IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Optimized VLSI Architecture for Adaptive Haze Removal

[1]ANKIT.K.NAG, [2]NIRANJAN E,

[1]PG Student, [2]Assistant Professor
[1]VLSI and Embedded Systems,
[1]Banglore Institute of Technology, Bengaluru, INDIA

Abstract: In realtime processing applications of the outdoor type, the systems depend on technologies like computer vision. Haze removal, which is a technique carried out before the processing of the data that is used for recovering clearer a image from a hazy source image, is essential for detection of any objects and avoidance. Hence, in this project, a simple and efficient haze removal method which is pertinent for VLSI hardware design has been proposed in order to obtain higher quality output image from a hazy source image. It is based on dark channel prior methodology and also the atmospheric light scattering model. In this technique we extract the atmospheric light from an entire image. We also extract the transmission map of the image. These two properties are necessary and important specifications for the image recovering model. Here, rather than using a single global atmospheric light for the restoration of the blurred scene, a method for estimating the local atmospheric light is exercised in the design in order to obtain better output result. To make sure that the overall image is homogeneous without block issue generation, we are dynamically adjusting the local light estimation based on the parameters for global light. Additionally, in order to attain the transmission map, an estimation method with refinement is being carried out to reduce the halo artifact generation. Finally in the evaluation of both qualitative and quantitative nature, the design shows better performance without oversaturating the colours and without creating any distortion. To adapt this operation for a real time application, a 6 stage VLSI architecture has been proposed for the algorithm.

Index Terms – **Haze removal, Local Atmospheric light, VLSI.**

I. Introduction

Along with the advancement in technology, the extent of technology for interaction of human with computers and different types of intelligent assistance systems which ease effort of different tasks for humans also increases. This increases the demand for sensor systems which mainly comprise of cameras and other sensors involved in surveillance systems for the execution of real time monitoring and recording of public and private zones for the sake of various applications. For example, in intelligent transport systems, cameras can be used for monitoring roads or the streets for the detection of traffic density or for identifying a vehicle for the sake of certain exceptional applications. Beside this, the video feed from road monitoring systems can provide essential information in relation to vehicle crashes or accidents, like the car license-plate numbers. Information such as this is very beneficial for the law enforcement agencies in investigation and resolution of incidents like road accidents and traffic rule violations. For the realtime safety and surveillance based applications, a quick, yet efficient adjustment algorithm to adjust the illumination for the purpose of improving the image and a pipelined VLSI design are constructed. When applied for the personal use, dashboard cameras mounted on vehicles can record the situation of the road like traffic conditions and position of other vehicles while commuting. Then, the advanced driver assistant systems (ADASs) may be used for performing analysis of the data in real time for maintaining the safety of the operator. Hence, in such applications, the quality of the data fed to the processing system, in this case, video data, plays an essential role. But the quality of the image taken via outdoor cameras and other sensor devices may be corrupted because of inclement weather conditions like haze or fog which cause disturbances in the image. Consequently, the image taken in such conditions will have reduced contrast and have much dimmer color, that will decrease the visual fidelity of the objects present in the image, which will further impact the quality of any processing applications carried out using this data. This issue can seriously affect the accuracy and versatility of the processing systems. Thus, it is essential to come up with a dehazing technology that can be utilized to improve the visibility of the degraded image.

Going by the principle of haze composition and imaging, an uncomplicated optical model is proposed, depicted in Fig. 1.1, in order to illustrate the occurrence of atmospheric scattering, reflection, and refraction. Using this principle, a simple mathematical expression has been derived as:

$$I(x)=J(x)t(x)+A(1-t(x)) \qquad (1.1)$$

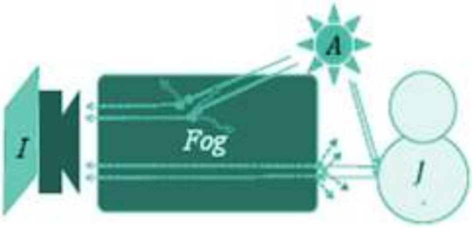

Fig. 1.1

here I(x) represents hazy scene in 3 (RGB) colour channels. (x) represents the scenario devoid of haze. t(x) denotes coefficient of transmission which represents the percent of light that penetrates the foggy environment, x is coordinates of the scene, and A represents the atmospheric light. A large number of single image processing based defog algorithms are derived from this model. Though there are many methods which use multiple images that are also available, obtaining multiple shots of the same scenario during varying weather conditions is simply not feasible. Hence, we opt for the implementation of defogging using a single image in algorithm for our design.

II. LITERATURE REVIEW

- In [1], the authors show that for the sake of driver safety and security, autonomous systems can be employed which help the human operators in this essential task of safe driving. Such systems could alert people of possible dangers which may not be apparent to the human driver, they can also be utilized to carry out steps to prevent accidents or drive the vehicle without any input or supervision as the autonomous systems are capable of faster and more accurate maneuvering. It is not easy to perform the image processing in such applications. There are a lot of factors to be considered as the application demands processing in changing conditions where the background may be hard to detect, the lighting available keeps varying and the processing speed has to be fast. The paper uses a 1st approximation to solution of problem where 2 different and complementing methods are followed for the detection as well as tracking of obstacles on video taken from the perspective of a train controller. For testing, they have utilised video footage in which pre-selected moving as well as fixed obstacles are placed. The system has shown a real-time performance for detection and tracking of obstacles.

- Sudden pedestrian crossing has generally been found to be one of the most common reasons for pedestrian accidents. In [2], the authors have focused on detecting SPCs at night time in support of an advanced driving assistant system (ADAS) utilizing far infrared (FIR) cameras which are placed on the front part of on roof of the test vehicle. This research focuses specifically on SPCs during summer season because according to data the quantity of pedestrian-vehicle collisions in Korea is statistically more during that season than during the rest of the year. For the purpose of real-time process, the ideal levels for the values of search area and image scaling are decided first. Then the proposed method is utilised for detection of virtual reference-lines that are linked with road segments not requiring the use of any colour data, these lines are changed based on the turning angle of vehicle. Pedestrian detection has been conducted by utilizing a cascading random-forest method with center symmetric local binary patterns and low dimensional Haar-like features. Assessment of SPC collision is based on the chances and spatio-temporal values of pedestrians, like ratio of overlap with the virtual reference lines, and the magnitude and direction the movement of each pedestrian. The algorithm proposed was applied successfully to various datasets captured via an FIR camera, the results showed that its action at detecting the occurrence of SPC is better than those of other methods.

- For the purpose of safety applications and real-time surveillance in intelligent transporta systems, there is a requirement for the high speed processing and it must be considered. In paper [3], an efficient and fast illumination adjustment algorithm suitable for the purpose of low cost VLSI implementation has been proposed. Experimental results in the work show that the method that has been proposed requires lowest number of calculations and yet manages to achieve comparable visual quality as previously existing techniques. In order to further satisfy the criteria for the real time image or video application, a 16-stage hardware design with pipelined architecture of this method has generated as an IP core. Processing rate yielded by this design is of around 200 MHz by utilizing the TSMC 0.13-μm technology. As it has the capacity of processing one pixel per clock cycle, for an input image with a resolution of QSXGA (2560 × 2048), it therefore necessitates about 27 ms to process 1 frame and this rate has been found to be usable for the purpose of realtime applications.

- Computer Vision, either by itself or in combination with technologies like RADAR or LIDAR, is a key technology that is part of the Advanced Driving Assistant Systems (ADAS). Utilization of these technologies in vehicles is only going to increase as automation levels increase. But, the process of embedding vision-based driving assistant systems (DAS) currently poses a difficult challenge owing to various specialized constraints of the vision algorithms, present technological constraints and stringent criteria which needs to be met. The aim of the authors in [4] is to show the existing progression and the future directions in the development in terms of the field of vision based embedded advanced driving assistance systems, and to bridge the gap that currently exists between the theory as well as practice. The various software and hardware options are reviewed, and discussions are made upon design, development and testing considerations of the technology.

- The authors in [5] present an approach that can be utilized in order to remove the effect of haze from input image data easily. It is based on the fact that the airlight, which is the light scattered by particles in the medium is partially polarised. Polarisation filtering only works in restricted situations and cannot be utilized to remove haze effects in all scenarios. The method proposed in this paper, however works under a varying range of viewing and atmospheric conditions. The authors have analysed the process of image formation, taking into account the effects of atmospheric scattering in terms of polarisation. Then they have inverted the process in order to enable the removal of the haze from input image data. This method can be used with as few as 2 images that are taken through a polarizer but with different orientations. This method has been shown to work instantly, regardless of the changes of weather conditions. The authors then present the experimental results of the completed dehazing process in conditions that are far from ideal for using polarization filtering. This has been shown to obtain a great amount of improvement in terms of the scene contrast and colour correction.

- In [6], the authors start off by studying the visual characteristics of various weather conditions. For this purpose, they draw on existing well known information about atmospheric optics. Next, they identified the effects caused by inclement weather conditions and how they can be converted to an advantage. Since the atmosphere is basically a medium that modulates the information transmitted from a scene point, through the medium, to the observer, it can be seen as a mechanism for the coding of visual information. Based on this observation, they develop models and methods for the recovery of relevant scene properties, such as 3D structures, from images that have been taken under bad weather conditions.

- The paper [8] has presented multiscale depth fusioning (MDF) methods for the purpose of defogging through a singular scene. Firstly, linear model that represents stochastic residual of executed nonlinear filter has been proposed. Multiscale filter result has been, in a probabilistic method, blended into a fused depth map model drawn from this model. This fusion has been generated as an energy minimizing problem which includes spatial Markov dependence. Also a non-homogeneous Laplace-Markov random field model for multiscaled fusion that is regularised with the edge preserving. The smoothing constraints are also developed. The problem of defogging is solved by an alternate optimizating algorithm that looks for solutions of the depth map by means of minimization of the nonconvex potentials in random fields. The multiscale depth fusion method has been experimentally verified via testing it out on real world foggy images which includes cluttered-depth scenes that are challenging for the purpose of defogging the minute details. The processed images have been restored as fog free with improved colour range and higher colour range but without any over saturation. Experimental results have demonstrated that accurate estimations of depth map by means of above edge-preserved multiscaled fusion manages to recover higher quality images which have sharper detail.

- In [9], an efficient and fast method for the purpose of haze removal has been presented. The authors have employed an extremum approximation method for extraction of atmospheric light. They have proposed contour preservation and estimation method in order to get the transmission via utilising edge preservation technique and mean filtering alternately. This method efficiently avoids the generation of halo artifacts in the image that is recovered as output. For sake of meeting the real-time application criteria, a 11-stage hardware architecture with pipelining of the haze removing method has been presented. It can achieve up to 200MHz with 12.8K gate counts by utilising TSMC 0.13-μm technology. Simulation results have indicated that this design has obtained results comparable with the lowest execution time in comparison to previous algorithms and is suitable for high performance yet low cost hardware implementation.

- In [10], the authors have presented a quick, single image based dehazing method which is based on the theories of atmospheric scattering and dark channel prior theory. The transmission map has been approximated using fast average filters, the mechanism of the subsection has been designed specifically for the purpose of avoiding the unwanted high brightness of sky regions in the processed image, in order to obtain the atmospheric light, a regional projection method has been adopted, and the Weber Fechner law has been implemented for the purpose of image colour compensation. The experimental results have shown that the algorithm presented can be used for the restoration of the input image to a natural, clear state while ensuring the balance between quality of output image and the speed of the image restoration process; hence it is suitable for use in a real time system.

- In [11] the authors have presented a novel technique for the purpose of enhancing colour in the compressed domain. This proposed technique has been shown to be more effective even though it is simpler than existing techniques that have been reported earlier. This method is novel as it treats the chromatic components whereas the previous techniques only considered luminance components. The results of both the new technique and the previous techniques are compared with respect to the results obtained via applying a spatial domain technique for the enhancement of colour which provides very good enhancement. The proposed technique has been shown to be more efficient computationally than the original method based on spatial domain. It is also found to provide enhancement which is better compared to other approaches based on the compressed domain.

- In [12], the authors have presented a model based on physics which describes appearances of scenarios in the case of bad weather conditions which are uniform. The changes in the intensity of certain scene points, under the various weather condition, will provide some simple constraint values which helps to detect the depth discontinuities in the scenario and also for computation of the scene structure. Then, an algorithm for the fast restoration of the scene contrast has been presented. Contrasting to the existing techniques, the weather removal algorithm proposed here does not require any details about the structure of the scene, or the distribution of reflectances or any detailed information about the weather conditions beforehand. All the methods that have been described here have been shown to be effective under a wide variety of weather conditions including but not limited to mist, fog, haze and other aerosol based conditions. Furthermore, these methods can be used for multi-spectrum, that is it is effective for use in grey scale, RGB, multispectral or even in the case of IR images. These techniques can also be extended for the purpose of restoring contrast of the scenes which have moving objects.

III. Proposed Methodology

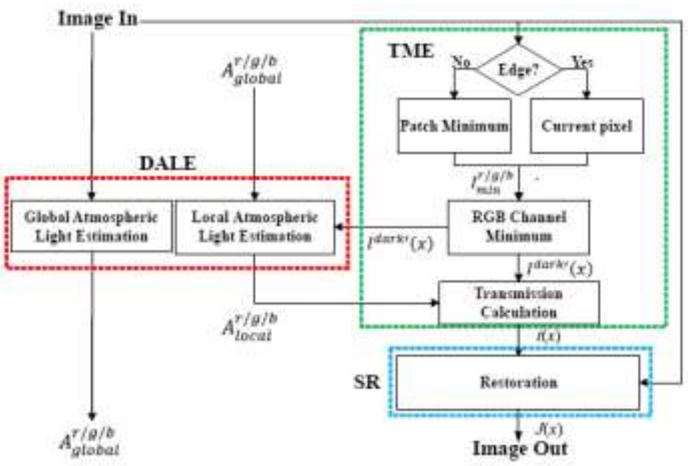

Fig. 3.1. Flow diagram of the proposed defogging algorithm.

Fig. 3.1 presents the flow diagram of the algorithm to be used for the purpose of defogging. This process consists of 3 main parts which are the dynamic estimation of atmospheric light (DALE), estimation of the transmission map (TME) and the final process of scene recovery (SR). Firstly we have the DALE, where we find the pixel which is having the highest dark channel value and keep it as Global atmospheric light value (A_{global}).We then utilize a linear weighted technique for purpose of local atmospheric light which can further be utilized for the reconstruction of the image. Therefore, for the functioning of this method there is a need for scanning the image two times for the proper dynamic atmospheric light estimation calculation. In the 2nd stage, the contours of the object are detected by means of the estimation of transmission mapping. Then, at the end the image can be recovered by means of scene recovery procedure which substitutes the atmospheric light estimation and the value of transmission into the equation below–

$$J^c(x) = \frac{I^c(x) - A^c}{\max[t(x), t_0]} + A^c, \ \forall c \in R, G, B,$$

The details of each process are as follows –

A. Dynamic Atmospheric Light Estimation

Atmospheric light denoted by 'A' plays a very important part in haze removal process. Atmospheric light is a key factor for the process of recovery of the image that is reconstructed and it is also used for the purpose of estimation of the transmission map. Another criterion for a suitable method that is used to estimate the atmospheric light is that it can also adjust the brightness value in the image that is recovered. For the purpose of comprehensive processing, we cannot utilize only the global atmospheric light values. The problem with this would be that if the atmospheric light value is greater, then the dark part would become much darker. If the atmospheric light value is lower, then the light portion becomes lighter. This would be undesirable. Hence, for the purpose of this work, we are using the concept of estimating the local atmospheric light dynamically to avoid the above pitfalls. This allows us to dynamically vary the atmospheric light value to get the data of the variations in the brightness of characteristics of the picture without compromising homogeneity of our recovered picture.

Firstly, in order to keep a basic value of the atmospheric light for entire picture as a whole, we have to calculate the global atmospheric light value. The method utilized here applies a 3x3 patch size which helps to keep the cost in terms of memory lower. The pixels that have the highest dark channel content get chosen as the Aglobal value in order to remove the process of having to sort the highest 0.1 value.

Next, in order to achieve better results of the restoration process in each of the pixels, an adaptive adjustment which is dependent on the features of the patch is proposed after the completion of the process of estimation of the global atmospheric light. Upon further examination, an observation is made that the higher visibility areas of the image are usually least affected by the effect of fog or haze, hence, it has a very low dark channel value. Conversely, the areas with the lower visibility are affected by the fog effects more; hence value of dark channel can be much higher. Considering this property, we need to set some value as a threshold so that the image can be divided into the high and low visibility partitions.

B. Transmission Map Estimation

Transmission map is a representation of rate of penetration of the light which is reflected by an object, which is obstructed by the presence of haze or fog in a scenario and it is also undergoes exponential attenuation proportional to the depth of the object. Hence estimation of the transmission for purpose of haze removal based on optical modelling is very important. As per the dark channel features, the transmission map can easily be obtained. More specifically, the estimation of the transmission map is straightforward and the atmospheric light estimation procedure that has been mentioned earlier.

For the estimation of the transmission which is based on the darker channel values, transmission values in a local window Ω(x) has to be taken as a constant value. This assumption may not hold good in practicality, especially when window lies across the contours of the object. 2 concurrent pixels that lie on the contour of an object which may be located at varying displacements from observing camera lens. Consequently, value of the transmission inside this window will have inconsistencies to the real world data. However, this would mean that any pixel which is located far away from camera lens can also be recovered by utilizing similar value as that used for a pixel that is nearer to the camera lens. This error in the evaluation leads to the occurring of halo objects in the pixel range along the contouring of the object. These halos have a very high contrast that is created by the residues of the haze on the restoration result. In order to decrease number of the halo artifacts, we use a method for detecting edges since as we have seen above the halo effect occurs usually at the contours of the object. To keep the hardware in low complexity, a simple yet efficient method for the detection of edges is used with a 3x3 mask in this design.

C. Scene Recovery

After the inference of the local atmospheric light value and mapping for transmission, the image (x) can be reconstructed by substitution of the A^{c}_{local} value and the transmission mapping value t(x).

VLSI Implementation

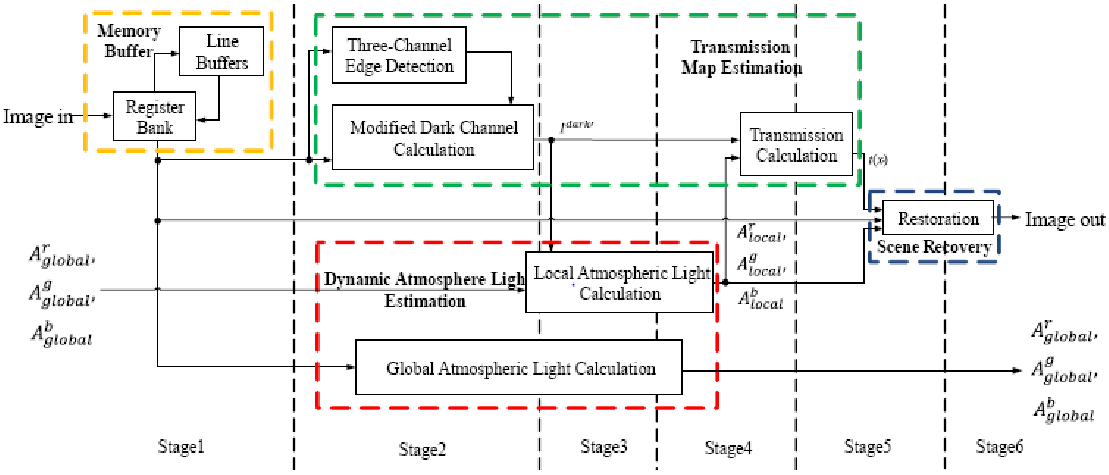

Fig 3.2. Block diagram of the hardware architecture of the proposed defogging algorithm

The circuit shown in Fig. 3.2 is divided into four parts: memory buffer (MB), DALE, TME, and SR. The MB contains a register bank (RB) unit and six line buffers (LBs) since two are required for each of R, G and B color channels. The RB unit provides nine pixel values in the current 3 × 3 window for the DALE and TME processes, and the LBs are used to store the pixel values of two rows in the source image for processing a 3 × 3 patch in the design. The following sections describe the units in the DALE, TME, and RS parts in detail.

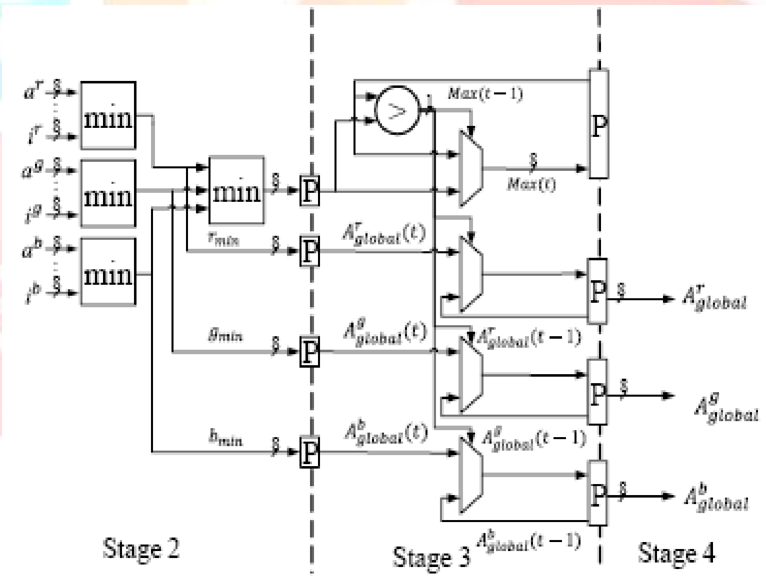

Fig 3.3 GALC unit

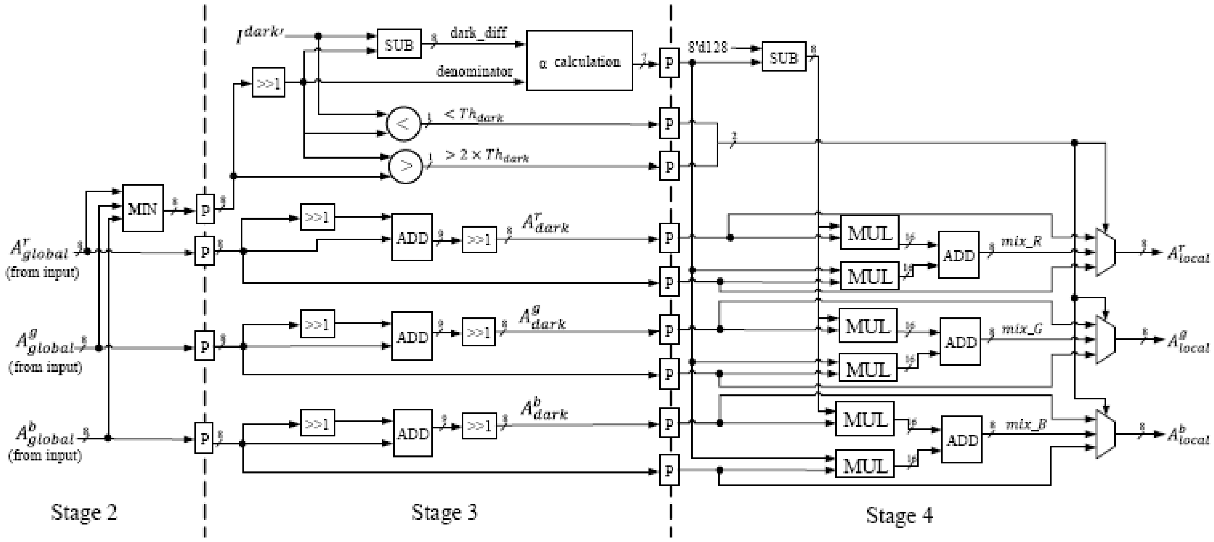

Fig 3.4 LALC unit

A. DALE Part

This part comprises two units: global atmospheric light calculation (GALC) unit and local atmospheric light calculation (LALC) unit. The main function of the DALE part is to compute a relatively suitable atmospheric light for the foggy image.

1) GALC UNIT

This unit is used to estimate atmospheric light, and its architecture is shown in Fig. 3.3. In stage 2, the dark channel is determined by the patch value from the RB. In stage 3, the temporary max value Max(t) is retained or re-placed by comparing it with the dark channel value from stage 2. After scanning the whole image, the Max(t) represents the maximum brightness of the dark channel in the im-age, which is also the atmospheric light.

2) LALC UNIT

This unit is used to adjust global atmospheric light to obtain a proper local value based on the patch feature, and its architecture is illustrated in Fig. 3.4. In stage 2, the minimum value of global atmospheric light is determined. The dark threshold and the atmospheric light of the dark part is produced in stage 3. In the same stage, the current pixel is checked to ascertain whether its dark channel is in the linear interpolation interval. If it is, a suitable weight value for the interpolation is calculated to compute local at-mospheric light. However, computing the weight using the traditional division approach based on (10) is extremely complex.

To avoid division operations, an approximation method that references the Euclidean algorithm is used to reduce computational complexity.

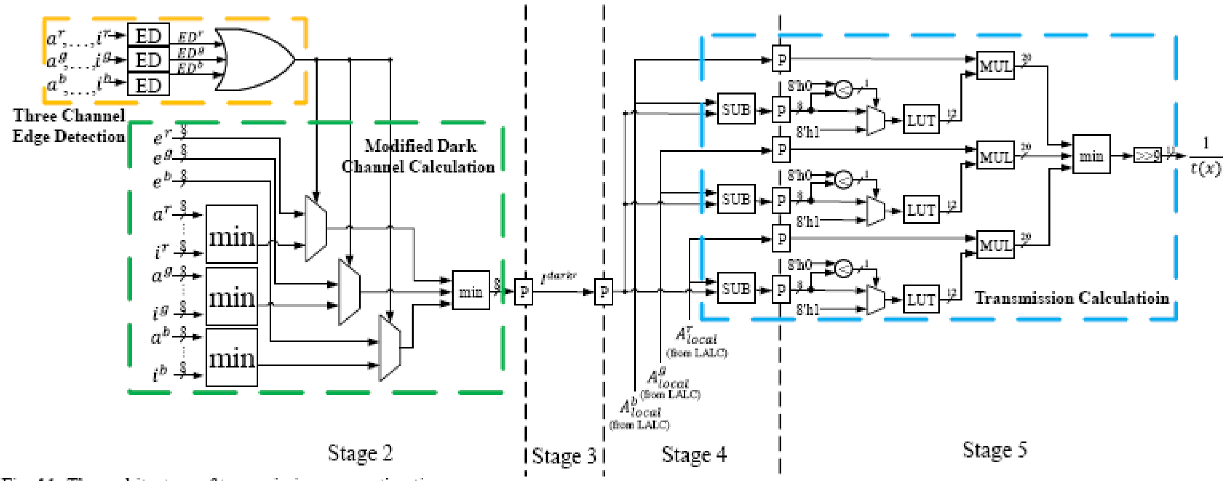

Fig 3.5 TME unit

B. TME Part

Fig. 3.5 shows the hardware architecture of the TME part. This part contains a three-channel edge detection (TCED) unit, a modified dark channel calculation (MDCC) unit and a transformation calculation (TC) unit. The MDCC unit comprises a traditional dark channel calculation and an edge dark channel calculation, which is the original values of the center pixel. As shown in the Fig. 11, the MDCC unit changes the corresponding input by signal produced from ED unit to re-duce the hardware cost. The ED unit, conducts a edge detection process in a 3 × 3 patch to deter-mine whether the center pixel of the patch is on the edge for one color channel. If it is, the original values of the center pixel are used to calculate the transmission. If it is not, the traditional dark channel is used.

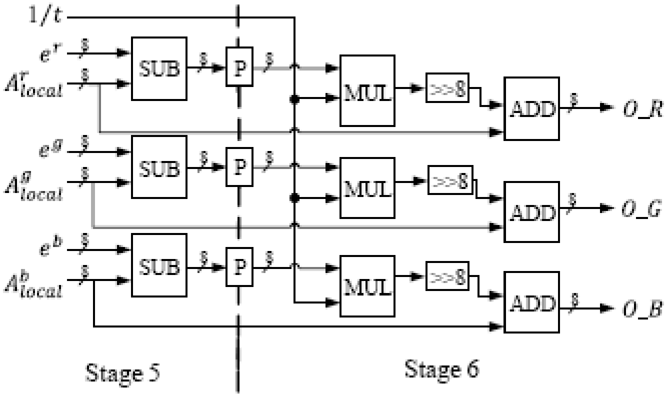

Fig 3.6 Restoration unit

C. SR Part

Fig. 3.6 illustrates the hardware architecture of the restoration unit, which is the only unit in this part. The LUT in the TE part provides the 1/t value from the look-up table. The 1/t is a multiple of (I-A) calculated from Stage 5. Moreover, the final results are shifted 8 bits to the left to drop the decimal, thus matching the accuracy of the LUT. The output pixel is arranged with the order of input pixel that is form the left-top corner to the right-bottom corner and construct the restored image within raw image format to store and display.

IV. OUTCOMES OF PROJECT

The VLSI implementation is carried out using Xilinx ISE and simulation is carried out using iSim simulator to obtain the following results.

The RGB data of the 3x3 matrix is processed for the GALC, LALC, TM and SR stages and the output is obtained as shown in Fig 4.1 and Fig 4.2.

To implement the proposed method with hardware circuit, we realize most operations with the lower-complexity manners. The fixed point number representation is used to per-form all addition, subtraction and multiplication operations in our hardware design. A low-cost approximation method is used to perform α calculation. Besides, we employ a look-up table to calculate the reciprocal of t(x) instead of a higher-cost divider. Obviously, the lower-complexity approximation techniques will damage the defogging effects.

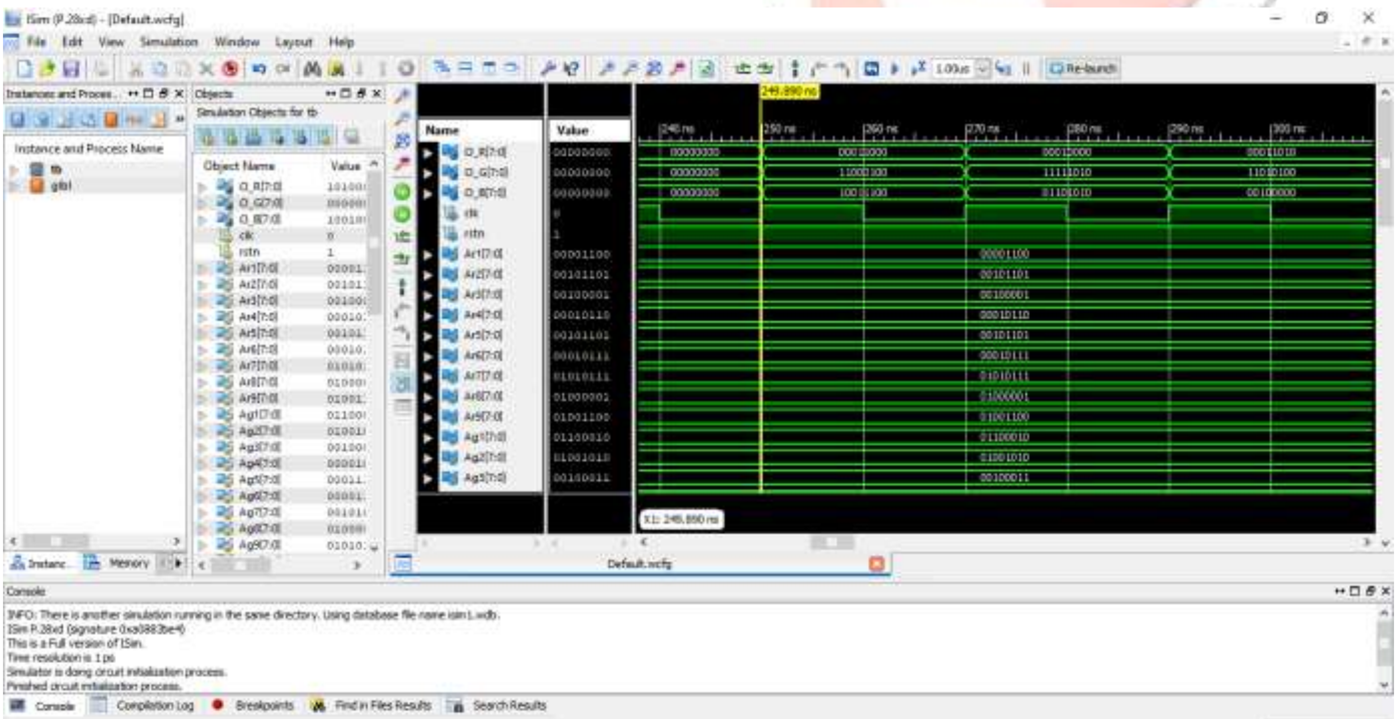

Fig 4.1 Simulation results

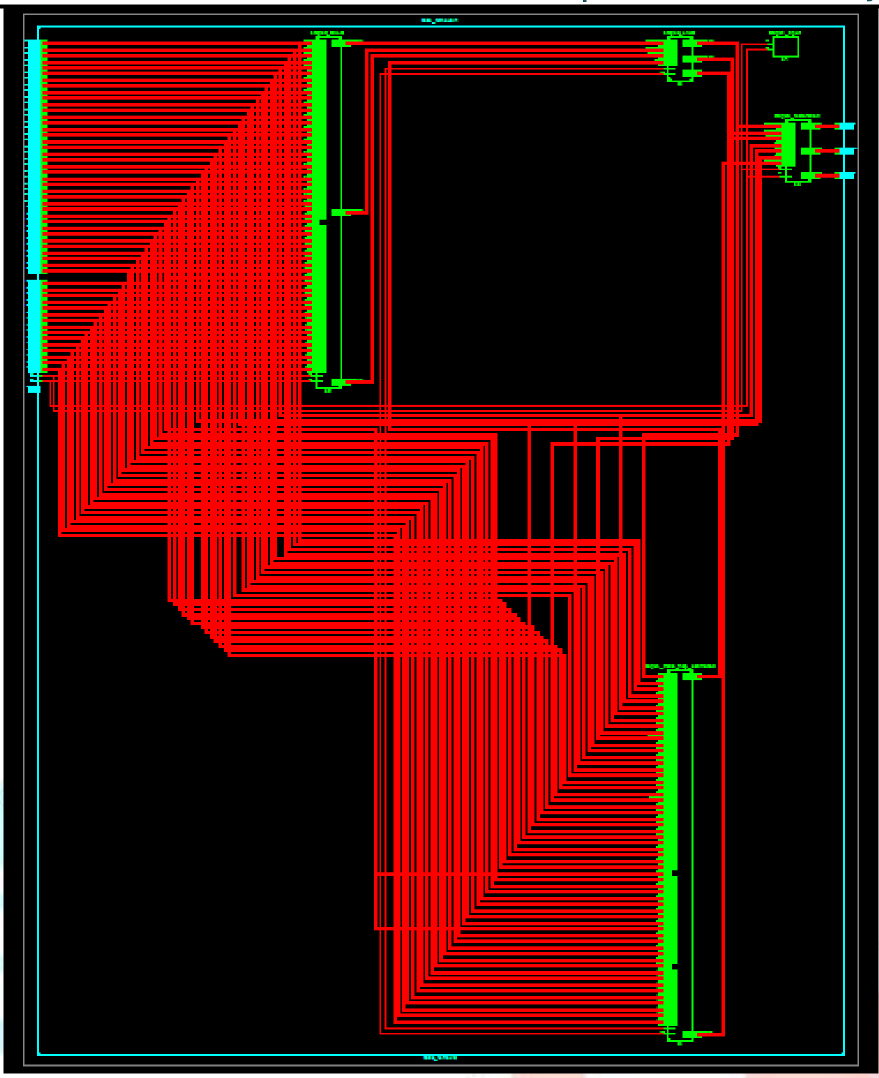

Fig 5.2 Schematic view of the VLSI architecture

```
Minimum period: 7.912ns (Maximum Frequency: 126.386MHz)
Minimum input arrival time before clock: 10.682ns
Maximum output required time after clock: 4.118ns
```

Fig 5.3 Timing report

Device Utilization Summary (estimated values)			[-]
Logic Utilization	**Used**	**Available**	**Utilization**
Number of Slice Registers	325	126576	0%
Number of Slice LUTs	439	63288	0%
Number of fully used LUT-FF pairs	159	605	26%
Number of bonded IOBs	242	296	81%
Number of BUFG/BUFGCTRLs	1	16	6%
Number of DSP48A1s	12	180	6%

Fig 5.4 Area report

Device	
Family	Spartan6
Part	xc6slx100t
Package	fgg484
Temp Grade	C-Grade
Process	Typical
Speed Grade	-2

On-Chip	Power (W)	Used	Available	Utilization (%)
Clocks	0.006	1	---	---
Logic	0.001	403	63288	1
Signals	0.006	919	---	---
DSPs	0.000	12	180	7
IOs	0.004	242	296	82
Leakage	0.081			
Total	0.099			

Supply Summary		Total	Dynamic	Quiescent
Source	Voltage	Current (A)	Current (A)	Current (A)
Vccint	1.200	0.051	0.013	0.038
Vccaux	2.500	0.009	0.000	0.009
Vcco25	2.500	0.006	0.001	0.005
		Total	Dynamic	Quiescent
Supply Power (W)		0.099	0.018	0.081

Fig 5.5 Power report

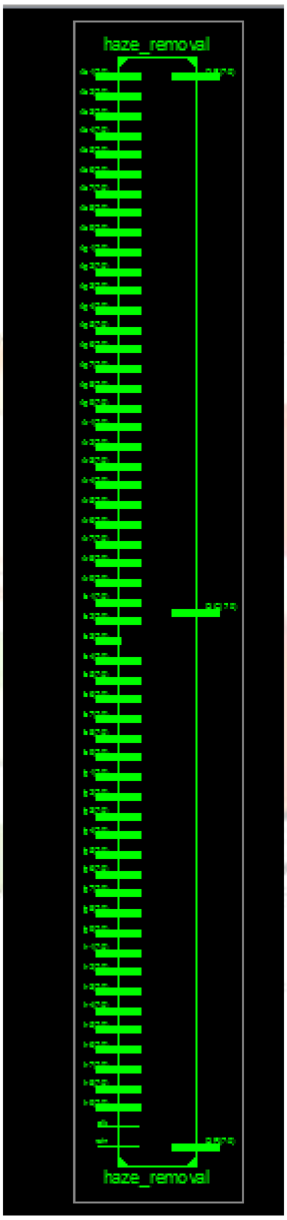

Fig 5.6 RTL View of the architecture

IJCRT

V. CONCLUSIONS

In this paper, a real-time and highly efficient VLSI architecture based on the dark channel prior method is presented. This algorithm can produce more colorful images without degrading the bright part or dark part while the opposite part is unaffected. The proposed method comprises three characteristics: Firstly, it applies the local atmospheric light estimation to restore the object within different ranges of visibility. It is noncomplex and suitable for hardware implementation as compared to previous methods. Secondly, it dynamically refines local atmospheric light with global atmospheric light to avoid the possibility of a block effect. Thirdly, it employs a simple and efficient method to calculate the transmission map. The experimental results show that the proposed algorithm can produce images that are more colorful than those produced by using previous hardware. Moreover, a 6-stage pipelined hardware architecture is proposed to implement the process and achieve real-time processing of full HD resolution (1920 × 1080) at 30 fps. This is fast enough to meet the expected requirements. This demonstrates that it is a good candidate for haze removal for producing high image quality and thus a form of hardware that can be implemented as a real-time application.

REFERENCES

1. Uribe, Jonny, L. Fonseca, and J. F. Vargas, "Video based system for railroad collision warning," in IEEE Int. Conf. on Carnahan Security Technology, pp. 15-18, Oct. 2012.
2. M. Jeong, B. C. Ko, J. Y. Nam, "Early Detection of Sudden Pedestrian Crossing for Safe Driving during Summer Nights," IEEE Trans. Circuits and Sys. Video Tech., pp. 1-13, 2016.
3. Y.-H. Shiau P.-Y. Chen H.-Y. Yang S.-Y. Li "A low-cost hardware architecture for illumination adjustment in real-time applications," IEEE Trans. Intell. Transp. Syst. vol. 16 no. 2 pp. 934-946 Apr. 2015.
4. G. Velez, O. Otaegui, "Embedding vision-based advanced driver assistance systems: a survey," IET Intelligent Transport Systems, vol. 11, no. 3, pp. 103-112, May 2017.
5. Yoav Y. Schechner, Srinivasa G. Narasimhan and Shree K. Nayar "Instant Dehazing of Images Using Polarization"
6. Shree K. Nayar and Srinivasa G. Narasimhan "Vision in Bad Weather"
7. Srinivasa G. Narasimhan and Shree K. Nayar "Removing Weather Effects from Monochrome Images"
8. Y. Wang and C. Fan, "Single image defogging by multiscale depth fusion," IEEE Trans. Image Processing, vol. 23, no. 11, pp. 4826–4837, Sep. 2014.
9. Y. H. Shiau, H. Y. Yang, P. Y. Chen and Y. Z. Chuang, "Hardware implementation of a fast and efficient haze removal method," IEEE Trans. Circuits Syst. Video Technol., vol. 23, no. 8, pp.1369–1374, Aug. 2013.
10. W. Wang, F. Chang, T. Ji, X. Wu, "A fast single-image dehazing method based on a physical model and gray projection," IEEE Access, vol. 6, pp. 5641-5653, 2018.
11. J. Mukherjee and S. K. Mitra, "Enhancement of color images by scaling the DCT coefficients," IEEE Trans. Image Process., vol. 17, no. 10, pp. 1783–1794, Oct. 2008.
12. S. G. Narasimhan and S. K. Nayar, "Contrast restoration of weather degraded images," IEEE Trans. Pattern Anal. Machine Intell. , vol. 25, no. 6, pp. 713–724, Jun. 2003.