INTRODUCTION

With the advance of power transmission and distribution technology, hyper-pressure long-distance power transmission has been gradually applied in China. Because of its high efficiency, low cost, and little impact from geographical environment, helicopter has become an important tool to do power line inspection [1]. During helicopter power line inspection, power line videos or image information are captured by photoelectric imaging equipment. Then, computer or manual method is applied to find if there’s any malfunction or defect on transmission equipment. However, due to influence of environmental factors, such as illumination, fog, and haze, images captured by photoelectric imaging equipment are usually low in contrast ratio and not obvious in image details, making it difficult to find transmission line defect by computer or manpower. It is also easy for inspection personnel to have visual fatigue and thus may increase inspection risk. Therefore, it is necessary to realize real-time enhancement on the videos and images captured by photoelectric equipment. At present, enhancement on images taken in greasy weather has become a research hotspot in image processing and computer vision [2].

Currently, processing of fog-degraded image is mainly divided into image enhancement based on non-physical model and image restoration based on physical model. Restoration based on physical model needs to have depth of field information of the required image which is still a bit difficult to obtain in reality [3-4]. Virgil E. Vickers [5] proposed platform
histogram equalization algorithm which can have certain effect on avoiding image over enhancement. Bingjian Wang [6] proposed a self-adaptive enhancement algorithm based on platform histogram. This algorithm contains better adaptation. Qian Chen et al. [7] proposed histogram two-way equalization algorithm to have histogram equalization processing on both gray-scale density and gray-scale interval at the same time. However, there’s still over enhancement problem in background and noise. In 1964, Edwin H Land [8] proposed color constancy Retinex theory. This is an image enhancement method based on Retinex that can effectively enhance image details and contrast ratio. Based on this, multiscale Retinex and multiscale Retinex algorithm with color restoration [9-10] have been established. In 2004, NASA did multiscale Retinex real-time enhancement processing on aerial photo [11] and obtained good effect. However, Retinex algorithm requires for high space complexity on HD image, making it hard to satisfy real-time requirement. Kaiming He et al. from Hong Kong [12] proposed dark-channel prior theory in 2009. It can provide better processing effect on images taken in greasy weather and is a major breakthrough in vision area. Nevertheless, due to the complexity in algorithm, this theory cannot satisfy the requirement for real-time processing. Fattal [13] proposed image enhancement method based on multiscale wavelet decomposition which can have good enhancement effect on image border. This thesis proposed a histogram equalization anti-fog enhancement algorithm based on logarithm transformation and pointed out how to realize it on FPGA. Thus, it can meet the 30fps real-time requirement of 1080p HD image with good enhancement effect.

2 SPATIAL IMAGE DETAIL ENHANCEMENT METHOD

Enhancement on image details in spatial domain is the most common processing method of which the processing method can be expressed as:

\[ g(i, j) = \alpha \tilde{f}(i, j) + \eta + \beta[f(i, j) - \tilde{f}(i, j)] \]  

In which, \( f(i, j) \) and \( g(i, j) \) respectively refer to gray level of image pixel before and after processing., \( \tilde{f}(i, j) \) refers to image after Gaussian smoothing; \( (i, j) \) refers to current pixel coordinates; \( \alpha \) and \( \beta \) respectively refer to weighting coefficient of smoothed image and detailed image; \( \alpha \) reflects global contrast ratio of enhanced image; \( \beta \) reflects detail improvement level of enhanced image; and \( \eta \) refers to constant of controlling image brightness.

3 A POWER LINE INSPECTION IMAGE ENHANCEMENT ALGORITHM

During helicopter inspection, photoelectric equipment may easily be influenced by rain, fog, haze and strong illumination. In rain and fog, image brightness is usually too dark with low contrast ratio which is hard for human eyes to tell transmission wires. In sunny days with sufficient light, brightness of ground part in images is usually lower while that of sky part is usually higher. Thus, the gray level covered by transmission line is very few. Direct linear transformation on image may further compress the gray level of transmission line. Logarithm transformation on image may improve information of dark domain details and have little impact on high-brightness domain. Low-frequency component of image can reflect global contrast ratio of image. Besides, the noise level can be lower than the original image. Histogram equalization on low-frequency component of image can improve low-frequency component of image without amplifying noise. High-frequency component of image can reflect image details. Linear pull-up on low-frequency component can improve image details. Based on this idea, this thesis will propose a histogram equalization method based on logarithm transformation. See Figure 1 for the algorithm flow chart.

The format of HD images obtained by line inspection photoelectric equipment is \( YC_bC_r \). Degraded images usually have lower contrast ratio and lower color saturation. While enhancing image details, image color saturation also needs to be improved. Here, we will directly have enhancement processing on image brightness \( Y \) and color component \( C_b, C_r \) in \( YC_bC_r \) color domain.

![Figure 1. Flow chart of image enhancement algorithm.](image-url)
The processing method for color component can be expressed as:

\[ C_{bh} = k \times (C_b - 128) + 128 \]  \hspace{1cm} (2)

\[ C_{rs} = k \times (C_r - 128) + 128 \]  \hspace{1cm} (3)

In which, \( C_b \) and \( C_r \) refers to original image color component while \( C_{bh} \) and \( C_{rs} \) refer to processed color component.

Subtract \( C_b, C_r \) by 128 so as to control \( C_{bh}, C_{rs} \) around 0. Then, multiply it by coefficient and expand the range of color component, so as to realize enhancement on saturation. Lastly, add it by 128 to adjust color component close to 128. The range of constant \( k \) shall be \([1, 3]\).

Processing for gray component \( Y \) is as follows:

\[ g(i, j) = \log(f(i, j)) \]  \hspace{1cm} (4)

In Equation (4), \( \log \) refers to logarithm transformation which can improve the gray range of dark domain.

Smoothed image can be obtained by conducting Lowpass filtering after logarithm transformation. \( f_b \) (base image) and high-frequency image \( f_d \) (detailed image) can be respectively expressed as:

\[ f_b = g \otimes h \]  \hspace{1cm} (5)

\[ f_d = g - f_b \]  \hspace{1cm} (6)

In which, \( h \) refers to \( 5 \times 5 \) Gaussian template.

After filtering, respectively conduct double-platform histogram equalization and linear pull-up transformation on base image and detailed image. Transform base image and detailed image to gray range of \([0,255]\). Double-platform histogram equalization can improve image contrast ratio and linear transformation can be used to enhance image details.

Double-platform histogram is an amendatory histogram statistic method. By choosing proper platform threshold value, excessive image enhancement can be restrained. Double-platform histogram can be expressed as:

\[ p_T(k) = \begin{cases} T_1 & \text{if } p(k) < T_1 \\ T_1 & \text{if } T_1 \leq p(k) \leq T_2 \\ T_2 & \text{if } T_2 \leq p(k) \end{cases} \]  \hspace{1cm} (7)

In which, \( T_1 \) and \( T_2 \) refer to platform threshold value. \( k \) refers to image gray level. \( p(k) \) refers to statistical histogram. \( p_T(k) \) refers to platform histogram.

Image accumulation histogram and equalized image can be expressed as:

\[ S_T(k) = \sum_{j=0}^{k} p_T(j) \]  \hspace{1cm} (8)

\[ F_T(k) = \frac{S_T(k)}{S_T(255)} \times 255 \]  \hspace{1cm} (9)

In which, \( S_T \) refers to accumulated histogram and \( F_T \) refers to equalized function of histogram.

For detailed image, relevant maximum value and minimum value can be obtained through statistic method and then be reflected to the gray level of \([0,255]\).

4 FPGA HARDWARE REALIZATION

In system design, high-performance EP2S90F1508 FPGA from Altera Company is used to realize image enhancement algorithm. Its internal hardware resources are abundant with 90960 LE, 4520488bits.
Figure 3. Power line image after enhancement.
internal storage resources, and 48 DSP modules. Image data source is 1080/30p HD image with pixels clock of 74.25MHz. FPGA can mainly realize logarithm transformation, Gaussian filtering, histogram statistics, and linear reflection. See Figure 2 for the structural diagram of image enhancement algorithm.

As logarithm transformation is involved in the algorithm, massive LE resources shall be occupied to realize logarithm transformation. Thus, optimization is required for this algorithm. Logarithm transformation can be realized by table lookup. Firstly, use matlab to generate 0-255 logarithm table. Then, fix the values to internal ROM of FPGA after enlargement roundness. Thus, logarithm transformation can be realized by reading the logarithm table in ROM.

To realize Lowpass filtering in FPGA is to form 5×5 sliding window. Take weighted sum of data inside the window. Use internal shifting module shift taps to buffer 5 rows of image data. The depth of each taps is 1920. Lastly, take weighted sum of data inside the window.

Histogram equalization can be realized by two dual-port RAM and several totalizers. As accumulation of each pixel requires one operation of reading and writing in RAM during histogram statistics, it will take at least 2 hours. Thus, multi-pixel clock operations shall be applied and system design difficulty will become higher. To simplify the design, 1/4 down-sampling on horizontal direction is conducted on image, so as to complete the statistics of one pixel within 4 clock cycles. During statistics, gray level value can be taken as the address of the dual-port RAM1 (256×16bit) inside FPGA. Read the data in RAM1 from the left port upwards pixel clock. Add the read data of the next pixel clock by 1 and write it into original address. Make statistics to the last row of the image, so as to complete histogram statistics. During blanking period of image, read the data of each address inside RAM1 from the right port and accumulate it. Write the accumulated data in corresponding address of RAM2 (256×16bit), so as to complete the statistics of accumulated histogram. Map currently input image gray level value according to the accumulated histogram of previous frame, thus can obtain the enhanced image.

5 EXPERIMENT RESULTS AND ANALYSIS

See Figure 3 for the 1600×1200 image obtained by photoelectric pod during the experiment. Figure 3(a) shows original power line image while Figure 3(c) and 3(d) respectively refer to the enlarged images of the 640×480 domain in red box of (a). As local lighting is too strong, the power line in the original image is not obvious to see and part power lines are hidden in strong lighting. Figure 3(e) and 3(f) show the enhanced images after double-platform histogram equalization. There’s improvement in contrast ratio on enhanced image. Power line outline in Figure 3(e) is more obvious than the original image. Power line details in Figure 3(f) are enhanced to a certain degree; however, some power lines are still hard to tell. Figure 3(b) shows the image enhanced by the algorithm proposed in this thesis. The overall details of enhanced image are more obvious. Figure 3(g) and 3(h) are the local enlarged images of Figure (b). Outline of all power lines in Figure (g) are very clear to see with clearer outline compared with that in Figure 3(e). Outline of all power lines in Figure 3(h) are clear with image noise controlled within a low level. Compared with Figure 3, it can be seen that the algorithm proposed in this thesis can have better enhancement effect on power line image.

6 CONCLUSIONS

This thesis proposed an image enhancement algorithm for power line inspection and the method to realize this algorithm on FPGA. The algorithm dealt with Y component and Cb, Cr, individually on YCbCr color space and conducted logarithmic transformation on Y component to improve the tonal range of image dark region. Then, it used Gaussian filter to break down image into base image and detailed image. Histogram equalization and linear pull-up were respectively realized on base image and detailed image, so as to enhance image contrast ratio and detail outline. At last, the algorithm reestablished Y component. Experiment results showed that this algorithm can have good enhancement effect on power line image. This algorithm has already been realized on FPGA and can meet the 30fps real-time requirement of 1080p HD image.

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