need to estimate the relationship between them through the simulation data that have been flown in advance, and use the statistical method called Linear Regression[15].

Linear regression attempts to model the relationship between two variables by fitting a linear equation to observed data. One variable is considered to be an explanatory variable, and the other is considered to be a dependent variable. A linear regression line has an equation of the form $Y = aX + b$ in Fig. 13, where $X$ is the explanatory variable and $Y$ is the dependent variable. The slope of the line is $b$, and $a$ is the intercept.

Here, the slope $a$ and the slope $b$ are calculated by the following equation 3.

$$a = \frac{rS_Y}{S_X}, \quad b = M_Y - aM_X$$

where $r$ is the correlation between $X$ and $Y$, $S_X$ is the standard deviation of $X$, $S_Y$ is the standard deviation of $Y$, $M_X$ is the mean of $X$, and $M_Y$ is the mean of $Y$.

4. Flight Attitude Estimation

4.1 Roll Angle

For X-Plane Simulator the Roll angle is the angle formed by the artificial horizon and the longitudinal axis of the wings. Because, we know the LEFT and RIGHT points of the main line of the wings, we can find the directional vector $(u)$ for the longitudinal axis. Likewise, we can find the directional vector $(v)$ of the line of artificial horizon, because we know the start and end points. The flow diagram in Fig. 14 describes the
process for calculate Roll angle using the main line of the wings and the artificial horizon line.

**4.2 Yaw Angle**

When the aircraft turn left or turn right, the distances between the points LEFT and RIGHT of the wings suffer variations; each one of these distances is associated with a specific yaw angle.

Fig. 16. Obtaining of correlation coefficients for Yaw angle using Matlab

For find the correlation coefficients between Distances and Yaw angle values we are using Linear Regression. The flow diagram in Fig. 15 describes the process for calculate Roll angle.

Fig. 16 shows the correlation between Distances (LEFT–RIGHT) and the Yaw angle values taken from X–Plane Simulator.

After apply the Linear Regression Algorithm, over the previous data using Matlab, we can obtain the line equation that describe the correlation between Distances and Yaw angle values.

**4.3 Pitch Angle**

For calculation of Pitch angle, previously, we need apply Linear regression for determine the correlation coefficients between the distance of the central point of the tail and the main line of the wings. The flow diagram in Fig. 17 describes the process for calculate Pitch angle using the vertical distance. Fig. 18 shows the process to obtain the correlation coefficients for Pitch angle.

Fig. 18. Obtaining of correlation coefficients for Pitch angle using Matlab

**5. Experiments and Results**

**5.1 Results for Roll angle**

For the Roll angle calculated from the virtual horizon line extracted from the Hough transform and the distance between the end points of the wing, the estimated roll angles are shown in Fig. 19. Fig. 19 (a) shows the Roll angle in the X–Plane and Roll angle estimated through image processing, and (b) shows the angle difference between them.
As a result of estimation of Roll angle, the maximum error of 21 degrees occurred, and an average error of about 9 degrees occurred except the instantaneous peak due to the sudden change of direction. However, the overall tracking flow shows that the attitude of the leading aircraft is well estimated and followed according to the direction of flight.

Fig. 19. Estimation Results for Roll Angle: (a) X-plane and estimated values, (b) comparison error

5.2 Results for Yaw and Pitch angle

For the regression line calculated from the observed data captured through simulation test, the estimated Yaw angles are shown in Fig. 20. Fig. 20 (a) shows the Yaw angle generated from the X-Plane and Yaw angle calculated through linear regression method, and (b) shows the angle difference between them.

And like the Yaw angle estimation results, for the regression line calculated from the observed data captured through simulation test, the estimated Pitch angles are shown in Fig. 21. Fig. 21 (a) shows the Pitch angle generated from the X-Plane and Pitch angle calculated through linear regression method, and (b) shows the angle difference between them.

Fig. 20, Estimation Results for Yaw Angle: (a) X-plane and estimated values, (b) comparison error

Fig. 21, Estimation Results for Pitch Angle: (a) X-plane and estimated values, (b) comparison error

As a result of Yaw angle and Pitch angle estimation, the estimation error of Yaw angle is maximum 7 degrees and the estimation error of pitch angle is maximum 2 degrees. Excluding the instantaneous peak due to the sudden change of direction, the Yaw showed
a fairly accurate estimate of about 2 degrees and the Pitch was about 1 degree.

6. Conclusion

In this paper, we propose a method to estimate the flight attitude of a suspicious aircraft in advance by using various image processing algorithms and statistical processing techniques from the video information captured by the camera attached to the following aircraft. Based the simulation results, the average estimation error between X-plane data and the estimated data was found to be very accurate except for Roll angle, which is about 9 degrees for Roll, 2 degrees for Yaw, and 1 degree for Pitch. We found that the proposed algorithm shows a very meaningful performance.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Ministry of Science and ICT (NRF-2017R1A5A1015311).

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