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Vision-Based Horizon Extraction Method under Kalman Filter Framework

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Abstract

As the demands of UAV's visual navigation technology, we bring out a new horizon extraction method in this paper. Firstly, we propose a horizon extraction algorithm for single image. We employ dark channel in single image to avoid the interferences from clouds and fogs, and use Sobel operator extract edges, among which we can extract the true horizon through an algorithm mentioned in Paragraph II. Secondly, we propose a horizon extraction algorithm for video streaming under Kalman Filter (KF) framework based on the horizon extraction algorism for single image. The position of horizon in each frame will be estimated by using the priori horizon positions under KF framework at first, and a search neighborhood will be determined around the estimated position, in which we can get the true position of the horizon through a certain search algorithm. Simulations and analyses are carried out with aerial video streaming, the results show that such algorithms work well on those videos with noise, clouds and fogs, while the time overhead decrease by about 50% than traditional algorithms.

Keywords: *horizon extraction algorithm, Kalman filter, video streaming, dark channel*

1. Introduction

Unmanned Aerial Vehicle (UAV) is a kind of unmanned aircraft controlled by radio or program, which can afford various mission payloads for military missions or civilian missions. Traditionally, the beyond-visual-range (BVR) flight control is relied on INS system combined with satellite navigation system. However, such framework has some disadvantages. Once the satellites' signal is lost, the accumulated error of INS system will grow so rapidly that it would reduce the stability and reliability of the whole control system. On the other hand, such systems are often too expensive and huge to be applied in low cost micro UAV. In this case, methods of visual navigation for UAV are brought out with the development of image processing technology and microchips.

The key point of visual navigation is to estimate the attitude information through markers in the captured image, which can be divided into artificial markers and natural markers. The former include runway, buildings, highway and other land markers [1-3], while the later generally refers to the horizon. The estimation of attitude information is generally though the horizon information for the principle of this method is relatively simple and often it does not require external information for assistance, which makes it widely used in designing of visual navigation systems. Without a doubt the effectiveness of this method depends on the reliability of the horizon extraction algorithm [4-6].

There are two mainstream horizon extraction algorithms, the methods based on regional characteristics and the methods based on edge features. On the first aspect, Ettinger S.M Nechyba M.C and Gao Ai-min gave out a horizon extraction method by using the color difference on both sides of horizon. Such algorithms work well when the image is in color, but it isn't suitable for grayscale images [6-8]. Terry Cornall and Greg Egan detected the position of horizon by image segmentation [9], while Wang Yu-jie extracted the horizon by the wavelet method [10]. By making use of the characteristics of the sky image's homogeneity, those methods above can handle most of the situation. Their main disadvantage is that they are inefficient, and hardly to meet the requirements of real-time systems. On the later aspect, G. Bao and Z. Zhou proposed a horizon method, which make use of the Omni-directional mapping

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of edge points [11]. Dusha employed the correlation of edges in each channel to reduce the edge points; the horizon extraction was done by Hough transform [12]. These two methods can achieve excellent results when the horizon is very significant. If the input images contain fog and mist, or be seriously polluted by noise, the performance of these methods will be not so satisfactory. The most important thing is, all of the methods mentioned above are rooted on single frame of image, which means they put the horizon extraction just as an image processing problem. This approach ignores significant information of inter-frames that could have been made good use of.

In this paper, we propose a horizon extraction method, which combined image processing and Kalman filter (KF). Firstly, we bring out a single frame edge extraction method by using dark channel information. Then we employ the method mention in literature [11] to search the position of horizon. After that we use KF to predict the positions of horizon in video streams. Such algorithm can avoid the interference from error edges, and it can also reduce the total time cost to improve the real-time ability. In the end, simulation and experiments are carried out to test the algorithm.

2. Horizon Extraction Algorithm of Single Frame Image Based on Dark Channel

In the visual field of UAV, not only the senses of ground are complex, but also the sky varies much due to the different illumination. For convenience, following assumptions are made in this paper:

(1) In visual field, the horizon acts as a straight line and it always exists.
(2) The edge separate sky from ground is a step edge.
(3) Dark channel exists always.

Dark channel is obtained from the outdoors non-fog image data base by statistical means [13]. For some pixels in local areas of non-sky area, there is always at least a color channel with low value, which means the minimum light intensity in this region is small. For an R-G-B format image J, we define:

$$J_{dark}(x) = \min_{c \in (r,g,b)} (\min_{y \in \Omega(x)} J_c(y)) \quad (1)$$

J_c presents one color channel of J, and $\Omega(x)$ is a rectangular area centered by x. The value of J_{dark} will always tend to 0 if the $\Omega(x)$ is located in the non-sky area. J_{dark} is called the dark channel, and such principle is named the dark channel priori. It is also suitable for grayscale image, the formula of which is as follow:

$$J_{dark}(x) = \min_{y \in \Omega(x)} J_c(y) \quad (2)$$

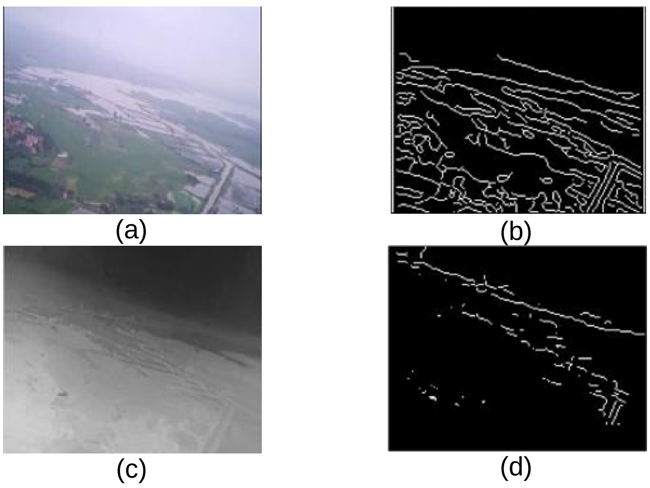


Figure 1. The Simulation of Edge Extraction with Dark Channel

The existence of fog or the strong reflection region (such as water, snow.) will interfere with the method described in literature [11]. So the dark channel priori offers us a better choice that means the edge extraction can be done based on the dark channel. Take an aerial photograph for example, which is shown in Figure 1. Figure 1(a) is a horizon image with fog and water, which made the features of the horizon difficult to extract. We employed method in literature [13] to process the image, as shown in Figure 1(b). Result shows that large amount of interference exist still and the horizon is not be fully extracted. As a comparison, we use the dark channel to extract the horizon. Figure 1(c) is the dark channel of Figure 1(a), and Sobel operator is carried out to get edges, as shown in Figure 1(d). Compared with Figure 1(b), the whole horizon is extracted fully and the interference of background is suppressed effectively.

After the edge extraction, we employed a rotation-projection method to calculate the position of horizon for images as Figure 1(d). Rotate the image about its center, suppose the rotation angle is $\sim$, $p(\sim,n)$ is the sum of column gray value after rotating $\sim$, where n present the ordinal of columns. Defined:

$$p(\sim,n_{\max}) = \max\{p(\sim,1),...,p(\sim,n)\} \quad (3)$$

Divided πinto n parts equally, the step of rotation is $\circledR\ /\ n$, let $\sim$ traverse the interval of [0,π) at a step of $\circledR\ /\ n$, defined:

$$p(\sim_{\max},n_{\max}) = \max\{p(0,n_{\max}),p(\circledR\ /\ n,n_{\max}),p(2\circledR\ /\ n,n_{\max})...,p(\circledR,n_{\max})\} \quad (4)$$

Where, $\sim_{\max},n_{\max}$ are the rotation angle and the ordinal of columns when $p(\sim_{\max},n_{\max})$ reach its maximum, by which we can obtain the longest edge in an image to locate the position of horizon.

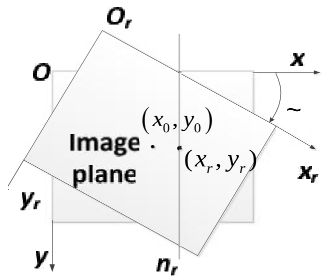


Figure 2. The Coordinate System of the Rotated Image

As shown in Figure 2, (x,y) is the original image coordinate system while Ox_ry_r is the rotated image coordinate system. (x_0,y_0) is the coordinate of image center under Oxy and (x,y) is the coordinate of a random pixel on horizon. After the rotation of $\sim$, the center's coordinate is (x_{r0},y_{r0}) while (x,y) is updated to (x_0,y_0), where:

$$\begin{cases} x_0 = x_{r0} \\ y_0 = y_{r0} \end{cases}$$

The transformation equation is as follow:

$$\begin{bmatrix} x_r \\ y_r \end{bmatrix} = \begin{bmatrix} \cos\sim & \sin\sim \\ -\sin\sim & \cos\sim \end{bmatrix} \begin{bmatrix} x - x_0 \\ y - y_0 \end{bmatrix} + \begin{bmatrix} x_{r0} \\ y_{r0} \end{bmatrix} \quad (5)$$

According to the assumptions above, we make $x_r = n_r$, expand Equation (5),

$$n_r = x\cos\sim + y\sin\sim - x_0\cos\sim - y_0\sin\sim + x_{r0} \quad (6)$$

As (x, y) is a point on horizon, Equation (6) is the horizon equation which can be written as the Slope-intercept form as Equation (7):

$$\begin{cases} k = -\cot\sim \\ b = -(x_0\cot\sim + y_0 + \dfrac{n_r - x_{r0}}{\sin\sim}) \end{cases} \quad (7)$$

Where, $\sim \in \left(0, \frac{®}{2}\right) \cup \left(\frac{®}{2}, ®\right)$. Specially, when $\sim = ®/2$, the horizon equation can be simplified as $y = y_0 - x_{r0} + n_r$; when $\sim = 0$, it is $x = x_0 - x_{r0} + n_r$.

3. Horizon Extraction Algorithm Through Video Stream Based on Kalman Filter (KF)

The positions of horizon change continuously in video stream, which remind us the extraction of horizon can be transform into a line's tracking problem. Based on the above, we propose a horizon extraction algorithm by KF, using the priori frames of video to locate the position of horizon in the next frame in a neighborhood area. In the end we search the precise position by means mentioned in Section 2.

For convenience, we transform Equation (7) into normal form:

$$x\cos\bar{} + y\sin\bar{} - \circ = 0 \quad (8)$$

Where:

$$\begin{cases} \bar{} = \sim \\ \circ = x_0\cos\sim + y_0\sin\sim - x_{r0} + n_r \end{cases} \quad (9)$$

Though Equation (8),we can map the horizon to a point $P = (\circ, \bar{})^T$ in Hough space, by which we can transform the line tracking problem to a point tracking problem in Hough space [14].

We established the movement model of P, suppose its movement can be describe as cubic polynomial line, which is:

$$X = \begin{bmatrix} \circ & \dot{\circ} & \ddot{\circ} \\ \bar{} & \dot{\bar{}} & \ddot{\bar{}} \end{bmatrix} \quad (10)$$

The equation of state is:

$$X_{i+1} = HX_i + n_i \quad (11)$$

Where,

$$H = \begin{bmatrix} I_2 & I_2 & \dfrac{\Delta t^2 I_2}{2} \\ 0_2 & I_2 & \Delta t I_2 \\ 0_2 & 0_2 & I_2 \end{bmatrix}, \; I_2 = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, 0_2 = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix}$$

Δt is the time interval between two frames, n_i describe the movement noise of P on the ° direction and the ¯ direction, we suppose n_i obey the Gaussian distribution, the mean equals 0, Q is its covariance matrix, so the observation equation can be written as:

$$Z_i = FX_i + ¦_i \quad (12)$$

Where,

$$F = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$¦_i$ is the two-dimensional Gaussian white noise, the mean is 0 and Λ is its covariance matrix.

The flow of Kalman Filter can be described as follow:

Step1: Search in the entire Hough space, predict the state vector of the point P:

$$X_{i|i-1} = HX_{i-1} \quad (13)$$

Step2: Calculate P_i, the covariance of the state vector and predict its Kalman gain matrix K_i:

$$P_{i|i-1} = HP_{i-1}H^T + Q \quad (14)$$

$$K_i = P_{i|i-1}F^T(FP_{i|i-1}F^T + \Lambda)^{-1} \quad (15)$$

Step3: According to the update of P' s observation, update the state vector of feature point:

$$X_i = X_{i|i-1} + K_i(Z_i - HX_{i|i-1}) \quad (16)$$

Step4: Update the covariance of the state vector P_i:

$$P_i = (I - K_i H)P_{i|i-1} \quad (17)$$

Step5: Back to ***Step1***.

In the algorithm above, we assume the dynamic noise n_i and $¦_i$ as the Gaussian white noise. However, the real noise cannot obey Gaussian distribution precisely. So the KF can only locate the approximate position of the horizon. We should designate a $M \times N$ neighborhood area centered by the approximate position, and use method mentioned in Section 2 search the position of horizon. The total flow chart of the algorithm is shown in Figure 3.

Where n is the parameters that before the nth frame horizon is obtained by horizon extraction algorithm of single frame image based on dark channel, and after that by method mentioned in this section.

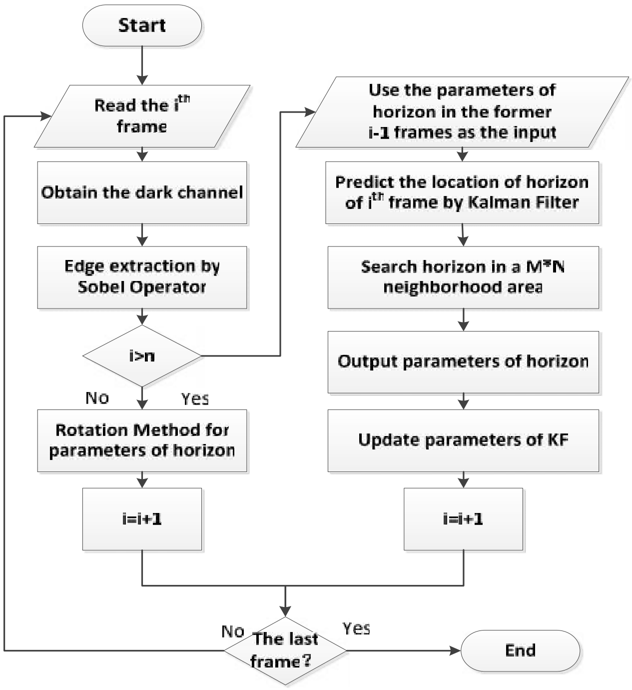


Figure 3. Flow Chart of Horizon Extraction Algorithm under KF Framework

4. Simulation and Analysis

In order to test the algorithm we bought out above, we captured aerial video by a fixed wing UAV. The camera we used has a 1024*768, 1/3 inch CCD, and the FOV equals 30°. The parameters of the UAV we used are shown in Table 1.

Table 1. Parameters of UAV

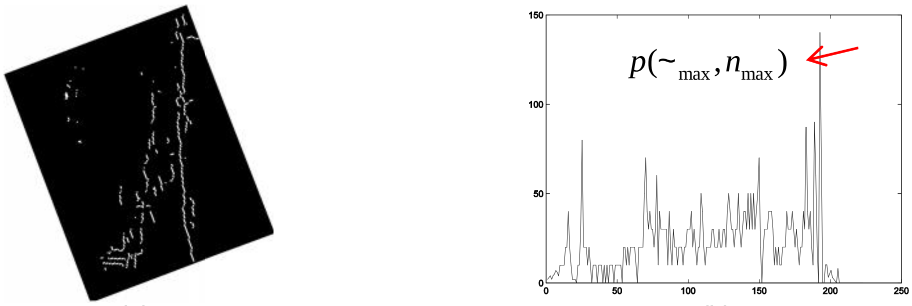
Variable	Parameter
Total Weight(kg)	6
Span(mm)	1823
Velocity (m/s)	35
Altitude(m)	>300

After that, we make simulations on the horizon extraction algorithm of single frame image based on dark channel and horizon extraction algorithm through video stream based on Kalman Filter (KF) separately.

4.1. Simulation on Horizon Extraction Algorithm of Single Frame Image Based on Dark Channel

We obtain the dark channel of Figure 1(a), and extract the edge of it. According to the horizon extraction algorithm of single frame image based on dark channel, we calculate the sum of column gray values, Figure 1(d) was rotated though [0,π) with a step of 1°. We can get the $p(\sim_{\max}, n_{\max})$ when $\sim = 61^{\circ}$. The illustration of sum of column gray values is shown as Figure 4(a), the peak marked with red arrow is where the $p(\sim_{\max}, n_{\max})$ is. Based on Equation (8), we can get the horizon formula: $y = 0.3033x + 10.2175$, and the horizon extraction is shown in Figure 5.

Results show that this algorithm can avoid the interference from fog and water, even the image is blurred this method still works well.



(a) (b)

Figure 4. Rotated Image (a) and the Sum of its Column Gray Value (b)

Figure 5. The Result of Horizon Extraction in Single Image

4.2. Simulation on Horizon Extraction Algorithm Through Video Stream Based on Kalman Filter (KF)

According to the flow chart of Figure 3, we make n=5, which means the first 5 frame of video employ the horizon extraction algorithm of single frame image based on dark channel, and the parameters obtained will be the input of the last frames. The size of search neighborhood area is made as 60×0.2. We employ 100 frames of video to test the algorithm, the tracking of feature point $P(°, ¯)$ of horizon in Hough space is shown as Figure 6 to Figure 10. the results show that KF can track the horizon well.

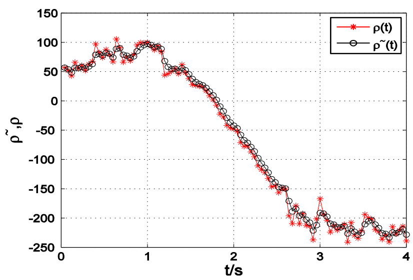


Figure 6. The Prediction Curve of ~° and the Real Curve of °

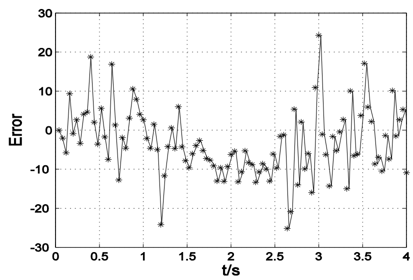


Figure 7. The Error Curve of ~°

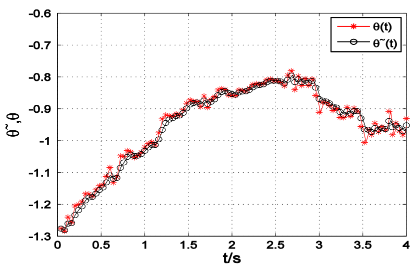


Figure 8. The Prediction Curve of ¯~ and the Real Curve of ¯

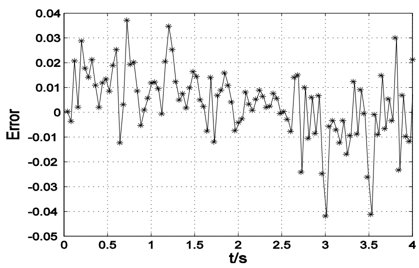


Figure 9. The Error Curve of ¯~

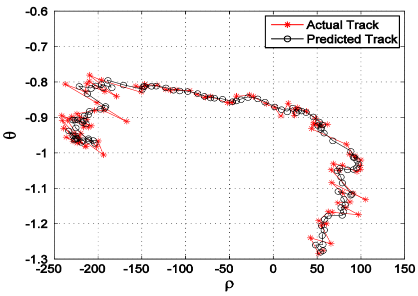


Figure 10. The Tracking of P(°, ¯) in Hough Space

Figure 11. The Predicted Horizon and Neighborhood Area

Since we obtain the predicted position of horizon, a neighborhood is expand by 60×0.2, as shown in Figure 11. The thick red line presents the predicted position of horizon, and the area between double thin green lines and double thin red lines is the searching area. By using rotation searching method, we can calculate the parameters of the horizon.

The simulation was carried on computer with Core i7 processors, the platform of which is MatLab 2012. The size of each test image is 180*140; the total time cost with horizon extraction algorithm through video stream based on Kalman Filter (KF) for 100 frames is 6.987s, while the time cost with horizon extraction algorithm of single frame image based on dark channel is 14.4s. The result shows the efficiency of the algorithm is improved by employing the KF framework. Horizon extraction results of some frames are shown as Figure 12.

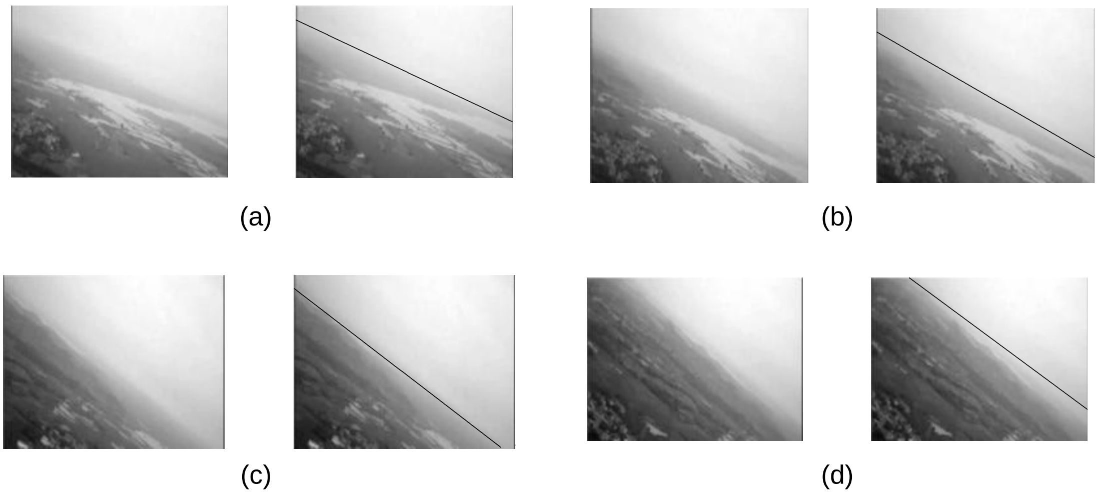


Figure 12. The Horizon Extraction of Video Streaming, and the Left Image is the Origin One

According to the simulation results above, the algorithm can extract horizon from video stream well, what is more, compared with those methods that extract horizon one frame by another, the time cost reduce almost 50%.

5. Conclusion

In this paper, as the visual navigation demands of UAV, we bought out a horizon extraction method based on Kalman Filter framework. The simulation shows that, compared with traditional method, this method cannot easily be interfered by clouds, fog or water reflection. Meanwhile, the total cost of processing video stream is less than traditional method, which means it is more suitable for real-time system such as visual navigation system.

References

[1] Saripalli S, F Montgomery J, S Sukhatme G. *Vision-based Autonomous Landing of and Unmanned Aerial Vehicle*. Proceedings IEEE International Conference on Robotics and Automation. 2002; (3): 2799-2804.
[2] S Sharp C, Shakernia O, S Sastry S. *A Vision System for Landing an Unmanned Aerial Vehicle*. Proceedings 2001 ICRA IEEE International Conference on Robotics and Automation. 2001; (2); 1720-1727.
[3] Eric Frew, Tim McGee, ZuWhan Kim, et al. *Vision-based road-following using a small autonomous aircraft*. IEEE Aerospace Conference Proceedings. 2004; 3006-3015.
[4] Zhao Shifeng, Zhang Hai, Fan Yaozu. Attitude estimation method for flight vehicles based on computer vision. *Journal of Beijing University of Aeronautics And Astronautics.* 2006; 32(8): 885-898.
[5] Da Xingya, Tu Hengzhang, Shen Huairong. Exploration of Vision-based Autonomous Flight Control for mavs in Complex Environment. Journal Of The Academy Of Equipment Command & Technology. 2007; 18(6): 41-44.
[6] Gao Aimi, Cao Yunfeng, Chen Songcan. The scheme of vision-based attitude detection for mav. *Aircraft Design*. 2002; 4: 70-73.
[7] Ettinger SM, Nechyba MC. *Towards Flight Autonomy: Vision-Based Horizon Detection for Micro Air Vehicles.* Proceedings of the IEEE International Conference on Robotics and Automation. Washington, Washington DC. 2002: 2134-2140.
[8] Grasmeyer JM, Keenan MT. *Development of the Black Window Micro Air Vehicle*. Proceedings of the 39th AIAA Aerospace Sciences Meeting and Exhibit, Califomia. 2001; 2001(12): 36-37.
[9] Terry Comall, Greg Egan. *Measuring Horizon Angle from Video on a Small Unmanned Air Vehicle.* Proceedings of the 2nd International Conference on Autonomous Robots and Agents, Palmeston North. 2004: 339-344.
[10] Wang Yujie. Research on visual navigation based on horizon dectation for MAV. Harbin: Harbin Institute of Technology. 2004.
[11] G Bao, Z Zhou, S Xiong. *Towards micro air vehicle flight autonomy research on the method of horizon extraction.* Proceedings of the 20th IEEE Conference on In Instrumentation and Measurement Technology, Colorado. USA. 2003; 2: 1387-1390.
[12] DUSHA D, WAGEEH B, RODNEY W. *Attitude estimation for a fixed-wing aircraft using horizon detection and optical flow*. Biennial Conference of the Australian Pattern Recognition Society on Digital Image Computing Techniques and Applications. Glenelg: IEEE, 2007: 485-492.
[13] HE K, SUN J, TANG X. *Single image haze removal using dark channel prior*. IEEE Conference on Computer Vision and Pattern Recognition. Miami: IEEE, 2009: 1956-1963.
[14] Chen Zhen. Research on image serial optical flow calculation and three-dimensional scene recovery. Xi'An: Northwestern Polytechnical University. 2003.