Vision-based Runway Recognition for UAV Autonomous Landing

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Summary
To meet the request of recognizing the runway synchronously and precisely for the UAV during the autonomous landing, the paper presents a method for automatic recognizing airport runway based on the knowledge of vision. Making full use of the characteristics of the runway region and boundary, this method first gets the approximate region by projection, then obtains the boundary by fitting line to recognize the runway using an algorithm combined Hough transform with least square according to the boundary characteristic of the runway. The test results prove that this method can recognize the runway quickly and accurately.

Key words:
Input the UAV; autonomous landing; runway recognition; vision-based navigation

1. Introduction

In the field of military aviation, the importance of the UAV autonomous landing has attracted much attention. There is stricter request for navigation precision and reliability for the UAV autonomous landing. The method based on vision navigation can reduce the dependence on the environment and realize the landing without the intervention of human. Therefore, the state estimate and flying control of vision-based autonomous landing for the UAV are gradually becoming a hotspot in and out countries[1-3].

At present, there is much research on autonomous navigation for the rotor UAV, and precise results could be acquired from field test [1-2] . However, it is still difficult for the fixed wing UAV to realize autonomous navigation[3]. There are many advantages for UAV to landing on the runway, such as lower overload, less damage, shorter time for takeoff again and longer working life[4]. As a result, research on vision-based technology for the fixed UAV autonomous landing is becoming one of the key problems that is to be solved urgently.

The essential problem for UAV to realize autonomous landing is to recognize the runway and acquire the corresponding information. Literature [5] can get precise results by the method of template matching to recognize the runway, while this method has the limitation of adjusting template size continuously according to the runway change. Literature [6] asserts that its method can recognize the runway by setting red marker on corner, which is simple, but not practical. This paper presents a double-deck algorithm for automatic identifying airport runway. The first-deck detects runway position approximately by projected method and gets original orientation, and the second makes use of the combined method of Hough transform and least square to get runway boundary and obtain runway information. Results indicate the double-deck algorithm can recognize runway quickly and accurately.

2. Runway Detection

Before identifying runway, it is important to analyze runway characteristics. When the UAV is landing, the camera is fixed on the nose and the light axis parallels to the body axis. The characteristics of runway images is as follows: First, compared with the scenery around, gray value is higher and changes reposefully; second, after projection transformation, aberrance occurred in runway area that original parallel borderlines becomes two intersect lines in the image, third, the area above horizon is sky and below is ground.

2.1 Preprocessing

The series of images acquired inevitably contain much noise which influences the accuracy of edge recognition. Therefore suitable filter must be used to restrain and eliminate the effect of noise. Considering reducing fringe illegibility when eliminating noise and satisfying real time request for system, a crisscross 3×3 Median-filter is applied.

2.2 Original Location of Runway Area

According to the runway model in the paper, when the UAV is landing, the images taken change from small to big and have some disturbance from propeller and runway marker. As a result, the area-based method could not detect runway correctly. When the runway area in image is smaller, the boundary-based method could not detect runway boundary easily. Taking into consideration of detecting approximate runway area at first, runway can be identified in inspected area by boundary-based inspecting method.

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First, we take horizon from images and get runway bound. Analysis from images indicates that there is obvious gray change in the intersectant area from sky to ground, which is horizon. Dots where the gray change occurs are where the horizon lies. Fitting these dots it will get the line equation of the horizon: $y = k_0 x + b_0$. The horizon was detected is Fig.4

By analyzing the images, it can find that the main runway in image is like a triangle the gray value of which is high. Then converting the gray image to a binary image by threshold segmentation, saving landing targets and removing other objects which disturb runway's detection. The paper uses double threshold method to segment images. After taking a great deal of experiments, the following threshold has been chosen:

$$T1 = g_{\min} + 0.60(g_{\max} - g_{\min}) \quad (1)$$

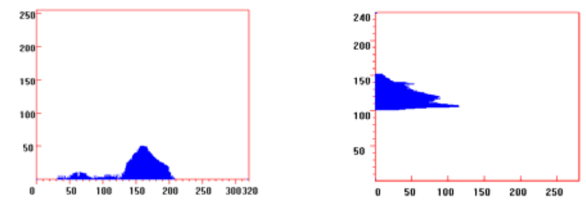
$$T2 = g_{\min} + 0.85(g_{\max} - g_{\min}) \quad (2)$$

Thereinto, g_{max} and g_{min} are maximum and minimum gray value respectively for image pixel. And then gray images are segmented by choosing threshold.

$$g(x,y) = \begin{cases} 255 & T1 \le f(x,y) \le T2 \\ 0 & \text{others} \end{cases} \quad (3)$$

Image segmented by threshold is a binary image, just as Fig.1 (a). Because of the complex landing situation that there are much disturbance near runway such as house road cars and so on, some disturbance exists in segmented image. In order to get relatively simple scene, this paper uses the method of corrupting and dilating to move small disturbance from image.

After corrupting and dilating operation, eliminating invalid little disturbance can make sure that original size for processing target does not change basically. Second, projecting respectively in vertical and horizontal direction to the processed binary image, and getting projection histogram Fig.1. The gray value of columns that belong to runway are higher than others columns. Therefore, when projecting in vertical direction, peak parts in projection image reveal the position of runway; when projecting in horizontal orientation, the first peak from up to down reveal vertical position of the runway. After the above procedures, the runway area can be determined. In order to reduce the amount of calculation and satisfying real time request, in further processing of the image, we only process runway area.



(a) Projection in vertical direction (b) Projection in horizontal direction

Fig 1 Projection histogram

2.3 Precise Detection of Runway Boundaries

After making sure runway area, the Sobel operator is used to detect edge in runway area and to get runway boundaries. We move horizontal template $\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix}$ and vertical template $\begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix}$ in boundary detecting area for runway image, and compute gradient value corresponding to center pixel in every position. The operation result is the image with edge range value. We reserve the edge dots which exceed certain threshold and get binary edge image. Yet such boundary detection is rough, which can influence the detecting precision, then thinning operation is applied to acquiring accurate edge.

3. Runway Boundary Extraction and Runway Recognition

After detecting runway boundary, the line parameter of two vertical boundaries can be obtained from runway, consequently acquiring the position relative to runway and the pose of UAV.

The extraction of runway boundaries mainly contains identifying line parameters of runway boundaries. At present, there are many methods to get line parameters, while these methods all have some flaws. For example, obtaining line parameter with the least square, if disturbance dots exist in obtained data, will bring big error. Hough transform[7] can control disturbance and yawp commendably, but the method has some drawbacks that the amount of calculation is large, the real time performance is bad and it's not easy to control the precision. When a higher line precision is needed, Hough transform can't meet the request.

After analyzing the two methods above, this paper presents a development. Firstly, the inspecting area of the runway is reduced, which make sure the rapidity of Hough transform and improve real time efficiency and eliminate disturbance. Then least square method is used to obtain line parameters of runway boundaries. Such method not only solve the problems that least square is influenced easily by disturbed dots and data dots around multiple lines can not be fit, but also result in improved line precision and real time performance.

The fundamental thought of Hough transform is duality of the dot and line. The pole coordinate equation in plane coordinate meets the following equation:

$$\rho = x\cos\theta + y\sin\theta \tag{4}$$

Thereinto, ρ is the distance from(x, y) on line *l* relative to original point, θ is angle between ρ and x axis.

Known from formula 4, points in line l form a group of curves which intersect into a point in parameter space. Obviously, if maximum point in parameter space can be acquired, line will be found out.

Because detecting range has been reduced to runway area when runway is originally inspected, Hough transform changes only in this area. Moreover, Hough transform is search for line parameter θ, as a result under the condition of no known knowledge, it must have the range in $[0, 2\pi]$ to search. The method proposed in this paper can make search range become smaller by known knowledge on runway boundaries. In image, we define left-low corner as the original point, so image locate in first quadrant in $O-xy$ coordinates. The Position of two runway boundaries in the coordinates is Fig.2 and Fig.3. Line parameter θ of the left runway boundary and right runway boundary locates separately in the range $[\pi/2, \pi] \bigcup [3\pi/2, 2\pi]$ and $[0, \pi/2]$. With the operation above of reducing parameter range, the processing time is greatly shortened and meets the real time request of system.

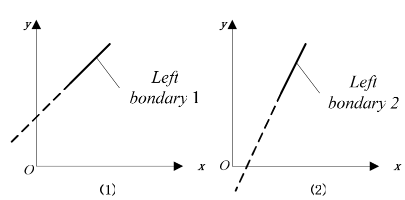


Fig.2 Distribution of left boundary

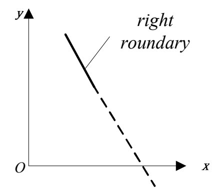


Fig.3 Distribution of right boundary

Rewrite formula 4 into following:

$$y = -\frac{\cos\theta}{\sin\theta}x + \frac{\rho}{\sin\theta} \tag{5}$$

By Hough transform we can get two maximum points in parameter space, which represent separately left and right boundary of runway. the line slope k and intercept b of the two boundary is as follows:

$$k = -\frac{\cos\theta}{\sin\theta}, \quad b = \frac{\rho}{\sin\theta} \tag{6}$$

the perpendicular distance from point to line is:

$$d = \frac{\left| -\frac{\cos\theta}{\sin\theta}x + \frac{\rho}{\sin\theta} - y \right|}{\sqrt{1 + (-\frac{\cos\theta}{\sin\theta})^2}} \tag{7}$$

Choosing suitable threshold d_k, when $d \le d_k$, reserving point (x, y), when $d > d_k$, and deleting point (x, y), we will get separately characteristic points of runway boundaries.

When getting characteristic points of runway boundaries, the line can drawn by least square fitting by these points, and the parameters of runway boundaries can be determined.

The linear equation of runway model is assumed as $\hat{y} = a + bx$ and the characteristic points of runway boundary is denoted as $(x_i, y_i)(i = 1, 2, \cdots, n)$.

If these characteristic points satisfy above equations, the mean square error $Q(a,b) = \sum_{i=1}^{n}(y_i - \hat{y})^2 = \sum_{i=1}^{n}(y_i - a - bx_i)^2$ must be the smallest. If $Q(\hat{a}, \hat{b}) = \min Q(a, b)$, least square estimated value of a and b can be acquired.

Make:

$$\frac{\partial Q}{\partial a}\Big|_{(a,b)=(\hat{a},\hat{b})}=0\,,\quad \frac{\partial Q}{\partial b}\Big|_{(a,b)=(\hat{a},\hat{b})}=0$$

the solution is denoted as：

$$\hat{a}=\overline{y}-\hat{b}\overline{x} \qquad (8)$$

$$\hat{b}=\frac{\sum_{i=1}^{n}(x_i-\overline{x})(y_i-\overline{y})}{\sum_{i=1}^{n}(x_i-\overline{x})^2} \qquad (9)$$

Thereinto,

$$\overline{x}=\frac{1}{n}\sum_{i=1}^{n}x_i\,,\quad \overline{y}=\frac{1}{n}\sum_{i=1}^{n}y_i$$

$\hat{a}$ and $\hat{b}$ are the least square estimation of line intercept and slope.

The algorithm approach is as follows:

1) Hough transform changes points in image space into parameter space and the step length of ρ and θ is 1;
2) Search for line in Hough plane and separately obtain line parameter on edge of two lines;
3) In the results, separately obtain edge points near two lines, delete the points far from line and reserve the points near line to draw characteristic points preparing for the next step;
4) According to above characteristic points, draw line with least square method, and obtain final parameter of the two runway boundary line;
5) According to line parameter, draw runway boundary in image.

4. Experimental Result and Analysis

In order to validate the algorithm, the paper makes use of a serial of images of the front sight airdrome, which are gotten from certain type UAV. We did many experiments in Visual C++ 6.0 environment. With the method presented in the paper, identifying result is illustrated in Fig.4. From Fig.4 we know that the paper's algorithm can get left and right runway boundary accurately.

Frame 21 Frame 77

Frame 87 Frame 97

Fig 4 Recognition results

Supposing the slopes of two boundaries are separately k_1 and k_2. With two slopes we can calculate two angles *α* and *β* between two boundaries and level. And according to size of *α* and *β*, we can analyze qualitatively whether UAV should fly left or right. Runway model for UAV is Fig.5.

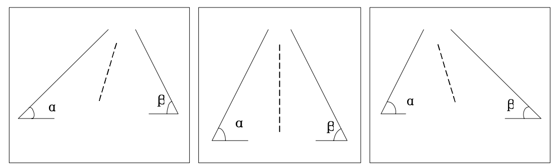


Fig 5 Runway model

1) when α<β, if the UAV is on the right of the runway, control the UAV fly to left;
2) when α=β, if the UAV is in the center of the runway, control the UAV fly in straight;
3) when α>β, if the UAV is on the left of the runway, control the UAV fly to right;

Generally speaking, the landing speed of the fixed UAV is about 60 k/h, and the sampling speed is 100 ms/f. Fig.6 illustrates variable curve of landing images about 80 frames intercepted from serial images, the average processing speed of which is about 90 ms/f, so this algorithm can meet real time request. Shown in Fig.6, the distance from runway is nearer and nearer, and the average processing time of every frame increases correspondingly. That's why the time of Hough transform increases correspondingly in runway area with the size of image increasing, but the processing time is in acceptable field. The percentage of the different part accounting for the total time during the processing procedures of each frame is illustrated as Table 1.

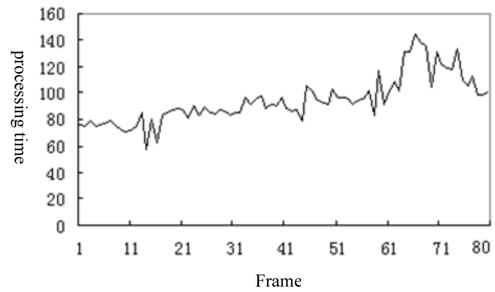


Fig .6 Curve of processing time

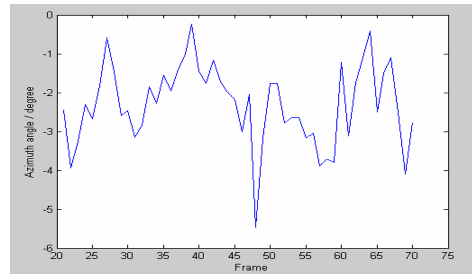


Fig.9 Curve of azimuth angle

Table 1: Processing time of images

Image processing	Processing time
Preprocessing	≈ 19%
original detecting	≈ 35%
precisely location	≈ 36%
computing and display image	≈ 10%

According to method of the literature [8], attitude angle for UAV can be acquired. Fig 7, Fig 8 and Fig 9 show the variable curve of attitude angle. Compared to actual attitude angle data, these curves can reflect variable situation of attitude angle when the UAV is landing. The controller of UAV can adjust duly plane pose and ensure landing safely and placidly. Experimental results indicate that the algorithm in this paper is effective.

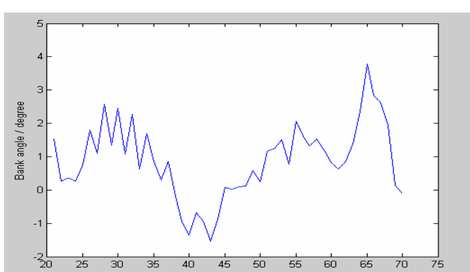


Fig.7 Curve of bank angle

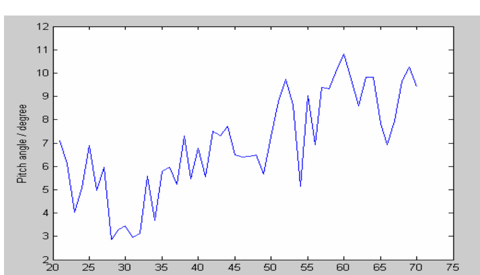


Fig.8 Curve of pitch angle

5.Conclusion

In order to solve the problems of runway recognition when UAV is landing, this paper presents an autonomous detecting method based on runway area and characteristic points, which makes full use of the runway information and reduce the time of Hough transform. The combination of Hough transform and least square fitting is applied to guarantee the accuracy of the extraction of runway boundaries.

Acknowledgments

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References

[1] Srikanth Saripalli, James F. Montgomery and Gaurav S.Sukhatme. Vision-based Autonomous Landing of an Unmanned Aerial Vehicle[J]. IEEE. 2002: 2799-2804.

[2] Srikanth Saripalli, James F. Montgomery, and Gaurav S. Sukhatme. Visually Guided Landing of an Unmanned Aerial Vehicle[J]. IEEE. 2003:371-380

[3] J. Hintze. Autonomous Landing of a Rotary Unmanned Aerial Vehicle in a Noncooperative Environment using Machine Vision[D]. Masters Thesis, Brigham Young University, 2004

[4] CaoYunfeng, TaoYong, ShenYongzhang, Guidance and Control for Automatic Landing of UAV[J]. Transactions of Nanjing University of Aeronautics & Astronautics, 2001, 18.(2): 229-235

[5] Ding Meng, CaoYun-feng. A Method to Recognize and Track Runway in the Image Sequences Based on Template Matching[J]. IEEE. 2006:1218-1221

[6] Alison A.Proctor, Eric N.Johnson. Vision-only Approach and Landing[J]. AIAA . 2005:1-10.

[7] Hough P V C. Method and Means for Recognizing Complex Patterns[J]. Patent, 1962,30(1): 54-69

[8] S.Sasa, H.Gomi, T.Ninomiya, T.Inagaki, Y.Hamada. Position and Attitude Estimation Using Image Processing of Runway[J]. AIAA: 38th Aerospace Sciences Meeting & Exhibit. 2000: 1-10

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