Image Processing Technology of FLIR-based Enhanced Vision System

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Abstract

An Enhanced Vision System (EVS), developed and demonstrated by Luoyang Institute of Electro-optical Equipment of China Aviation Industry Corporation I (LIEOE of AVIC I) is introduced in this paper, including its composition, technical characteristics and recent developments.

EVS has to deal with 3 typical image processing problems:1)image noise reduction;2) image enhancement;2)landing information extraction. Solutions in system hardware level are proposed and described in this paper: 1)neighborhood averaging is used to reduce image noise; 2)Laplacian pyramid algorithm, featuring multiple resolutions, is used to enhance image, and quantized image quality parameters are used as the feedback of image processing effect to adjust enhancement processing parameters automatically;3) aided by navigation system, airport runway edges in IR image are detected and identified by edge detection & segmentation method based on gradient operator and morphology operations, and runway edge straight-line detection technology based on Hough transformation.

1 Introduction

Safe take-off and landing of an aircraft in low visibility is one of the key issues for aviation. Complicated weather conditions such as dark night, fog and rain are primary causes of aircraft flying accidents, which influence aircraft take-off and landing most. According to statistics, approach landing takes 14% of the whole flying time. However, 55% of accidents occur in this period. So, people have tried all technical measures to break the limitation which weather conditions imposing on flight. Enhanced Vision System (EVS) [1] [2] is one of the attempts to break the limitation, and has been developing vigorously and quickly in the world .

In low visibility conditions, with current technologies, EVS on aircraft can be used to display runway and its environment images, generated by FLIR or micro-wave radar, on HUD to increase situation awareness so that pilot can control the aircraft to land or take off successfully in adverse weathers such as fog and rain. This system can be used in aircraft approach and landing in low visibility and at night, can be used in taxis and take-off in airport, and can be used to increase visibility of pilot in air, to detect obstacles in runway and to implement emergency control.

EVS, developed by Luoyang Institute of Electro-optical Equipment of China Aviation Industry Corporation I (LIEOE of AVIC I), is composed of FLIR, overhead holographic HUD, EU and system control panel (SCP). EVS is shown in Fig.1. All units functions and characteristics are described as follows:

1) FLIR provides environment images in day/ night and adverse weathers for pilot, which enable pilot to observe and identify ground objects such as runway, so as to take off and land correctly and safely. It converts IR radiation image of scenery into video image signal via EO conversion and related processing, which will be displayed on HUD

so that pilot could locate target coordinate accurately such as runway and buildings, and implement safe landing and take-off. FLIR is composed of optical system, focusing driving unit, detector unit, signal processing circuit, control interface circuit, power supply and damper. FLIR adopts HgCdTe FPA detector with elements of 320 × 240, working in 3~5 μ m wavelength. NETD is 60mk and F number of optical system is 2.

Fig.1 EVS Units of LIEOE

2) Video image information from FLIR is processed by EU, then integrated with data information from airborne avionic systems (such as INS, air data computer, radio altimeter), and after that, raster image, overlapped with flight guidance symbols, is provided for pilot, which includes all information required by pilot to take off and land safely in adverse weather. EU receives external commands to control the system. EU adopts high-speed CPU, which integrates control logic through FPGA.
3) Overhead holographic HUD receives control command from EU, and displays different pictures according to operation modes, with flight guidance symbols. Overhead holographic HUD can display conventional symbols only, and can also overlap symbols onto raster to display raster image with symbols overlapped. When FLIR is initiated to work and display raster image overlapped symbols, declutter processing will be performed automatically in HUD picture. Symbol brightness, raster brightness and contrast brightness adjustment knobs are located in conjugation site of HUD combiner above pilot head so that pilot could adjust easily, meanwhile, HUD combiner can be folded. HUD total FOV is up to 30°×20°. Optical-electronic integration calibration method is used to perform distortion calibration so as to make FOV distortion reduce to acceptable range.
4) System control panel is the system control unit, used to control EVS operation modes, load EVS parameters and adjust FLIR.

To demonstrate EVS functions and performances, LIEOE installed it onto an aircraft for trial flight. To help the trial flight, video recorder and bus/non-bus signal recording device are mounted to the aircraft as well, to measure and record the trial flight data. The whole system for the trial flight is configured as Fig.2. FLIR is half-embedded onto the aircraft, and connected with the aircraft through mounting rack. Sealing skin is added to external surface of FLIR and IR optical window is mounted on the skin. Overhead holographic HUD is connected with the aircraft body stiffly through mounting rack. The mounting rack can be adjusted and calibrated in several directions. HUD and FLIR are mounted on the aircraft as shown in Fig.3.

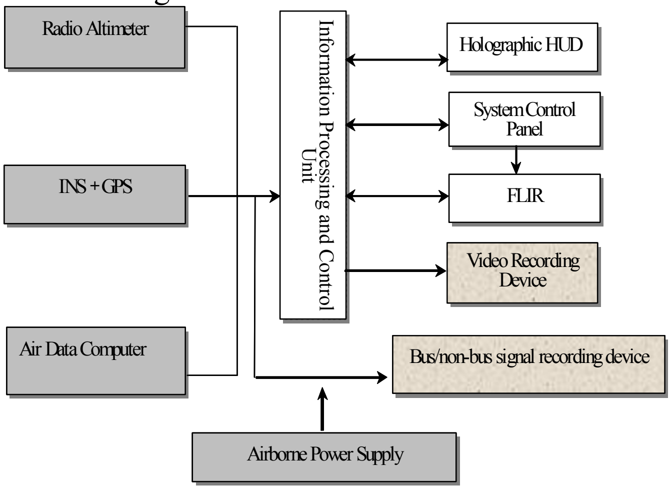

Fig.2 EVS Composition for Trial Flight

In the demo, EVS experienced all flying phases such as runway taxi, take-off, cruising in air, approach and landing. In each phase, EVS worked very well: it was connected properly with related equipment in the aircraft; IR imagery sensor worked properly; HUD displayed correct and clear symbols and images. The demo effects are shown in Fig.4. The trial flight indicates that: EVS could improve operation effectiveness of air crew significantly in air and ground; EVS enables pilot to have the capability to approach and land in complicated weathers, so as to increase flight safety. Meanwhile, interfaces with micro-wave radar, synthetic vision system (SVS) and related processing capabilities have been reserved in EVS design, which is the basis to study on image fusion and multi-spectral-imagery-based flight guidance technologies.

Fig.3 EVS Installed on Aircraft

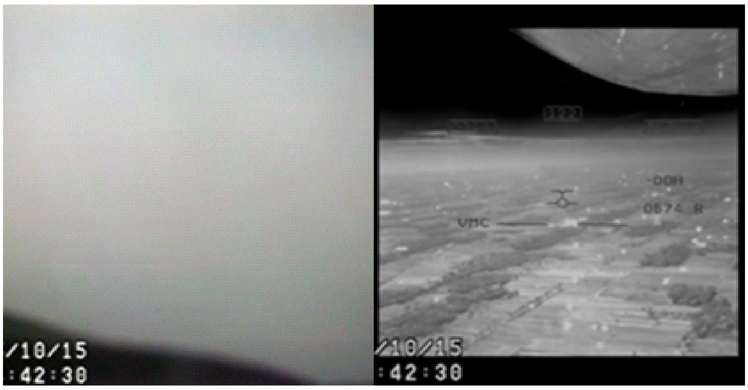

Fig.4 EVS Trial Flight Effects (Left view is visual image and right view is EVS image)

2 Design of EVS image processing

With FLIR, EVS could get airport runway and its surrounding environment images in real-time so that pilot can see the runway clearly through cloud and fog, and control the aircraft safely. From system design point of view, EVS asks IR image processing for following requirements:

1) Atmospheric attenuation, one of the problems caused by adverse weather, needs a FLIR with higher detection performance. However, cost is a very important issue to limit EVS development. Considering from system design, appropriate trade-off has to be made between available effective image quality and realization cost, so as to determine an optimized proposal for performance/cost. FLIR is designed to increase SNR of IR image appropriate with image processing algorithm;
2) Image information display is required to have deviation from detector imagery characteristics. As an objective information display system, it is necessary to carry out related transformation processing on IR image to meet display requirements;
3) Multi-source and multi-wavelength image fusion processing and image stitching;
4) To provide airport runway orientation indication for pilot in time, EVS extracts runway information required to fulfill given mission (approach landing in adverse weather) from IR images through image processing technology, aided by airborne avionic equipment, digital map, etc, and detects obstacles in runway.

Fig.5 Image Processing System

As an important issue in design, many manufacturers started research activities for image processing technology when they were developing EVS and FLIR [3] [4] [5]. As part of EVS developed by LIEOE, image processing system experienced the trial flight together with the whole system. This paper focuses on the solutions to IR image noise reduction, IR image enhancement and runway identification.

2.1 Composition of image processing system

In technology research phase, the image processing system is composed of following equipments:

1) Industrial computer IPC-610H (CPU card PCA6186-VE, motherboard PCA-6114P7);
2) Image capture card Matrox Genesis LC;
3) Image processing card Matrox Genesis PLUS, dinode;
4) Video output card(Corona II);
5) Cable, etc.

In image processing system, video signal from FLIR is sent to Matrox Genesis LC image capture card, where the video image is transformed and captured. After that, digital signal is transferred with high speed to Matrox Genesis PLUS image processing card through special channel, and processed with image algorithm by digital signal processing chip on the card. After that, digital signal is sent to video output card (Corona II) via PCI bus, where digital signals are re-synthesized for output.

2.2 Image Processing algorithm design

2.2.1 Neighborhood averaging method to reduce image noise

Neighborhood averaging method is used to determine and reduce image noise, which could be expressed in discrete convolution as follows:

$$\hat{f}(m,n)=\sum_{r=-k}^{k}\sum_{s=-l}^{l} f(m-r,n-s)H(r,s) \qquad \begin{matrix} m=0,1,\ldots\ldots M-1 \\ n=0,1,\ldots\ldots,N-1 \end{matrix} \qquad (1)$$

Where, H(r,s) is mask, low-pass mask used in the design is:

$$H=\frac{1}{10}\begin{bmatrix} 1 & 1 & 1 \\ 1 & 2 & 1 \\ 1 & 1 & 1 \end{bmatrix} \qquad (2)$$

2.2.2 Laplacian pyramid algorithm to enhance image

Laplacian pyramid algorithm is an algorithm based on tower image processing method, including decomposition, enhancement and re-configuration. At first, source image is decomposed into low- frequency part and high-frequency part in all resolutions. By image enhancement, the image high-frequency part in all resolutions is magnified to enhance the image details. At last, information of the image low-frequency part in all resolutions is integrated with information of magnified high-frequency part through re-configuration, so as to form an enhanced output image.

2.2.2.1 Image decomposition

Input image is decomposed with Gaussian pyramid. Original image is the bottom of Gaussian pyramid. Supposed the decomposed image is G_l, the computation between layer is :

$$G_l(i,j)=\sum_{m=-2}^{2}\sum_{n=-2}^{2}\omega(m,n)G_{l-1}(2i+m,2j+n)$$

$$0<l\le N \qquad (3)$$

Where, i and j are horizontal and vertical coordinates respectively; $\omega(m,n)=h(m)h(n)$ is a function featuring low-pass and h is Gaussian density distribution function. In this way, an image sequence, with size decremented by half layer by layer, is built up, i.e. Gaussian pyramid. With interpolation, Gaussian pyramid is interpolated and expanded to make expanded size of the l^{th} layer image G_l is identical to the size of the $(l-1)^{th}$ layer image G_{l-1}, which is computed as follows:

$$G'_{l-1}(i,j)=4\sum_{m=-2}^{2}\sum_{n=-2}^{2}\omega(m,n)G_l\left[(i+m)/2,(j+n)/2\right] \qquad (4)$$

All layers of Gaussian pyramid are interpolated and expanded respectively so that an expanded sequence is achieved, in which, $\omega(m,n)$ is fifth-order Gaussian template

$$\frac{1}{256}\begin{bmatrix} 1 & 4 & 6 & 4 & 1 \\ 4 & 16 & 24 & 16 & 4 \\ 6 & 24 & 36 & 24 & 6 \\ 4 & 16 & 24 & 16 & 4 \\ 1 & 4 & 6 & 4 & 1 \end{bmatrix}$$

.

Supposed G_l^* is the l^{th} layer image of Laplacian pyramid, that is:

$$LP_l = G_l - G_l^{'} \quad N > l \geq 0 \tag{5}$$

$$LP_N = G_N$$

Laplacian pyramid is composed of LP_0, LP_1,…LP_N. Sub-image in every layer of Laplacian pyramid is obtained by subtracting the image achieved from interpolation and expansion of corresponding layer image in Gaussion pyramid and that achieved from interpolation and expansion of its higher layer image. LP_l is the l^{th} layer high-frequency part; $G_l^{'}$ is the predicted value of the l^{th} low-frequency part.

2.2.2.2 Enhancement

Image details can be enhanced by magnifying high-frequency part of source image in all resolutions. As for high-frequency information in all resolutions, it is necessary to multiply a magnification factor:

$$LP_l^* = C * LP_l \qquad N > l \geq 0 \tag{6}$$

Where, C is a variable, same to all layers of image. LP^* is the high-frequency part after enhancement.

Magnification factor selection should be related to contrast of original image. Standard deviation of normalized histogram is used to estimate image contrast. Supposed appearing probability of the i^{th} grey level is $p_i = n_i /(length \cdot width)$ .All grey level probabilities constitute vector $\boldsymbol{P} = [p_0, p_1, ..., p_{255}]$, i.e. $\sum_{i=0}^{255} p_i = 1$. Histogram normalized standard deviation can be expressed as $s = stdev(\boldsymbol{P})$, in which $stdev(\cdot)$ means to achieve standard deviation of the content inside of brackets. Magnification factor is inversely proportional to contrast, but proportional to s, so C=s/m, in which m is a constant.

2.2.2.3 Re-configuration

After magnification of high-frequency part in all resolution is finished, final output image could be worked out by re-configuration of low-frequency part in all resolutions and of magnified high-frequency part. Laplacian tower architecture can be re-configured by following equation:

$$G_N = LP_N^* \qquad N > l \geq 0 \tag{7}$$

$$G_l = LP_l^* + G_l^{'}$$

2.2.3 IR image runway identification processing

Based on image pre-processing mentioned above, runway target is identified in relatively certain area, aided by navigation system. The whole automatic identification algorithm includes:

1) 1-D grey level morphology closed computation: to make grey level inside of runway more uniform, and meanwhile to increase grey level difference with both sides of background to facilitate runway edge points detection;
2) 1-D Gaussian template smoothing + derivative operator: to get 2 points with max. gradient absolute value in positive and negative direction from every line to implement runway edge point detection;
3) Hough transformation: to get runway edge direction and azimuth;
4) End searching: to get runway edge end.

2.2.3.1 1-D grey level morphology closed computation

1-D grey level morphology closed computation(Close)enables grey level distribution inside of runway more uniform, and meanwhile increases grey level difference from both sides of background to facilitate runway edge points detection. Closed computation is operated only in horizontal direction, in which structure factors number is 9. Closed computation includes expansion and corrosion, which is realized as follows: supposing $f_0(x)$ is any line in the image and $f(x)$ is the situation after this line is processed.

For expansion, that is

$$f(x) = Max(f_0(x+i))$$
$$i = -(s-1)/2 \sim (s-1)/2 \tag{8}$$

For corrosion, that is

$$f(x) = Min(f_0(x+i))$$
$$i = -(s-1)/2 \sim (s-1)/2 \tag{9}$$

2.2.3.2 1-D Gaussian template smoothing + derivative operator

The edge point is found by deriving gradient absolute value with 1-order derivative operator of 1-D and deriving zero-cross point with 2-order derivative operator. Before derivative operator is employed, 1-D Gaussian template is used to smooth noise.

The algorithm to find the edge point is shown as follows, to define the structure:

```
Struct Pixel
{ int x; //coordinate in x direction
  int y; // coordinate in y direction
  int wide; //distance between 2 edge points in 1 line
  Pixel * link; // point to next node}
```

2 Chained lists are built up by using above mentioned structure, which are corresponding to 2 boundaries on left and right sides of runway. Beginning from the 1st line of image:

1) Calculate horizontal gradient of every pixel in this line with [1,-1]; and find the pixels where maximum gradients in positive and negative directions are located;
2) If the pixel, where positive maximum value is located, is on the left side of the pixel, where negative maximum value is located, this line has to be rejected, then go to step 4);
3) Write 2 pixels coordinates of this line and the distance between the 2 pixels into chained list;
4) Go to next line.

Where, step 2) is designed on the basis of the assumption that runway grey level is higher than background. Point gradient of runway left boundary should be negative and point gradient of runway right boundary should be positive. If it is not like this, the 2 boundary points are definitely not the right edge points and should be abandoned.

2.2.3.3 Hough transformation

After independent edge points are achieved, Hough transformation is used to extract straight line from these points. During Hough transformation, every point (x, y) in X-Y plane is transformed into a sine curve in $\rho-\theta$ space according to the equation of $\rho = x\cos\theta + y\sin\theta$. Colliear point in X-Y plane is corresponding to the sine curve intercepted to given point in $\rho-\theta$ space. In detailed operations, number of curves going through all elements of the matrix is recorded via the accumulative matrix. Whereupon, those matrix elements with high accumulated value are corresponding to crossing point several curves intercepted, and corresponding to straight line. Supposed angle resolution is 1°, distance resolution is 3 pixel and angle scope is [0°-180°], Hough transformation is performed on left boundary point and right boundary point, and the straight line, where maximum value of accumulative matrix is located, is marked.

2.2.3.4 End searching

With Hough transformation, the straight line, where runway edge is located, is derived. After that, the last step for identification is to determine ends of the 2 straight lines. Take example of left edge chained list: calculate the distance *dist* between the point and the pixel where right straight line on the line. If the point is on the runway edge, absolute value difference of ℓ between pixel.wide (1-order Gaussian + derivative operator) and dist should be close to 0. Any point whose ℓ is more than 1 threshold will be deleted. Then, find maximum and minimum coordinate points in vertical direction from remaining points, and define them as the ends of straight line. Same operations for the right edge chained list. As a result, 4 pixel points are obtained. The quadrilateral with these 4 points as fixed points is the area where the runway is located.

3 Conclusion

During EVS development, LIEOE uses the image processing system described in this paper to study image processing technology. The enhanced IR image and runway identification effects are shown in Fig.6 and Fig.7. EVS could improve IR image displaying effect, and meanwhile EVS could implement runway identification and marking as well. It should be noted that the method described in this paper is part of preliminary research activities of LIEOE for EVS. The method does not cover all image processing technologies used in this EVS. Beside, the real system hardware running environment and algorithms are also different from descriptions in this paper.

Fig.6 Image Processing Effect（1）

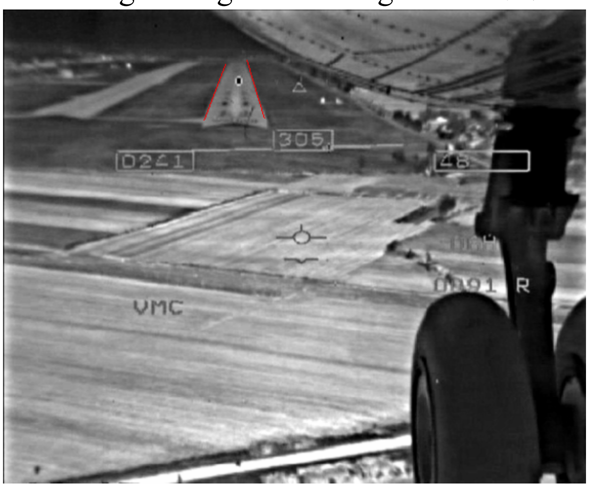

Fig.7 Image Processing Effect（2）

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References

[1] J. Richard Kerr, Chiu Hung Luk, Dan Hammerstrom, Misha Pavei, Advanced integrated enhanced vision systems, Enhanced and Synthetic Vision 2003, pp 163-176;

[2] Scott Way, Richard Kerr, Joe Imamura, Dan Arnoldy, Richard Zeylmaker, Greg Zuro,Development and testing of the EVS 2000 Enhanced Vision System, Enhanced and Synthetic Vision 2003, pp 51-57;

[3] Dennis J. Yelton, Ken L. Bernier, John N. Sanders-Reed，Processing System for an Enhanced Vision System, Enhanced and Synthetic Vision 2003, pp 90-101;

[4] B.Korn, H.U.Doehler, P.Hecker, Navigation integrity monitoring and obstacle detection for enhanced-vision systems, Enhanced and Synthetic Vision 2001, pp 51-57;

[5] R. M. Müller, G. Palubinskas, H. Gemperlein, Image processing in an enhanced and synthetic vision sysyten, Enhanced and Synthetic Vision 2002, pp 168-177.