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Design of Real-time Haze Image Restoration System Based on FPGA Technology

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Abstract: With the development of science and technology, the outdoor image acquisition system has been widely used in various sectors of the national economy, such as transport, agriculture and aerospace. But by the impact of inclement weather, the image quality will be a serious decline. Therefore, the defog processing of digitized images is one of the research focus in recent years. The traditional approach is to upload the image data to the host computer and then process the image on software platform. Since it is difficult to achieve real-time processing by this method, portability and mobility of the platform is too weak, we present a FPGA-based image defogging system. The system includes algorithm and hardware platform. The algorithm is based on fog degradation model and has been optimized and streamlined for FPGA platform. The hardware part using D5M provided by Terasic to acquire the image, using DE2-70 provided by Altera to process the image and using LTM provided by Terasic to display the result. Experimental results show that this system has achieved real-time processing and has also met the design requirements of de-fog effects.

Key words: De-fog, restoration, real-time, FPGA, fog degradation model

INTRODUCTION

Digital image processing technology has been rapid development in recent years and has been applied in more and more fields. Able to process the image after it has been captured is one of the most important advantages of the digital image technology, studies about the post-processing of digital image are too numerous to mention. Among the variety of post-processing technology, fog image restoration is currently one of the most important issues.

Image quality is greatly decreased in applications such as video surveillance, traffic management, aerospace and astronomy research due to the effects of suspended particles in the atmosphere. This influence reduces the effect of outdoor image acquisition system. While the de-fog process can largely of digital image can largely change the status quo, restore the quality of the images which have been captured by the outdoor system.

Currently, there are two common ways to process the fog image. The first process the image using image enhancement methods without considering the reasons of image degradation, using methods such as wavelet transform, histogram equalization, homomorphic filtering and local contrast enhancement to improve the imaging results of the fog image. This method is simple, versatile but will cause a loss of image detail. Another class of defogging method based on the physical model, study the fog image imaging principle, establish fog physical model inversion degradation process. Through a series of calculations, compensate the degradation of the fog image. This method is more complex but based on the physical principles of fog image imaging, so the effect is obvious (Hautiere *et al*., 2006, 2007).

Although there are many ways to process the fog image, most of them are PC-based which greatly limits the defogging system's ease of use and real-time. This study presents a FPGA-based hardware platform for real-time defogging processing system, in the case of ensuring the defog effect, improves the process speed of most of the existing software algorithms and lower the requirements of platform. Use FPGA platform to restore the fog image has the following advantages: Firstly, FPGA platform can completely real-time processing while the PC running the software for processing usually can't do real-time processing; secondly, FPGA platform has the characteristics of the portable which is convenient in outdoor image capture and immediately process the fog image; thirdly, the FPGA platform can be designed for specialized applications, more targeted.

PHYSICAL MODEL

By bad weather such as fog and haze, images collected from outdoor scenes often have many problems such as low contrast, color shift and so on. Effectively

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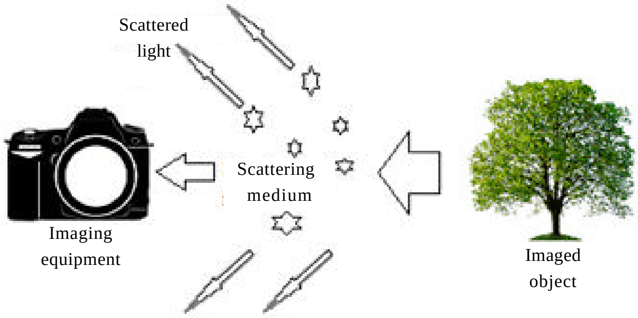

Fig. 1: Atmospheric attenuation model

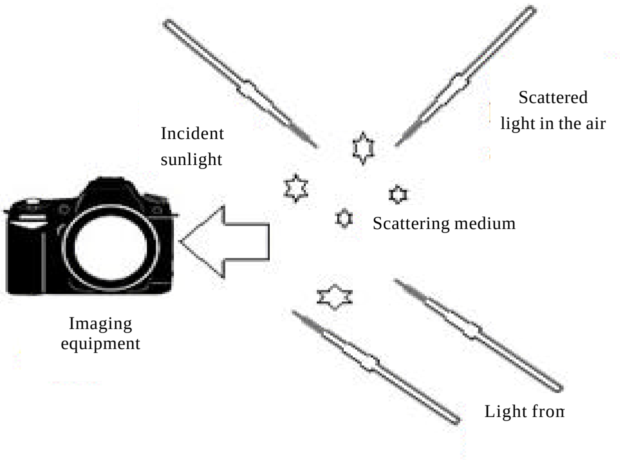

Fig. 2: Atmospheric optical model

recovery of the collected images has an important significance on subsequent image processing and pattern recognition. Fog degradation model is a mature fog imaging model, there are many algorithms based on this model most of which is single image restore, suitable for situations requiring high recovery effect, restoration effect is remarkable (Veit *et al*., 2008). By the physical model of fog, the fog image degradation has reasons mainly consists of two parts, one part is atmospheric attenuation which is shown in Fig. 1. Due to atmospheric scattering, reflected light of outdoor scenes reaches the imaging device with exponential attenuation which is shown in the first item of Eq. 1.

The other part is the ambient light around reached the imaging device due to scattering synthesis, shown in Fig. 2 (Fattal, 2008).

Koshimider put forward the fog imaging physical model equation, shown in Eq. 1 (He *et al*., 2009; Tan, 2008).

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

where, I(x) is observed fog image, J(x) represents recovery image, A is sky brightness, t(x) indicates the medium transfer function, used to describe the part of light which directly to the camera without scattering. J(x)t(x) is the process shown in Fig. 1 while A(1-t(x)) is the process shown in Fig. 2. The goal of this algorithm is to restore the recovery image J(x) from the fog image I(x), from Eq. 1 we know that the recovery process need to estimate the value of A and t (x).

DEFOG ALGORITHM

As can be seen by the Eq. 1, during the recovery process, the estimation of A and t(x) directly affects the quality of image restoration. As the depth of field is unknown, it is difficult to estimate t(x, y), so we introduce the atmospheric dissipation factor V(x, y), let V(x, y) = 1-t(x, y), Can be obtained a new transformation Eq. 2 (Tarel and Hautiere, 2009):

$$I(x, y) = R(x, y)(1-\frac{V(x, y)}{I_s})+V(x, y) \qquad (2)$$

where, I(x) is the fog image, R(x, y) is the recovery image, I_s is the brightness of the sky which has the same meaning as A in Eq. 1.

The atmospheric dissipation factor of the fog image V(x, y) has two limits considering its physical nature:

- V(x, y) value of each pixel must be positive, that is $V(x, y) = 0$
- V(x, y) value of each pixel is not greater than the minimum value of each component of this pixel in the original fog image, that is $V(x, y) \leq \min_{c\in(R, G, B)} (I^C(x, y))$

Considering these limits and the physical nature of V(x, y), we can estimate V(x, y) by following method:

- Calculate the minimum value of the RGB components W(x, y) of the original image:

$$W(x, y) = \min_{c\in\{R,G,B\}} (I^C(x, y)) \tag{2}$$

I (x, y) is the original input image.

Find the Median of W(x, y):

$$A(x, y) = \text{median}_{S_v} (w(w, y)) \tag{3}$$

S_v is the template size of the median filter.

Calculate the difference of W and A, then calculate the absolute value of the difference:

$$B(x, y) = A - \text{median}_{S_v} (|W - A|)(x, y) \tag{4}$$

S_v is the template size of the median filter.

Find the maximum value of the minimum:

$$V(x, y) = p \max(B(x, y), W(x, y))0) \tag{5}$$

Multiplicative factor p is used to control the intensity of haze removal, Can be adjusted according to different image (Narasimhan and Nayar, 2003).

The implementation of the hardware platform and software implementation is very different, embodied in Logical resources and floating-point computing power of the hardware platform is limited and so on. So, there are still some problems to implement above-mentioned algorithm in FPGA hardware platform. FPGA platform floating point arithmetic is running slow, take up a lot of resources, so floating-point operations should be avoided. Take the maximum or minimum value of the whole image need to wait for the data of whole image is read and stored and then take operations, this will take up a lot of storage space and has a great impact on the real-time processing. So, we should avoid whole image processing.

Considered the characteristics of the hardware platform, the algorithm is streamline and optimize as follow.

First, in the derivation of the algorithm, all values are normalized to 0-1. In hardware computing process, floating-point operations is very slow but also takes up a lot of resources, therefore, the Eq. 2 should be normalized to 0-255, in the process of hardware implementation, computational less, better real-time.

Second, as hardware platforms require real-time processing of images in a variety of environments and considering that calculating the single image of the sky brightness will be an impact on the real-time, we set brightness of the sky I_s to the maximum possible value 255 while restoring the fog image.

Last, the method to obtain the atmospheric dissipation function V has been modified. Smoothing function of the original algorithm is median filter, median filtering process often need to use the 61×61 template, even the fastest median filter algorithm can get the median after 61×61 data taken. Such process is resource-intensive and real-time will have a great impact. So in Hardware implementation, we use average filter other than median filter as the smooth function in Eq. 2 and 4.

The restoration image R(x, y) can be obtained according to the inverse transform of Eq. 2, shown in Eq. 6. This equation shows that when the value of V is determined, we can get restored image (Tarel and Hautiere, 2009):

$$R(x, y) = \frac{I(x, y) - V(x, y)}{1 - \frac{V(x, y)}{I_s}} \tag{6}$$

Substituted V(x, y) and I(x, y) into Eq. 6, the restored image is available.

HARDWARE PLATFORM

The system uses a CMOS image sensor in real-time image acquisition,uses FPGA to do the restoration and displays the restored image on a LCD monitor. According to the desired function, we have designed a corresponding system. System architecture is shown in Fig. 3.

The COMS sensor of this system is TRDB-D5M provided by Terasic, LCD is TRDB-LTM touch screen and FPGA is Altera Cyclone II EP2C70 which is on the

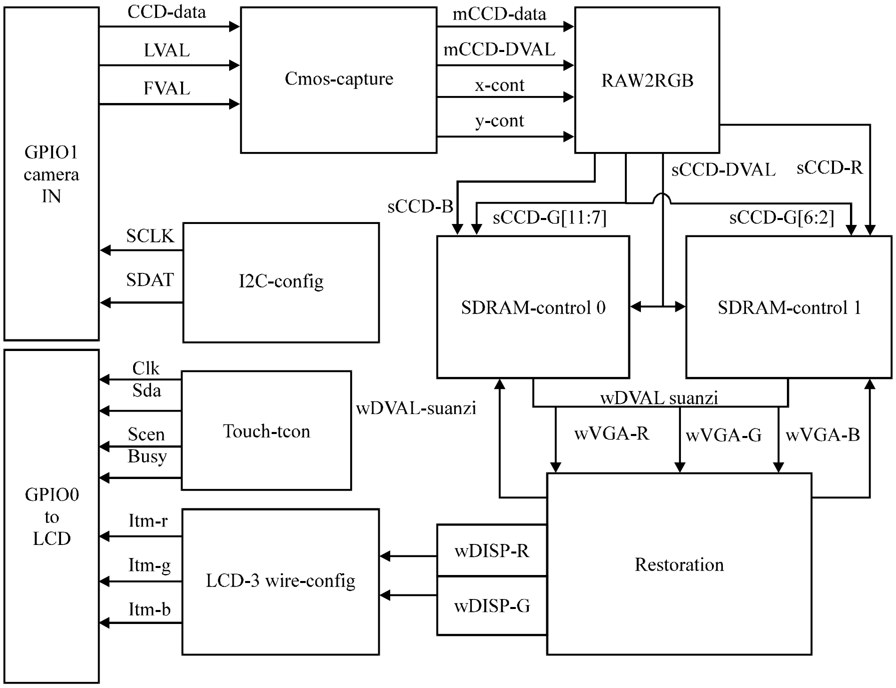

Fig. 3: Overall architecture of the system

DE2-70 development board provided by Altera. We can modify the corresponding values of the image sensor registers to set the parameters of the CMOS. The Cmos_Capture module can capture real-time image into the type of RAW image data. The RAW2RGB module can convert the RAW data to RGB data and respectively store these data in the two-chip SDRAM. The restoration module will request data from the SDRAM for processing. Touch_Tcon and LCD3 module will display different images according to the buttons and DIP switch.

ALGORITHM ON FPGA

According to the Eq. 6 and the optimization for the hardware platform, we can obtain a suitable equation of the hardware platform which is using Integer arithmetic instead of floating-point operations in order to save hardware resources. See Eq. 7 and 8:

$$J(x) = A\frac{A-I(x)}{t}\times 255 \tag{7}$$

$$t = 255\text{-}pv \tag{8}$$

In the optimized algorithm, the A value assignment for a possible maximum value of 255; the experimental results show that the restoration has a best result when p-value is from 6.0 to 9.5. In the design of the hardware, in order to meet the processing requirements in a variety of different environments and save the hardware resources to avoid the use of the divider, the p-value is set to 0.875.

According to Eq. 7 and 8, hardware platform algorithm flow chart shown in Fig. 4 (R channel for example).

Figure 4 shows that we must get the V value by analyze the fog image and then substitute the V value into the equations. So, find the steps to get V value is the core and difficult part of this algorithm.

According to the Eq. 2~5 and the optimization for the hardware platform, we can obtain the process to get the V value. Shown in Fig. 5.

After V value is obtained according to this process, Substitute the calculation results into the "V input" section in Fig. 4, calculated in accordance with the process, then we can get the restored image.

In order to implement the algorithm on FPGA platform, we need design function modules and connect these modules according to the process shown above, form the Restoration module shown in Fig. 3.

Avg Module is the largest sub-module in the system, its function is to calculate the mean of the 4×4 template and assign the mean value to point (1, 1) in the template. This module comprises the LineBuffer for temporarily storing the image information, MAC and Adder for numerical summation and Shifter for simulate the division averaging. Buffer storage, MAC summation, Shifter

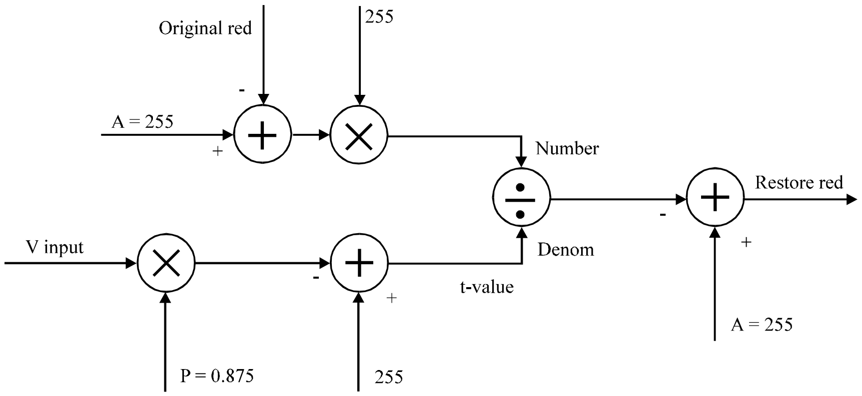

Fig. 4: Algorithm processing flow chart

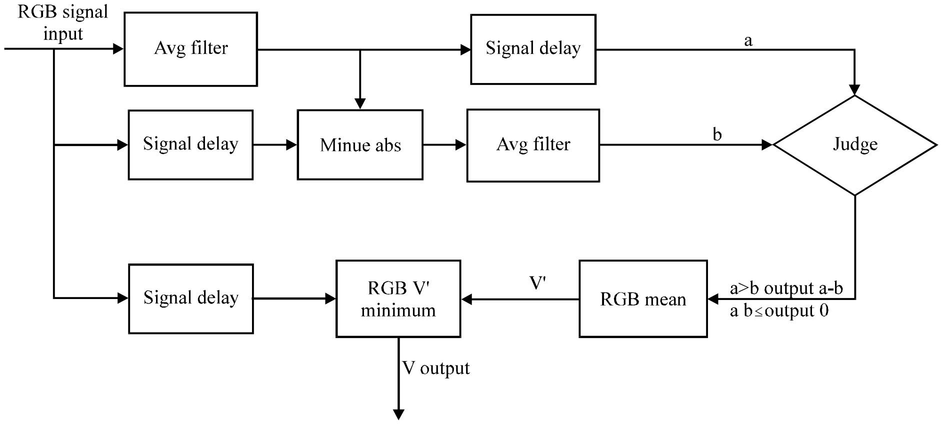

Fig. 5: Flowchart of getting veil value

averaging operation, three steps in series in order calculate mean value. Module input signals: ICLK as clock input, iRST_N as reset signal, iDVAL as input data validation signal and RGB as image data input. Module output signals: oDVAL as output data validation signal and RGB as image data output. Avg Module is shown in Fig. 6a.

Delay Module is used as a cache to store the data not involved in the calculation temporarily, in order to maintain data synchronization. This module includes LineBuffer which can specify the delay time by writing the register. Module input signals: ICLK as clock input, iRST_N as reset signal, iDVAL as input data validation signal and RGB as image data input. Module output signals: RGB as image data output. Delay Module is shown in Fig. 6b.

The main function of Minus-Abs module is to take the absolute value after subtraction of the two data. This module uses subtraction module and absolute module. Module input signals: Inputa and inputb as two input signals. Module output signal: Outdata as result output signal. Minus-Abs module is shown in Fig. 6c.

The function of Cmp-Minus module is compare the value of two input, inputa and inputb, if a>b, then the output is a-b; if a = b, then the output is 0. Module input signals: iCLK as clock input, abs and med as two comparison signals. Module output signal: odata as result output signal. Cmp-Minus module is shown in Fig. 6d.

By using Adder, Shifter sub-modules, the V-value Module achieves the operation described in Eq. 5 and the output is the V value in Eq. 8 and Fig. 4. Module input signals: iCLK as clock input, indata as the processed RGB data and iOriginal as the RGB data from the original fog image. Module output signal: odata as the V value output signal. V-value Module is shown in Fig. 6e.

The t-value Module use the output of the V-value module to get t value according to Eq. 8. The p value has been set to 0.875 as previously described. Module input

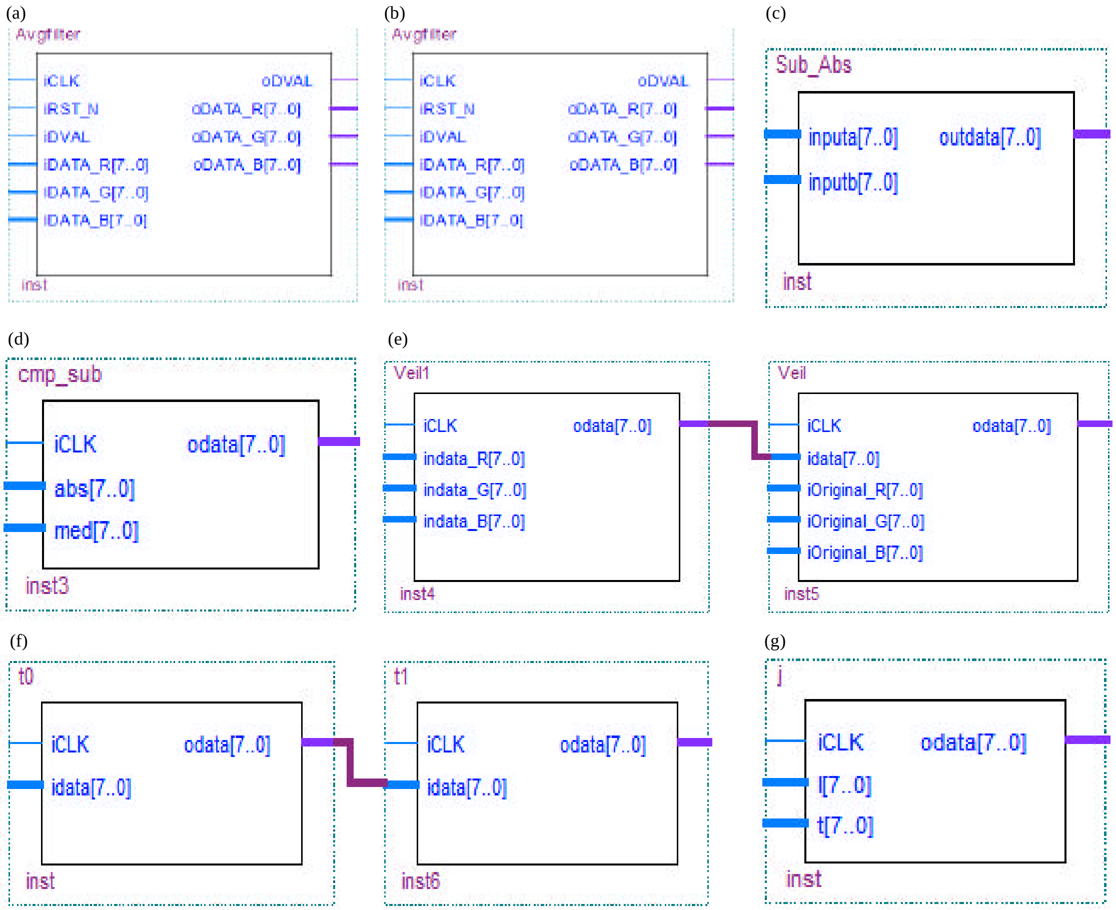

Fig. 6(a-g): Modules, (a) Avg module, (b) Delay module, (c) Minus-Abs module, (d) Cmp-minus module, (e) V-value module, (f) t-value module and (g) Restoration module

signals: iCLK as clock input, idata as V value input. Module output signal: Odata as t value output signal. T-value Module is shown in Fig. 6 f.

Restoration module is designed based on Eq. 7, use data obtained by other modules to do the last process of the defog algorithm, output of this module is the restored image. Each module process one of RGB component, so we need totally three restoration modules to complete the process of RGB component.

Module input signals: iCLK as clock input, I as the original image data and t as t value obtained by t-value Module. Module output signal: odata as the restored image data output. Restoration module is shown in Fig. 6g.

Modules above are designed according to the functional blocks of the flowchart shown in Fig. 4 and 5, each module implements one or more process. We can achieve fog image restoration process by connecting these modules. Figure 7 shows the internal structure of the Restoration module shown in Fig. 3.

The inputs of the restoration module are from wVGA_R, wVGA_G, wVGA_B in Fig. 3, after a series of process, the restoration module outputs the restored image data and send the data to LCD display through three signal line wDISP_R, wDISP_G and wDISP_B. At the same time, after the completion of current process, the signal wDVAL_suanzi will request data from SDRAM to get the data for next process.

RESULTS

The original images are using the D5M camera to direct acquisition, all the images hasn't been post-processing. While testing, the system defog effectively with completely real-time processing.

By the following contrast of the images, we can clearly see the effect of this defog system.

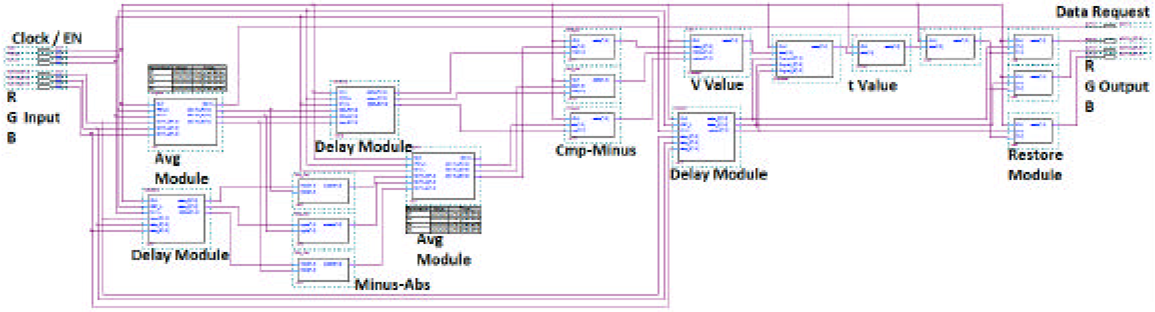

Fig. 7: Internal structure of the restoration module

Fig. 8(a-b): Restored image compared with original image, (a) Original image and (b) Restored image

Fig. 9(a-b): LTM display effect, (a) Oiginal image and (b) Restored image

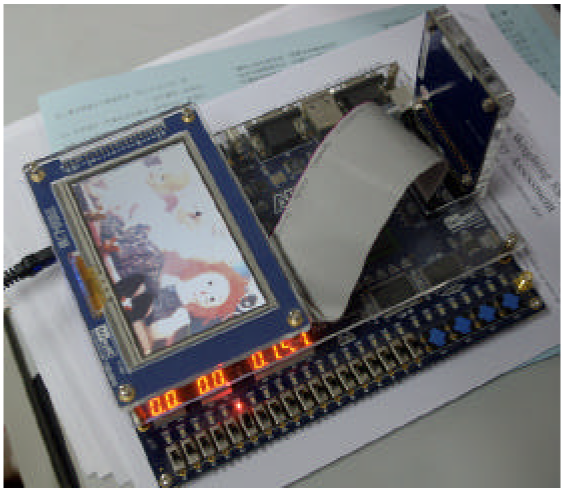

Fig. 10: System hardware photo

CONCLUSION

The system is implemented on the DE2-70 development board, TRDB-D5M sensor and TRDB-LTM LCD screen hardware development environment; Hardware system uses a buffer, addition, subtraction and shifter module, designed according to the defog algorithm which is optimized for the hardware platform; The algorithm is based on the fog degradation model and has been optimization according to the characteristics of the FPGA hardware, using Verilog HDL language to programming. The entire system uses FPGA hardware resources 6727LEs, in which the restoration module uses 3529 LEs.

Experimental results show that this algorithm meet the real-time requirements and has good quality of defogging. On the real-time side, restored image display has no sense of hysteresis; on the quality side, the clarity and contrast of the fog image has been greatly improved after restore, the quality of defog is satisfying; in addition, the system is portable, whole weight is less than 1 kg; At the same time, the FPGA set aside a variety of input and output interface for further more extend requirements.

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REFERENCES

Tarel, J.P. and N. Hautiere, 2009. Fast visibility restoration from a single color or gray level image. Proceedings of the IEEE 12th International Conference on Computer Vision, September 29-October 2, 2009, Kyoto, Japan, pp: 2201-2208.

He, K., J. Sun and X. Tang, 2009. Single image haze removal using dark channel prior. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, June 20-25, 2009, Miami, FL., USA., pp: 1956-1963.

Hautiere, N., J.P. Tarel and D. Aubert, 2007. Towards fog-free in-vehicle vision systems through contrast restoration. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, June 17-22, 2007, Minneapolis, MN., USA., pp: 1-8.

Hautiere, N., J.P. Tarel, J. Lavenant and D. Aubert, 2006. Automatic fog detection and estimation of visibility distance through use of an onboard camera. Mach. Vision Appl., 17: 8-20.

Fattal, R., 2008. Single image dehazing. ACM Trans. Graphics, Vol. 27, No. 3. 10.1145/1360612.1360671

Tan, R.T., 2008. Visibility in bad weather from a single image. Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition, June 23-28, 2008, Anchorage, AK., USA., pp: 1-8.

Narasimhan, S.G. and S.K. Nayar, 2003. Contrast restoration of weather degraded images. IEEE Trans. Pattern Anal. Mach. Intell., 25: 713-724.

Veit, T., J.P. Tarel, P. Nicolle and P. Charbonnier, 2008. Evaluation of road marking feature extraction. Proceedings of the 11th International IEEE Conference on Intelligent Transportation Systems, October 12-15, 2008, Beijing, China, pp: 174-181.