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FPGA Implementation of Dark Channel Prior and Defogging for Video Images

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Abstract. To solve the problem of the image defogging Algorithm through dark channels proposed by He Kaiming which is too complicated to implement in hardware. This article introduced an improvement to the original algorithm and transplantation to the FPGA-based hardware systems. We discussed the three main modules including the module of dark channel processed and the estimation of atmospheric light, the module of edge detection and filtering and the module of image restoration in the algorithm implementation process. The Experimental showed good results in the restoration work of outdoor acquisition images. The output images quality is also significantly improved.

Keywords. dark channel prior; FPGA; edge detection

1. Introduction

In recent years, haze has continued to hang over most areas of China, and it has also had a great impact on the clarity of outdoor images. Image clarity is very important in military reconnaissance, video surveillance and remote sensing monitoring. Therefore, in order to achieve the reliability and robustness of the outdoor vision system in the haze weather, it is necessary to clear the haze image.

At present, the image defogging algorithm is mainly divided into two types based on image enhancement and image restoration. The defogging algorithm based on image restoration has been more widely studied. After He Kaiming et al.proposed the prior knowledge of the shadow channel, the problem of image defogging was effectively realized [1]. However, due to the complexity of the soft matting algorithm in the process of transmittance thinning in this algorithm, it is difficult to be effectively applied in practice. Under the premise of ensuring that the improved haze image processing effect is close to the original algorithm, this paper mainly improves the transmittance optimization process which takes the longest time in the original algorithm, and achieves ideal results. After that, it is transplanted on the FPGA[2] hardware platform to realize the effective restoration of the foggy image, thus providing an effective and feasible scheme for the realization of the defogging system.

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2. Improved Defogging Algorithm Based on Dark Channel Prior

2.1 Physical model and algorithm flow

The Eq. (1) is a commonly used atmospheric scattering physical model.

$$I(x) = t(x)J(x) + A(1 - t(x)) \quad (1)$$

This equation is defined in the RGB color channel, I representing the obtained fog image, J representing the image that needs to be restored, A representing the overall atmospheric light, and $t(x)$ representing the medium transmission rate of haze. The principle of removing haze is to recover $J(x)$, $t(x)$ and A. A and t can be estimated by the dark channel prior, and then the smoothing process is realized by filtering the edge part of the rough estimated transmittance separately. Finally, the image to be restored is obtained according to the three parameters obtained[3].

2.2 Dark channel prior

In most outdoor fog-free images in non-sky scene areas, the brightness value of at least one color channel on each pixel is relatively low. Formally, for an image J, we define :

$$J^{dark}(x) = \min_{c \in \{r,g,b\}} (\min_{y \in \Omega(x)} (J^c(y))) \quad (2)$$

It represents a color channel of the image J (i.e., a kind of RGB three colors), which is a local image module centered on it. If J is a fog-free natural image of the outdoors, remove the sky area, the intensity value of J^{dark} is very low and approaches 0, J^{dark} called the shadow channel.

2.3 Estimate the overall atmospheric light A and transmittance

Select 0.1 % of the brightest pixels in the dark channel, and then input these pixels into the original haze image and select the pixel with the highest brightness as the overall atmospheric light[4]. In addition, the fog concentration and transmittance t at the imaging time can be estimated by using the dark channel value and the fog image degradation model. After the minimization operation at both ends of Eq. (1), the dark primary color of the foggy image can be obtained by the same division A_c:

$$\min(\min_{y \in \Omega(x)} (\frac{I_c(y)}{A_c})) = t(x) \min_c (\min_{y \in \Omega(x)} (\frac{J_c(y)}{A_c})) + (1 - t(x)) \quad (3)$$

It can be seen from the shadow channel that it is almost 0, so the first item on the right is almost 0, so it can be obtained that

$$t(x) = 1 - \min_c (\min_{y \in \Omega(x)} (\frac{I_c(y)}{A_c})) \quad (4)$$

Among them, the minimum term on the right side of Eq. (4) is the dark primary color value of the local area of the foggy image, so the coarse transmittance t can be obtained.

2.4 Transmittance optimization smoothing

There are some small squares in the rough estimation map of the transmittance, which is difficult to achieve satisfactory results visually. [5] After fully considering the possibility of hardware implementation and the high processing time required by the outdoor real-time video defogging system, this algorithm mainly performs edge detection on the transmittance map, and then performs mean filtering on the edge part to achieve the transmittance optimization process[6].

2.4.1 Edge detection of transmittance map using prewitt classical operator.

This method uses two directional templates to perform neighborhood convolution with the image in the image space [7]. Firstly, the horizontal and vertical gradients are calculated, and then the larger value of the two gradients is taken as the output gradient, that is :

$$P(\mathrm{i},\mathrm{j}) = \max[\mathrm{G(i)},\mathrm{G(j)}] \tag{5}$$

Finally, the threshold TH is appropriately selected. If P (i, j) > TH, it is a step edge point, and the calculation result is its edge image.

2.4.2 Smoothing the edge part.

It can be seen from the observation that the block effect in the original algorithm is mainly concentrated in the edge part of the image. Here, the 3 * 3 region template is used for mean filtering to smooth the edge. Its mathematical formula is expressed as :

$$\begin{aligned} g(x,y) = \{ & f(x,y-1)+f(x,y)+f(x,y+1) \\ & +f(x-1,y-1)+f(x-1,y)+f(x-1,y+1) \\ & +f(x+1,y-1)+f(x+1,y)+f(x+1,y+1)\}/\mathrm{M} \end{aligned} \tag{6}$$

In the Eq. (6), g (z, y) is the gray value of the processed image at this point, (x, y) is the current pixel point, M is the number of pixels contained in the region template, and M is 9.

2.5 Image restoration

Using Eq. (7), we can solve the restored image :

$$J(x) = \frac{I(x)-A}{\max(t(x),t_0)} + A \tag{7}$$

The parameters in the formula have been obtained in the previous steps, and then the restored image $J(x)$ can be obtained.

3. System Structure and Working Principle

3.1 System structure

The system uses the DE2-70 and TRDB-D5M image acquisition board produced by Youjing Company as the development platform[8], and its hardware structure is shown in Figure 1. The video acquisition and processing display system mainly includes image acquisition card configuration module, image acquisition module, image format conversion module [9], image storage module, image processing module, image display module [10]. The system mainly realizes the storage and calculation process of the defogging algorithm through two SDRAMs. The working principle of the system is as follows : Firstly, the CMOS image acquisition card is configured by the clock reset control I^2 C bus. After a certain delay, the image of the target scene is collected by the image acquisition module, and then the image data of the BAYER mode is converted into the commonly used RGB data and written to SDRAM0.Finally, the foggy image is processed by the algorithm and displayed by the VGA module.

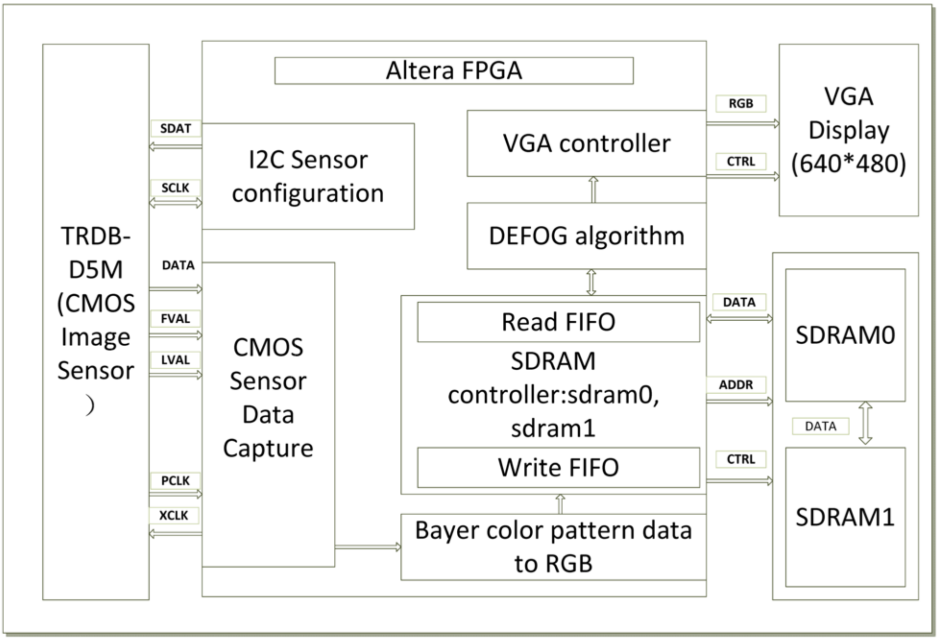

Figure 1. Video acquisition and processing system hardware structure diagram

3.2 Shadow channel calculation module design and A calculation

The process of obtaining the shadow channel involves each color channel. Firstly, the three color channels are minimized respectively, and then the smallest one is selected from the three color channels as the final output dark channel value. Through the IP core altshift-taps (shift registers) provided by quartus2, the regionalization of image pixels is realized on FPGA. The IP core can realize the parallel output of serial data and can specify the width. In this algorithm, the minimum template is selected as 3 * 3 area, the number of probes needs to be set to 3, and the interval width between probes is set to 640 width of each row of image to achieve minimum processing. As shown in Figure 2, it is possible to simultaneously read the data values of the same column in three adjacent rows :

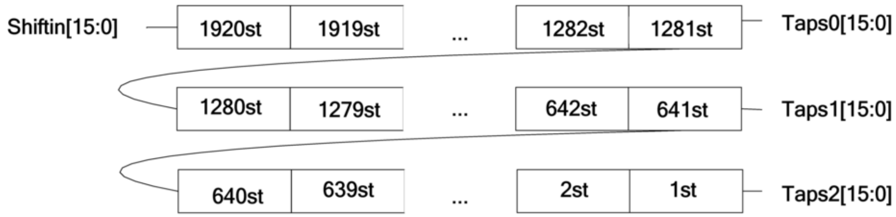

Figure 2. Realization of regionalization processing on altshift-tap

After obtaining the data of the three probes at the same time, it is necessary to compare them to take the minimum value, and store the minimum values of the adjacent three clocks respectively. Then, a small operation is performed to obtain the dark channel value of the color channel. Finally, the minimum values of the three color channels are selected to obtain the dark channel value. The maximum value of the whole image is obtained after comparing the size every time the dark channel value is obtained. Then the J value of the pixel in the original image is read as the overall atmospheric light A[11].

3.3 Design of transmittance calculation module

Considering that the size of t is between 0 and 1, and the floating point [12] operation will greatly improve the calculation accuracy, the main addition, subtraction, multiplication and division in the calculation process are calculated by floating point numbers. Here, a floating-point multiplier, a floating-point divider, and a floating-point subtractor are required. Since the obtained t is 32 floating-point numbers, and the SDRAM data width is only 16 bits, it is necessary to multiply t by a factor K to become an integer for storage. In order to avoid the rounding error caused by too small t, the comparison process with the size of 0.1 is advanced here, and the larger value of the two is taken as the output value, and then multiplied by the factor K, K is selected 20.

3.4 Design of edge detection and smoothing filter module for transmittance

3.4.1 Transmittance edge detection module

The core operation of Prewitt edge detection is to perform 8-neighborhood template convolution on each pixel. Here, the shift register is also used to convert the serial data into parallel data, and then the template is multiplied and added. Finally, the final gradient is obtained by judging the size of the horizontal gradient and the vertical gradient, and this gradient is compared with the set threshold. Here, the threshold is set by external buttons, and the threshold size is adjusted according to different external environments to obtain ideal edge detection results. The main process of edge detection is shown in Figure 3 :

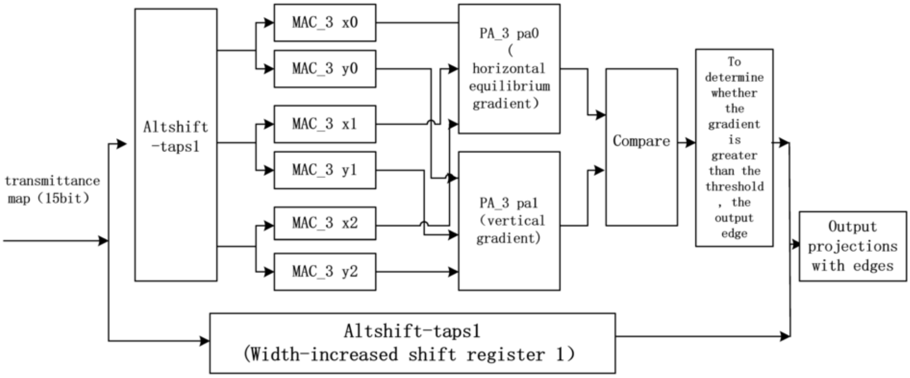

Figure 3. Structure diagram of transmittance edge calculation

In Figure 3, MAC _ 3 is implemented by using the IP core ALTMULT _ ADD provided by quartusII, which mainly realizes the multiplication and addition of three consecutive numbers and templates on the same line. PA _ 3 is implemented by using the IP core PARALLEL _ ADD (parallel adder) provided by quartusII, which mainly realizes the sum of the results of the three multipliers under the same clock to obtain the final gradient, so the horizontal gradient pa0 and the vertical gradient pa1 are obtained respectively.

3.4.2 Transmittance edge filtering module

After obtaining the transmission map with edges, two shift registers are used to average all the image data on one side, and output the data of the original transmission map on the other side. Finally, the output is selected by judging whether it is an edge. When it is the edge of the image, the transmission image after the mean value processing is output ; when it is not the edge, the original transmission map data can be output. The following diagram is the mean filter hardware implementation block diagram :

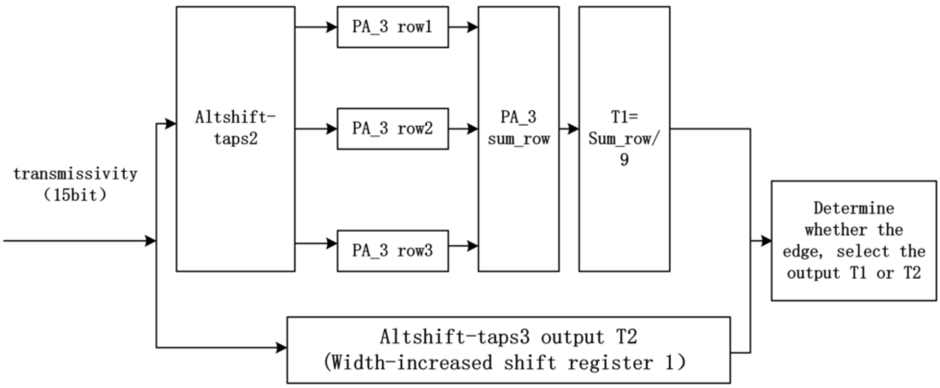

Figure 4. Structure of edge filtering process

It can be seen from Figure 4 that the shift register, multiply-accumulator and accumulator IP core provided by quartusII are mainly used in the figure. The most critical part is to ensure that the data under the same clock is correctly matched. This part mainly realizes the correct matching by setting the delay of the IP core and modifying the timing through simulation observation. The transmittance here is an enlarged integer, so there is a certain degree of error.

3.5 Restoration module design

After obtaining the distribution map of the transmittance t and the atmospheric estimator A, the final recovery process uses the formula $J(x)=\frac{I(x)-A}{\max(t(x),t_0)}+A$ to recover. The two parameters I and t that need to be used are stored in SDRAM0 and SDRAM1 respectively. In the calculation process, only SDRAM0 and SDRAM1 are required to read data at the same time to achieve synchronous calculation[13].

4. Analysis of the Results

As described above, the system uses Taiwan Youjing 's DE2-70 and TRDB-D5M image acquisition modules to build the system. Through continuous debugging, the defogging algorithm has been completed in the video acquisition system. Figure 4 shows the final restored image output on the display, followed by the original image, the dark channel module, the transmittance calculation module, and the restored image.

(a) Original image (b) Shadow channel

(c) Optimized transmittance map (d) Restoration image

Figure 5. Hardware recovery diagram

Figure 5 shows some hardware restoration images. From the restored images, it can be seen that the system realizes the effective restoration of the images collected in the foggy scene, and the restored images are bright in color, natural and realistic, and high in clarity.

5. Conclusion

In this paper, aiming at the problems existing in the hardware transplantation of the dark channel prior defogging algorithm, the longest time-consuming transmittance optimization process in the algorithm is improved, and the implementation process of the algorithm transplanted to the main modules in the FPGA hardware platform is introduced in detail. Finally, the experimental results are given. The experimental results show that the system effectively realizes the effective defogging of the dark channel defogging algorithm on the FPGA hardware platform, and basically meets the requirements of real-time defogging.

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