FPGA Implementation for Enhancing Image Using Pixel-Based Median Channel Prior

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Abstract

Poor weather condition such as fog, rain or haze causes problem in getting information from image. As computer vision system extracts features from the scene, it is important that reliable information could be obtained by removing haze. This paper proposes a fast fog removal method which is implementable in hardware for single image. Using pixel-based median channel of haze image, we can estimate atmospheric light. As a result, high-quality image can be recovered with lower computation complexity compared to patch-based dark channel prior. FPGA implementation shows that real-time dehazing is achievable with median channel prior.

Keywords: Dehaze, Dark channel, Image restoration, FPGA

1. Introduction

Many applications in computer vision assume input images are clear. Unfortunately, it is not always true [1]. Especially for cameras installed in outdoor, removing haze is indispensable for computer vision systems.

Recently, several algorithms for single image haze removal have been proposed. Tan [1] observes that the haze-free image must have higher contrast compared with the input haze image. Fattal [2] estimates albedo of the scene, and infers medium transmission under the assumption that the transmission and the surface shading are locally uncorrelated. Tarel [3] imposes constraints on the depth variation by maximizing the atmospheric veil assuming that it must be smooth most of the time. However, these approaches are complex and lose too much color information. Kaiming [4] proposes dark channel prior(DCP). He points that in the most of the local regions which do not cover the sky, it is very often that some pixels have very low intensity at least one color channel of RGB. DCP is simple but it needs post processing because of halo effect.

In this paper, we propose improved DCP using pixel-based median channel prior that does not cause the halo effect.

2. Haze Restoration Algorithm

In computer vision, the optical haze model used to described the formation of a haze image is given as follows [1,2,4],

$$I(x,y) = J(x)\, t(x) + A\, (1 - t(x)) . \tag{1}$$

Where $I(x)$ is the observed image, $J(x)$ is the haze-free image, A denotes Air light, and $t(x)$ is medium transmission.

2.1. Dehazing Based on Patch-Based Dark Channel Prior

Dark channel prior uses the fact that at least one channel of image patches without sky is close to zero. For dark channel $J^{dark}(x)$ is given by [4],

$$J^{dark}(x) = min_{y \in \Omega(x)}[min_{C \in R,G,B} J^C(y)] . \tag{2}$$

Where $\Omega(x)$ is center of local patch at x,y, C is three channel(RGB) of a pixel, and J^c denotes each of the color channels.

After picking up the top 0.1% brightest air lights in dark channel, the RGB value located at the brightest air lights is converted to V(Intensity) of HSV color space. Then, the transmission map t(x) can be derived as,

$$t(x) = 1 - w\, min_{y \in \Omega(x)}\left[min \frac{I^C}{A^C}\right] . \tag{3}$$

Where w is constant parameter that keeps depth perception, $0<w\leq1$ (w is set to 0.95 in [4]), I^C is the color channel in the observed image(I), and A^C is the top brightest air light via dark channel process in each of the color channels.

Finally, we can recover the dehazed image according to Eq. (1-4),

$$J(x) = \frac{I(x) - A}{max(t(x), t_0)} + A . \tag{4}$$

2.2. Proposed Dehazing Based on Pixel-Based Median Channel Prior

Our proposed method takes advantage of the property that one of RGB channels is close to zero in the image without the sky. We call this as "pixel-based median channel prior".

The median channel J^{median} is inferred as,

$$J^{median}(x) = med_{C \in R,G,B} J^C(x) . \tag{5}$$

Where J^C is the each of the three channels for a pixel.

To extract the air light, we find the maximum value among R, G, and B for a pixel. Then each maximum values for a pixel are compared to decide the highest value,

$$Air\ light = max[max_{c \in R,G,B} J^C(x)] \tag{6}$$

After estimating air light, we can derive the transmission map as,

$$t(x) = 1 - w * [med_{C \in R,G,B} \frac{I^C}{Air\ light^C}] \tag{7}$$

A constant parameter, w ($0<w\leq1$), is used for preserving the original color. w is fixed at 0.875 for all experiments in this paper.

With the transmission map, we can recover the haze image. Dehazing image J(x) is given by,

$$J(x) = \frac{I - A}{t(x)} - A \tag{8}$$

In the next Section, we discuss the comparison of DCP based patch and MCP based pixel.

3. Comparison Experiments

We discuss two algorithms, the patch-based DCP and pixel-based MCP. We compare the performances of the two algorithms. In Table 1, our method needs about 20.87 seconds to process a 720 X 480 image in Visual Studio 2013 using the OpenCV 2.0 on a PC with 3.5Hz Intel i5 processor. From these result it seems that pixel-based MCP outperforms patch-based DCP.

Table 1. Results Showing the Speed Comparison of Our Method and Kaiming

Image size	Patch-based DCP	Pixel-based MCP
320*240	2.91s	0.59s
600*450	42.84s	4.01s
720*480	68.03s	20.87s

Figure 1 shows original image and artificial haze image. Figure 2(a) shows the resultant image after using DCP to enhance the image. It looks sharp and has halo effect of which post-processing is needed to get rid. Meanwhile, Figure. 2(b) shows the result from our method that does not need post-processing. Our method causes high chroma, but complexity is lower than DCP. Figure 3 shows the dark channel images and Figure 4 shows the transmission maps.

(a)   (b)

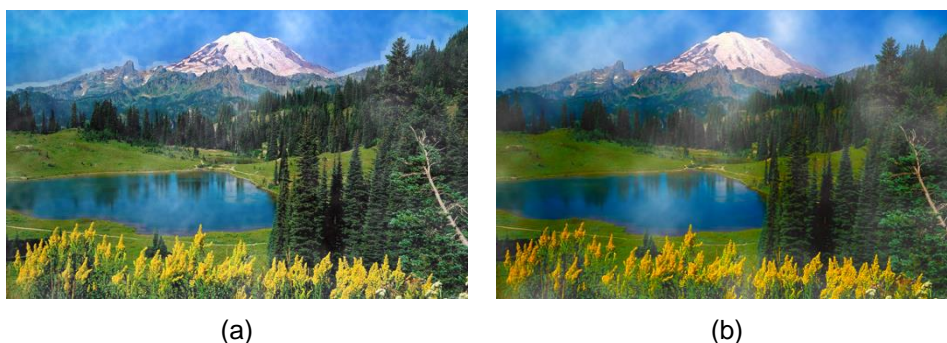**Figure 1. (a) Original Image, (b) Image with Artificially Applied Haze**

(a)   (b)

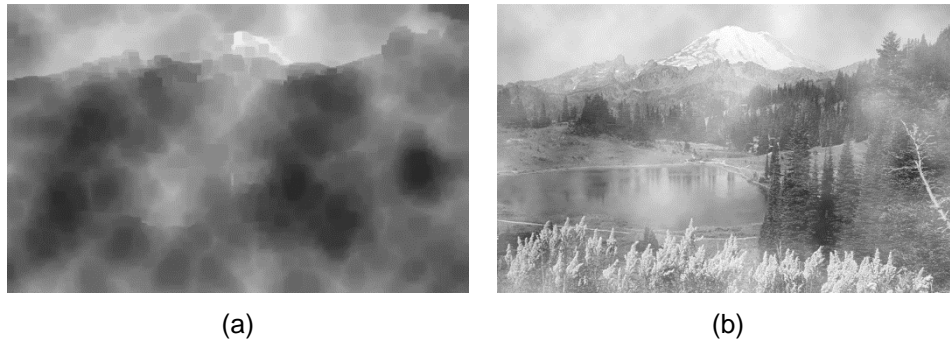**Figure 2. (a) Dehazed Image Using Patch Based DCP, (b) Dehazed Image Using Pixel Based MCP**

| (a) | (b) |

Figure 3. (a) Dark Channel Patch Using DCP, (b) Median Channel Using MCP
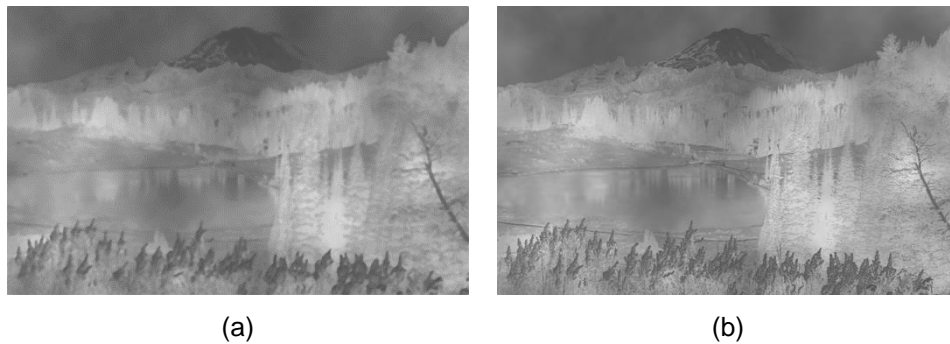

| (a) | (b) |

Figure 4. (a) Transmission Map Using Patch Based DCP, (b) Transmission Map Using Pixel Based MCP

4. Design of Hardware

Based on the description of the algorithm in the Section 2, we describe our hardware architecture. Figure 5 shows the block diagram of our hardware. Input image format of our design is 24-bit RGB and the output is same. The median channel block chooses the brightest intensity to decide air light. After picking up the air light, transmission map is obtained in the transmission block. The input data is divided by the value of the air light. Then the divided value is fed to redefine median channel block to extract median value. The median value is multiplied by a constant parameter w using subtractor and shifter to produce the transmission map. The transmission map is used in restoration block to finally make image without haze. The image is stored in buffer for video output.
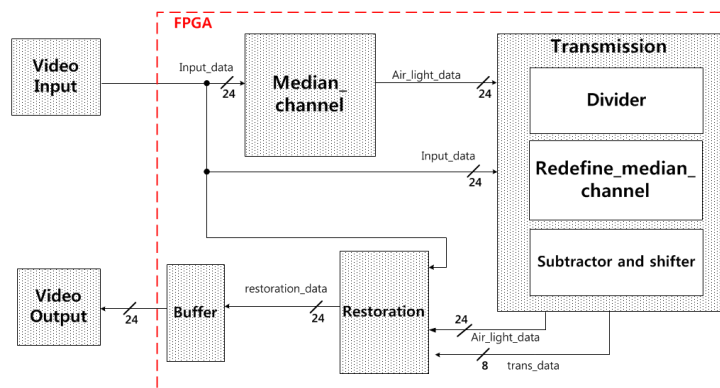

Figure 5. Hardware Architecture for Removing Haze

The detailed block diagram of the median channel is illustrated in Figure 6. Red, green, and blue values of a pixel are compared each other to find the median value of that pixel. Then all the median values are compared to find the highest value to determine air light value.

The transmission block consists of three modules, divider, redefine median channel, and subtractor and shift. Figure 7 illustrates the divider used in this paper. Because the operation of dividers usually takes a few cycles, we apply pipeline scheme to the divider to increase throughput thus enabling real-time operation. The sequential divider is unrolled to form 9-phase pipelined divider to obtain 1-bit integer and 8-bit fraction. If the resultant 1-bit integer is one, overflow occur and the quotient is set to the highest value. Otherwise, 8-bit fraction is used as the quotient. The quotient is fed to the redefine median channel block to produce median value. In subtractor and shifter block, the parameter w to preserve the original color should be multiplied to the median value. To simplify the hardware implementation and accelerate the operation, multiplier is replaced by a subtractor and a shifter. Moreover, the value of parameter w, 0.875, is chosen to reduce the complexity.

As shown Table 2, the block RAM(BRAM) used in FPGA implementation is as small as 0.6KB. Because our hardware architecture can process the input image on-the-fly, the whole frame of image does not need to be stored in FPGA. Therefore, we use small amount of memory only for buffering output. The operation frequency is 113 MHz which can process the image of UHD resolution in real-time. Our design is verified in NEXYS4 board, which is based on Xilinx Artix 7. The development environment is Vivado 2014.4. suite.
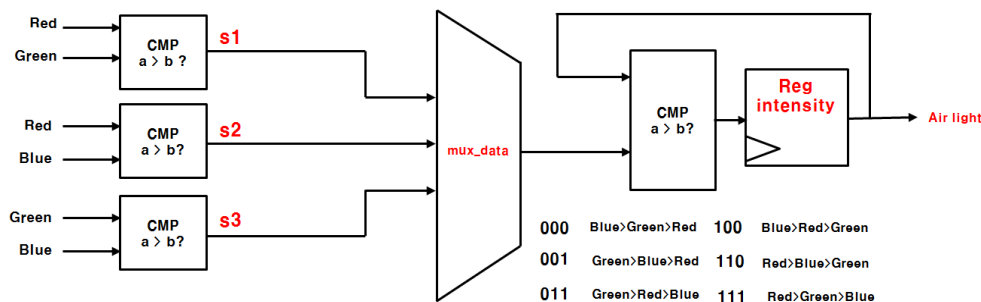

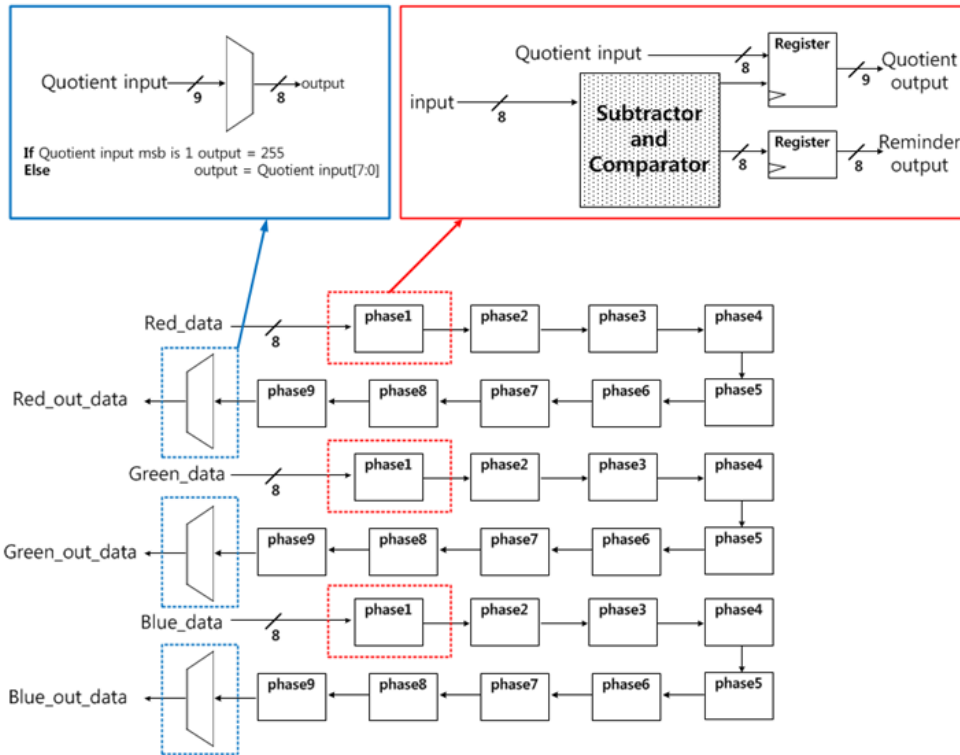**Figure 6. The Scheme of Median Channel**

Figure 7. Pipelined Divider

Table 2. FPGA Resource Requirements for Our Method

Resource type	Resource used	Total available	Ratio
Slice LUT	1501	63400	2.36%
Slice Register	813	126800	0.64%
BRAM	0.64Kb	135Kb	0.47%

Figure 8 shows results from software programmed with 32-bit fixed point and hardware with 8-bit. Although the precision used in hardware is lower than software, they looks similar. In MATLAB simulation, the mean difference between software and hardware results is as small as 1.4%.
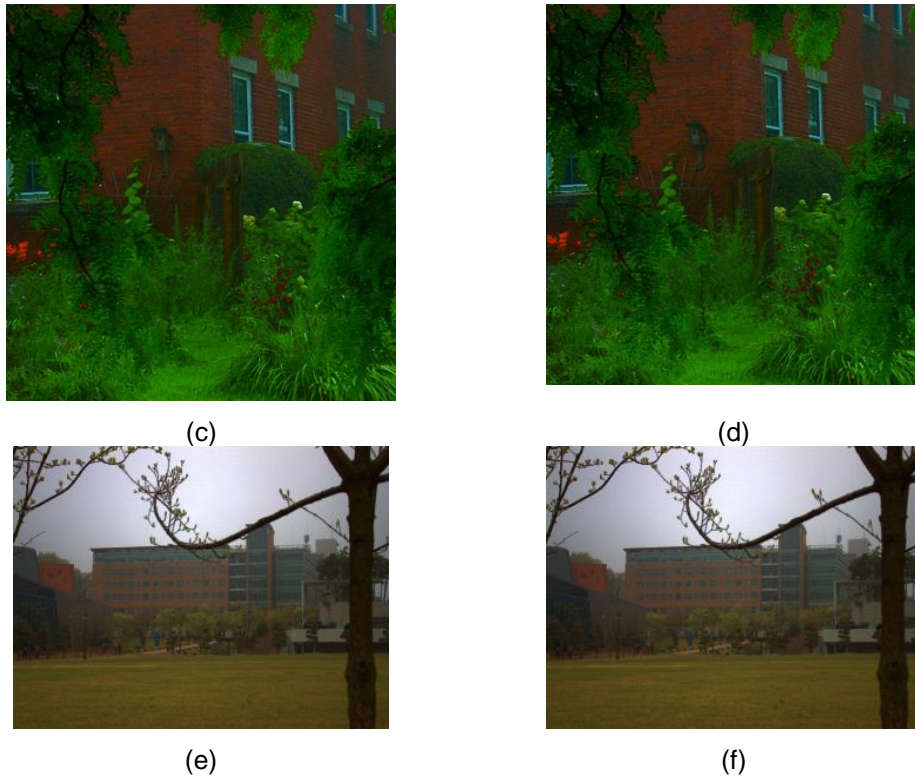

(a)

(b)

Figure 8. (a)-(b) Original Image, (c)-(e) MCP Pixel-Based in Software, (d)-(f) Result of MCP in Hardware

6. Conclusion

In this paper, we designed the hardware for pixel-based MCP. We simulated bilateral filter and matting filter in MATLAB and OpenCV to find the proper dehazing algorithm. However, due to the halo effect and the hardware complexity, we devise and propose the application of median filter. For low-complexity hardware implementation, multiplier is replaced by subtractor and shifter, and pipeline architecture is applied to divider. The FPGA result shows that the operation frequency is 113MHz which is enough to process UHD in real-time.

Acknowledgements

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