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Steering Angle Measurement of UAV Navigation Based on Improved Image Processing

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Abstract. *Because traditional magnetic sensors such as gyroscope and six-axis sensor are easily interfered from the surrounding magnetic fields, CCD camera is recommended in steering angle measurement of UAV navigation. We used an experimental platform of UAV carrying a downward camera, and proposed a steering angle measurement of UAV navigation based on improved image processing including Gaussian filtering and improved Bernsen binarization. The proposed method binarizes captured frames and segments out feature objects. Two object's centroids are used to calculate angle differences between consecutive frames. The experimental results indicate that the improved Bernsen method performed a more stable angle measurement than the traditional Bernsen method. In the stability experiment, maximum angle difference of* ± 0.10 *degrees is obtained. The proposed method is also computational efficient to 0.0876 sec/frame.*

Keywords: Image processing, Angle measurement, UAV Navigation

1. Introduction.

Steering angle measurement plays an important role for airy vehicle navigation. The traditional steering angle measurements of airy vehicles depend universal angle ruler, sine bar and so on, but these methods exist disadvantages of low efficiency and large man-made error. A better solution of angle measurement is non-contact method. For example, the angle measurement in small UAVs mostly adopts gyroscope and six-axis sensor to achieve convenient and fast measurements. However, most gyroscope and six axis sensor are magnetic and are easy to be interfered from the surrounding environment, such as large electricity field caused by high voltage electricity. Therefore, how to use non-magnetic sensors to obtain higher accuracy and better stability of angle measurement has been received many attentions by research communities.

Magnetic sensors are easily interfered from the surrounding magnetic fields, so that measuring errors happen and effect the navigation of air vehicles. CCD camera is a non-magnetic electronic component and it can perform well without the effect of the surrounding magnetic fields. Moreover, its low cost and high stability are attracted by many developers of UAV navigation. A UAV carries a CCD camera and captures images from grounds. And then machine vision algorithms process and compute images frame by frame such as optical flow [1]-[2]. For example, the steering angle of the UAV is obtained by the computation of several feature points in consecutive frame images [3].

In this paper, we propose an improved method of image processing to find feature points in every frame and compute more accurate steering angle. Gaussian Filtering is first used to smooth frame images and reduce noise. Then, image binarization segments target objects and their feature points are referred to compute steering angles. We propose an improved algorithm based on traditional Bernsen method. The proposed algorithm considers both global and local characteristics of frame images and the shadows and incomplete contours of the binarized objects are greatly reduced. Therefore, more segmentation accuracy is improved by the improved algorithm than Bernsen method.

The remainder of this paper is organized as follows. Section 2 describes the proposed algorithm. Section 3 demonstrates and discusses experimental results of the proposed methods. The conclusions are drawn in Section 4.

2. **Proposed method.**

Two processes of our proposed method contain smooth filtering and image binarization. The following subsections will introduce the two processes.

2.1. **Image Segmentation.**

Due to avoiding noise in the binarization process, a preprocessing of image smoothing is applied after image frame acquisition. Gaussian filtering is very common in many images smoothing processing and it is able to reduce noise effectively. The filtering result is more suitable to different noises than that of mean filter. Its side effect of blur is quite few. Gaussian distribution function is shown as Eq.(1). x and y are the coordinates of neighboring pixels around a center, and σ is a standard deviation of Gaussian distribution to determine filter's window size.

$$h(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}} \tag{1}$$

We discretize the Gaussian distribution function to form Gaussian filter. The weights of the filter are the function values in discretized spatial locations. The filtering value for a current pixel is computed by a weighting sum of neighborhood pixels of a testing image. Fig.1 shows a Gaussian distribution function.

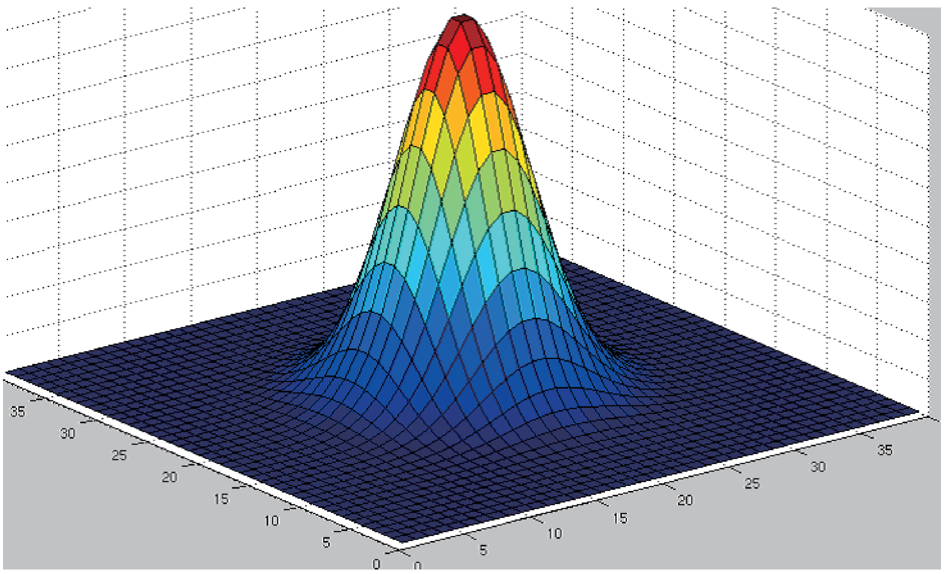

FIGURE 1. A gaussian distribution function

After that, considering the filtering effect of Gaussian filter, the standard deviation is selected by an optimization process. We refer a signal-to-noise ratio of an image to determine the filtering window's size and the ratio is defined in Eq.(2).

$$SNR = \frac{I_g}{\sigma_w} \tag{2}$$

where I_g means an estimate of image signal's intensity and σ_w means an estimate of image noise's standard deviation [4]. The estimate process computes a criterion of least correlation coefficients. Fig.2(a) shows the original image and Fig.2(b) demonstrates the filtering result by Gaussian filter. We found that the image becomes more blurry but the unwanted noise in the image is removed. Finally, we obtain an image with less noise by the preprocessing.

(a) (b)

FIGURE 2. (a)Original image of a four-rotor UAV (b)Filtering result by Gaussian filter

2.2. **Improved Image Binarization.** Image binarization plays an important role in object segmentation and its critical point is how to find an optimized threshold. A pixel's gray level is compared with the threshold and then the pixel is classified into foreground or background. The threshold is whether suitable or not that will affect segmentation result. Three categories of image threshold methods are described as follows.

i) According to illumination distribution, a global threshold is selected. Then, an image is partitioned into blocks and each block is binarized by the global threshold.
ii) A preprocessing is used to modify a background illumination of an image. That makes the background illumination to approach to an even gray level. Then, a global threshold is applied to binarization the image.
iii) A local threshold is applied each pixel and the threshold is adjusted according to neighbor pixels, such as Niblack [5][10] and Sauvola methods [6].

However, the methods of three categories have disadvantages respectively as follows.

i) A large illumination difference between background and foreground in image block will perform binarization result well for the 1st categorized methods. However, the binarization result becomes worse when no discriminating threshold exists in an image block.
ii) The computational amount of background estimation is large in 2nd categorized methods. The estimation also exist over-fitting and under-fitting disadvantages. When the gray levels between foreground and background are close, the segmentation result also becomes worse [9].
iii) Due to the pixel-by-pixel threshold adjusting in the 3rd categorized methods, large computational amounts are needed. And, the poor segmentation often results from low discriminating target objects.

The traditional Bernsen method cannot perform binarization well because of image contrast caused by environment change [7]-[8]. A condition of uneven lighting largely affects image binarization. Therefore, we propose a modification of pixel-by-pixel binarization to improve Bernsen method. The purposes of the improvement are to reduce computation and to increase segmentation accuracy. The processing of improved method is described as the following steps.

S1. Calculate the largest T_s to make $\sum_{i=T_s}^{255} hist[i] \geq S \times 10\%$, where $hist[i]$ is a histogram of an image and S is the total number of image pixels.

S2. Calculate $T_0(x,y)$ image of filtering operation as

$$T_0(x,y) = 0.5 \times \left[\max\left(f(x+k,y+l)\right) + \min\left(f(x+k,y+l)\right)\right], for - W \leq k,l \leq W \quad (3)$$

where $f(x,y)$ is image gray level value in (x,y), the value of the threshold image in (x,y) is assigned by a mean value of maximum and minimum in the neighborhood centered in (x,y) and the window size is $(2W+1) \times (2W+1)$.

S3. Calculate $T_1(x,y)$ image of filtering operation as

$$T_1(x,y) = \left[\max\left(f(x+k,y+l)\right) - \min\left(f(x+k,y+l)\right]\right., for - W \leq k,l \leq W \quad (4)$$

where the value of the threshold image in (x,y) is assigned by a difference value of maximum and minimum in the neighborhood of (x,y).

S4. Calculate $T_2(x,y)$ image of filtering operation as

$$T_2(x,y) = \text{mean}\left(T_0(x+k,y+l)\right), for - W \leq k,l \leq W \quad (5)$$

where the value of the threshold image in (x,y) is assigned by a mean $T_0(.)$ of the neighborhood of (x,y).

S5. We first compare pixel gray level with $(1+a)$ and $(1-a)$ times of T_s as Eq.(6). If gray levels are great than $(1+a)$ times of T_s, the binary pixel of $b(x,y)$ is assigned bit-1. Otherwise, if the gray levels is less than $(1-a)$ times of T_s, $b(x,y)$ is assigned bit-0. The factor of a is assigned $0.25 \sim 0.5$ experimentally.

$$\begin{cases} \text{if } f(x,y) > (1+a) \times T_s, \text{ then } b(x,y) = 1 \text{ else} \\ \text{if } f(x,y) < (1-a) \times T_s, \text{ then } b(x,y) = 0 \end{cases} \quad (6)$$

S6. After S5, the pixels between $(1-a) \times T_s$ and $(1+a) \times T_s$ continue to process. If $T_1(x,y)$ of a pixel is less than $a \times T_s$, the responding $b(x,y)$ is assigned bit-0. Otherwise, we compare the pixel gray level with $T_2(x,y)$. If the pixel gray levels are greater than $T_2(x,y)$, the responding $b(x,y)$ is assigned bit-1, bit-0 or not.

$$\begin{cases} \text{if } T_1(x,y) < a \times T_s, \text{ then } b(x,y) = 0 \text{ else} \\ \text{if } f(x,y) \geq T_2(x,y), \text{ then } b(x,y) = 1 \text{ else } b(x,y) = 0 \end{cases} \quad (7)$$

Fig.3 shows the segmentation results of four methods. Fig.3(a) is the result of 1st category method using a global threshold. Many shadows are not correctly segmented into the foreground. Fig.3(b) is the result of 2nd category method using local thresholds. No shadow results but the foreground is incomplete in the object's body. Fig.3(c) is the result of the method using point by point binarization. The foreground is more complete but there is still some holes inside the object. Fig.3(d) is the result of the proposed method using a global threshold and point by point binarization. The result is the best of the four methods. The object contour is complete with very few inside holes.

Our proposed method takes care of global characteristics of an image and improves the disadvantages of Bernsen method. Meanwhile, the method greatly reduces shadows and incomplete contours. About the computational time, Bernse method and our proposed method respectively consume 0.1103 seconds and 0.0876 seconds per image frame under Matlab platform. Therefore, our proposed method performs better segmentation and consumes fewer computational time than Bernse method.

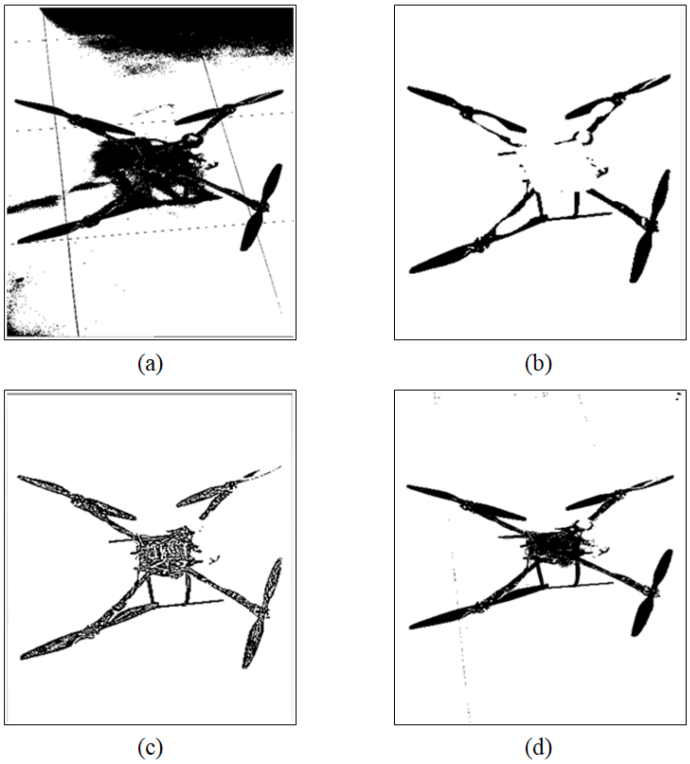

FIGURE 3. Segmentation results of four methods: (a) 1st category method, (b) 2nd category method, (c) point by point binarization, (d) our proposed improved Bernsen method

3. **Experimental Results.** Our experiment has applied a low-cost camera and its resolution is 640x480. We used Visual Studio with a image processing library of OpenCV2 to develop our navigation system. The implementation of our proposed algorithm has been done by C/C++. The function worked efficiently and fluently. The frame rate of the image acquisition is 30 frames per second. By the way, to ensure that image feature points can reflect the real location of the UAV, the camera is needed to install perpendicular to the plane.

We performed our proposed method of Gaussian filtering and image binarization as the above mentioned, and applied image moments operation to compute a object's centroid. Fig.4 displays segmentation results of two objects and their centroids. Then, two object's centroid can be used to calculate a slope angle. Finally, the difference of two slope angles of the two centroid pairs between two consecutive frames can be used to estimate the rotation angle of the camera.

Our experiment used two rectangles to be feature objects. The operation of image moments obtains two object's centroids after our proposed binarization in a frame image, denoted by (x_0, y_0) and (x_1, y_1). Two other centroids of the two objects in the next frame are denoted by (x_2, y_2) and (x_3, y_3). Then, the difference of two slope angles from ϕ_0 to ϕ_1 between the two consecutive frames is obtained by Eq.(8).

$$\Delta\phi = \phi_1 - \phi_0 = \tan^{-1}\frac{y_3 - y_2}{x_3 - x_2} - \tan^{-1}\frac{y_1 - y_0}{x_1 - x_0} \tag{8}$$

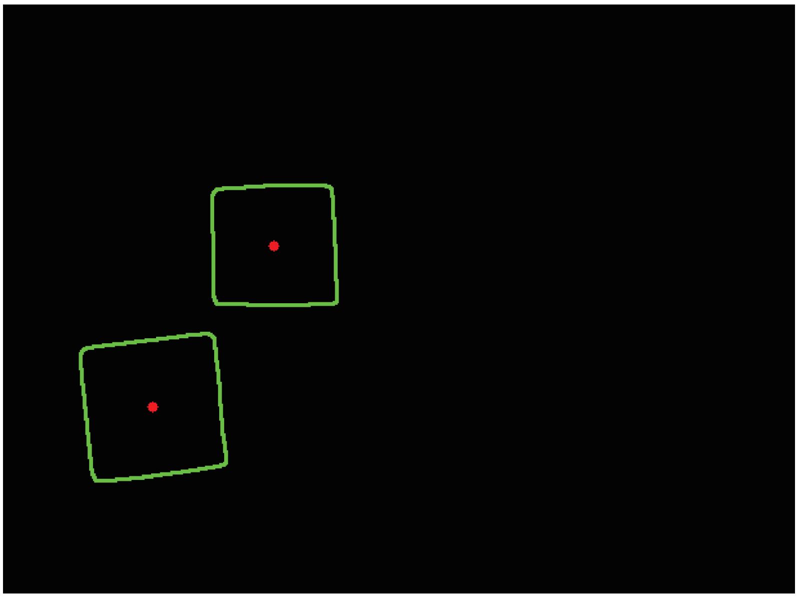

FIGURE 4. Segmentation results of two objects and their two centroids

FIGURE 5. Our UAV kept at a fixed height

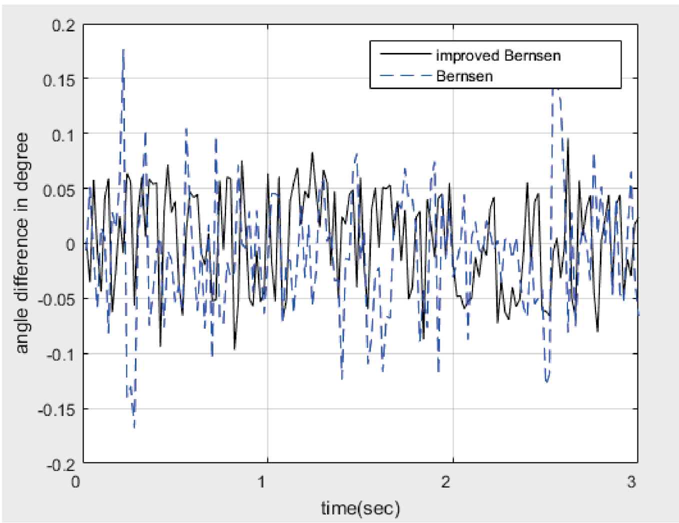

FIGURE 6. Two curves of slope angle difference in time

We have done an experiment of angle measurement by a four-rotor UAV. Our UAV rose and then kept itself at a fixed height without any rotation, and then the camera captured downwards two rectangle objects, as shown in Fig.5. Then, an image binarization method performed to compute a slope angle difference between consecutive frames. We plotted a curve of slope angle difference in time for a binarization method and compared traditional Bernsen and our improved Bernsen. Fig.6 displays that the curve changes less by improved Bernsen than by Bernsen. That indicate the slope angle by improved Bernsen is closer to zero angle in the stability experiment. Table 1 lists the comparison of the two methods. Less maximum angle difference is resulted by improved Bernsen, and its computational time is less than Bernsen. In addition, we observed these extracted centrods in image frames. We found that the positions of centrods change less by improved Bernsen than by Bernsen.

Table 1. Comparison of two binarization methods

??	Maximum angle difference	Computational time
Bernsen	$\pm 0.17°$	0.1103 sec/frame
Improved Bernsen	$\pm 0.10°$	0.0876 sec/frame

We also have done an rotation experiment. Our UAV rose and kept itself at a fixed height. The UAV rotated a 90° angle and then kept to the fixed height. Similarly, we performed an image binarization method to compute a slope angle difference between consecutive frames. We plotted a curve of cumulative slope angle difference in time for a binarization method, as shown in Fig.7(a)-(b). Both of the two curves of cumulative slope angle difference increase and approach 90° degree from 0°. The curve by improved Bernsen method is little earlier to approach 90° than Bernsen method. Fig.7(c) displays two curve of slope angle difference by the two methods. We found that the improve Bernsen method made smaller variance than Bernsen method. Therefore, our proposed improved Bernsen method performed better than Bernse method for practical steering angle method.

4. **Conclusions.** This paper presents a new method to measure a UAV's navigation angle. Based on computer vision, our proposed method solves the problem of traditional sensors easy to be disturbed by surrounding on a UAV. The proposed method applies Gaussian filtering and improved Bernsen binarization to reduce image noises and to segment a more complete foreground object, so that more accuracy of angle measurement can be achieved. In the stability experiment, maximum angle difference of $\pm 0.10°$ is obtained. The proposed method is also computational efficient to 0.0876 sec/frame.

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REFERENCES

[1] D. Honegger, P. Greisen, L. Meier, P. Tanskanen, and M. Pollefeys, *Real-time velocity estimation based on optical flow and disparity matching*, 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Oct 2012.

[2] F. Kendoul, I. Fantoni, and K. Nonami, Optic flow-based vision system for autonomous 3D localization and control of small aerial vehicles, *Robotics and Autonomous Systems*, vol. 57, no. 67, pp. 591-602, 2009.

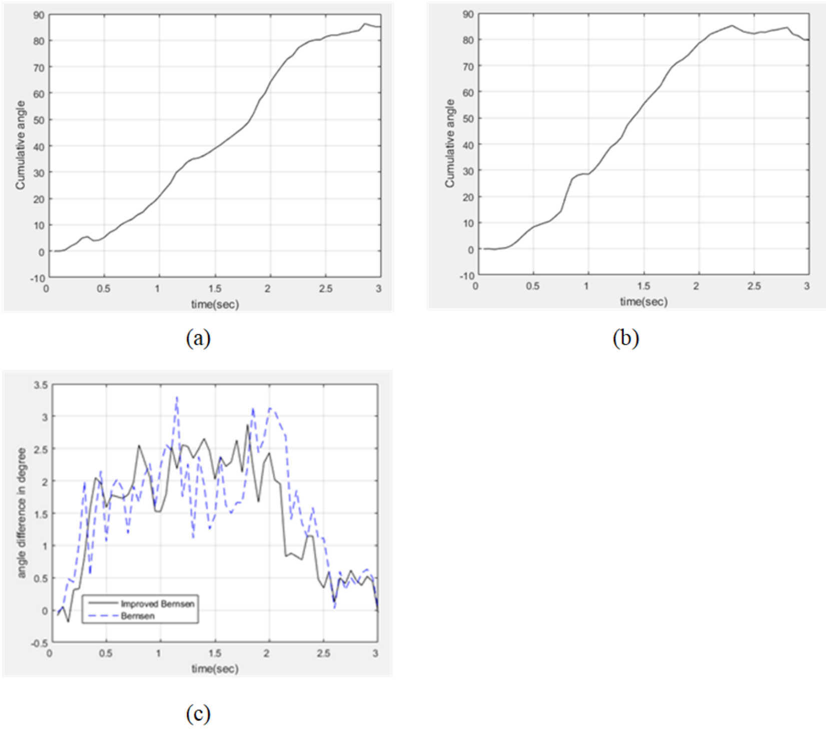

FIGURE 7. Results of angle measurement: (a)-(b) two curves of cumulative slope angle difference by Bernsen and improved Bernsen respectively (c) two curves of slope angle difference by two methods

[3] Y.L. Xu, H.W.Yu, J.Y. Zhong et al., Real-time image capturing and processing of seam and pool during robotic welding process, *An International Journal of Industrial Robot*, vol. 39, no. 5, pp. 513-523, 2012.
[4] Mohsen E M and Mansour J, Linear motion blur parameter estimation in noisy images using fuzzy sets and power spectrum, *EURASIP Journal on Advances in Signal Processing*, vol. 1, pp. 1-8, 2007.
[5] W Shi, L Fang, S Chen, et al., Algorithm for Image Binarization Based on Improved Otsu and Niblack, *World Sci-Tech R& D*, 2013.
[6] Sauvola J and Pietikainen M, Adaptive document image binarization, *Pattern Recognition*, vol. 33, pp. 225-236, 2000.
[7] Q. Ouyang, Study on license plate binarization method under non-uniform illumination, *Engineering Journal of Wuhan University*, vol. 39, no. 04, pp. 143-146, 2006.
[8] D. Chen, F. Zhang, G.M. He, An improved binarization algorithm for text image, *Science and Technology Information*, vol. 29, no. 13, pp. 85-86, 2003.
[9] W. C. Hu, C. Y. Yang, D. Y. H. and C. H. Huang, Feature-based face detection against skin-color like backgrounds with varying illumination, *Journal of Information Hiding and Multimedia Signal Processing*, vol. 2, no. 2, pp. 123-132, 2011.
[10] Jen-Chang Liu and Tsung-Min Lin, Location and image-based plant recognition and recording system, *Journal of Information Hiding and Multimedia Signal Processing*, vol. 6, no. 5, pp. 898-910, 2015.