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Real-Time Implementation of a novel Detail Enhancement algorithm for Thermal Imager

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***Abstract*—This paper presents real time implementation of a new detail enhancement algorithm to effectively visualize High Dynamic Range (HDR) InfraRed (IR) images on Low Dynamic Range (LDR) display with reduced noise amplification. Rendering real world IR images on state of the art display devices requires compression of HDR IR images without losing the perceptibility of details. The proposed algorithm is a combination of preprocessing module for detail enhancement and Dynamic Range Compression(DRC) for LDR display. In the preprocessing module, the base and detail components of input HDR image are obtained using bilateral filtering. The detail component of IR image is scaled and added back to its base component and then the resultant is compressed using DRC method for display on LDR monitors. MATLAB simulation and Real-Time implemented results show a significant improvement in the results obtained when a given DRC method is preceded by the proposed preprocessing module. The DRC algorithms referred here are AGC, classical Histogram Equalization, Histogram Projection and Adaptive Plateau Equalization. The real time implementation procedure of current proposed algorithm using xilinx Virtex-4 FPGA is explained.**

***Index Terms*—Thermal Image, Bilateral Filter, Histogram Projection, DRC, FPGA.**

I. INTRODUCTION

Thermal image is generally a visualization of IR radiation, emitted by the observed object and its surroundings. The output image from a thermal camera differs significantly from visual image. Images produced by IR cameras are a specific source of information. The perception and interpretation of such image greatly depends on thermal properties of observed object and surrounding scenery. Modern high-quality IR cameras produce imagery with very high dynamic range ranging from 8192 to 32768 gray levels (13 to 15 bits per pixel), this data should be remapped to lower dynamic range ranging from 256 to 1024 gray levels (8 to 10 bits per pixel) for real time display [1]. The process of compressing the High Dynamic Range (HDR) values into the displayable Low Dynamic Range (LDR), termed as Dynamic Range Compression (DRC) inevitably incurs the loss of image details. Loss of details makes it very hard to detect targets even though they are within the theoretical limits of the system. Hence the drive should be towards achieving DRC in a pleasing manner for display on LDR monitors without reducing the perceptibility of small details.

Many DRC methods exist in literature. Most of them are either based on gray level transformation or histogram modification [2] [3]. Moreover, these conventional techniques are not automated and are not generalized for wide range of images.

Automatic Gain Control (AGC) linearly maps the input dynamic range to required output domain. Major drawback of AGC is that it tends to produce very low contrast output for a high dynamic range input. In Histogram Equalization [4] Cumulative Distribution Function (CDF) of the image intensity is used to normalize the intensity distribution. It works on the principle of providing more dynamic range (contrast) for dominating temperature range and less dynamic range to image areas in the non-dominating range. This means, the details pertaining to a very small hot object against a very cold background gets completely submerged and will not be visible. Plateau Equalization [5] is a variation of histogram equalization, in which, a parameter called plateau is defined. The plateau is a predefined clipping value that is applied to input histogram. By removing the pixels above a plateau value in histogram, the details of non dominating objects against the dominating objects can be preserved. To make this method automatic, adaptive plateau equalization [6] was developed which calculates the value of plateau based on the characteristics of input histogram. In summary, histogram based methods compress the dynamic range of the raw images more effectively than AGC. However these images tend to have washed out appearance with increased noise. Also they lack flexibility in manipulating the small details of the input images since they are based only on histogram information.

Our motivation is to develop a technique which faithfully reproduces the HDR image on a LDR display with equal enhancement of all details regardless of the temperature range they happen to be in. In this paper, we propose a preprocessing module for DRC methods which seamlessly enhances the hidden details in the image with reduced noise amplification. The basic idea is to decompose the image into high frequency component (detail component) and low frequency component (smooth component) using bilateral filter, recombine them after manipulating the high frequency component, and then

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compress the resulting image to yield a detail enhanced image.

The paper is organized as follows. In section II, the proposed method is explained. Section III discusses the hardware implementation procedure and the resource utilization of current algorithm. The evaluation results showing the performance of proposed method in comparison with general DRC methods is presented in section IV, followed by conclusion in section V.

II. PROPOSED ALGORITHM

The proposed algorithm consists of two modules. One is preprocessing module, in which input HDR IR image is processed and the resultant image is detail enhanced HDR output. Other one is a standard DRC method to map the HDR image to LDR image for real time display. The proposed algorithm is summarized in in Fig. 1.

A. Preprocessing Module

As the first step in preprocessing module, the image is decomposed into base and detail components. As discussed earlier, the proposed method relies on Bilateral filtering to obtain the base component $I_b(i,j)$ [7] [8]. A spatial Gaussian filter has the tendency of weakening the strong edges. So it produces halo artifacts along the edges. On the other hand bilateral filter blurs the small variations of the signal (texture details) but preserves the large discontinuities (strong edges). Thus the homogeneous areas like sky or sea appears smooth and strong edges due to horizon or buildings are preserved. Thus bilateral filter acts as an edge preserving filter.

The detail component is obtained by subtracting the base component from the original image. The base component has large amplitude variation and must be compressed. The detail component has small signal variations related to fine texture and hence must be expanded. A scaling factor decides the extent of expansion carried out on the detail component.

Let I_{in} be the input infrared image obtained after Non Uniformity Correction (NUC). First, bilateral filter is applied to obtain the base component I_b.

$$I_b(i,j) = \frac{1}{k(i,j)} \sum_{(i^{'},j^{'}) \in S_{i,j}} g_s(i-i^{'}, j-j^{'}) \\ g_r[I_{in}(i,j) - I_{in}(i^{'} - j^{'}] I_{in}(i^{'}, j^{'}) \quad (1)$$

where *k(i,j)* is a normalization term.

$$k(i,j) = \sum_{(i^{'},j^{'}) \in S_{i,j}} g_s(i-i^{'}, j-j^{'}) g_r[I_{in}(i,j) - I_{in}(i^{'} - j^{'}] \quad (2)$$

Here $(i^{'}, j^{'}) \in S_{i,j}$ is the neighbourhood of (i,j).

Generally g_s is a normalized gaussian kernel in the spatial domain and g_r is a gaussian in the intensity domain. σ_s and σ_r are the corresponding standard deviations. σ_s determines the level of smoothing to be applied on the input image. The choice of σ_r is crucial as it determines the influence of spatial smoothing filter on a pixel. If the gradient of a pixel from its neighbor is less than σ_r , it will be smoothened by the spatial smoothing. If the gradient is more than σ_r , it will be less altered by the filter. Thus a clear sharp edge in the image is unaltered and minute textures are smoothened. The detail component is obtained as

$$I_d(i,j) = I_{in}(i,j) - I_b(i,j) \quad (3)$$

The detail component is added back to the base with Detail Scale factor (α) and resultant is given by

$$I_{out}(i,j) = I_b(i,j) + \alpha I_d(i,j) \quad (4)$$

Where $\alpha (1 \leq \alpha \leq 5)$ is the scaling factor which decides the proportion of detail added back to the base component. If α = 1 output is equivalent to input image. A very high value of α results in an edgy image with increased noise. It is observed that α = 3 results in reasonably good amount of details with minimal noise. The result of recombination of base and scaled detail components is then mapped to the required output range using standard DRC methods mentioned in section I. A brief discussion on some of these DRC methods is given below.

B. Dynamic Range Compression methods

The output of preprocessing module is the enhanced version of input image. The dynamic range of this image is still the same as that of the input image. This HDR image is then mapped to LDR output image using any of the following DRC techniques [11].

- Automatic Gain Control (AGC)
- Histogram Equalization (HE)
- Histogram Projection (HP)
- Adaptive Plateau Equalization (APE)

1) Automatic Gain Control (AGC): AGC is a global operator and it linearly maps the HDR input to LDR output. It is accomplished by the equations as follows

$$Gain = \frac{DynamicRange_{out}}{H_{Max} - H_{Min}} \quad (5)$$

$$Offset = -H_{Min} \quad (6)$$

$$I_{Corrected}(x,y) = Gain \times (I_{input}(x,y) - Offset) \quad (7)$$

Where I_{input} is the intensity of pixel (x,y) before compression
$I_{Corrected}(x,y)$ is the intensity of pixel *(x,y)* after compression
$DynamicRange_{out}$ is the required output dynamic range
H_{Min} and H_{Max} are the first and the last occupied gray levels in the histogram of the input frame respectively.

2) Histogram Equalization: In Histogram Equalization cumulative distribution function of the image intensity is used to normalize the intensity distribution. It works on the principle of providing more dynamic range (contrast) for dominating temperature range and less dynamic range to image areas in the non-dominating range. The mapping function for the gray level x is given by

$$C(x) = \left\{ \frac{\Sigma_{y=0}^{x-1} H(y)}{Total\_Pixels} \right. \quad (8)$$

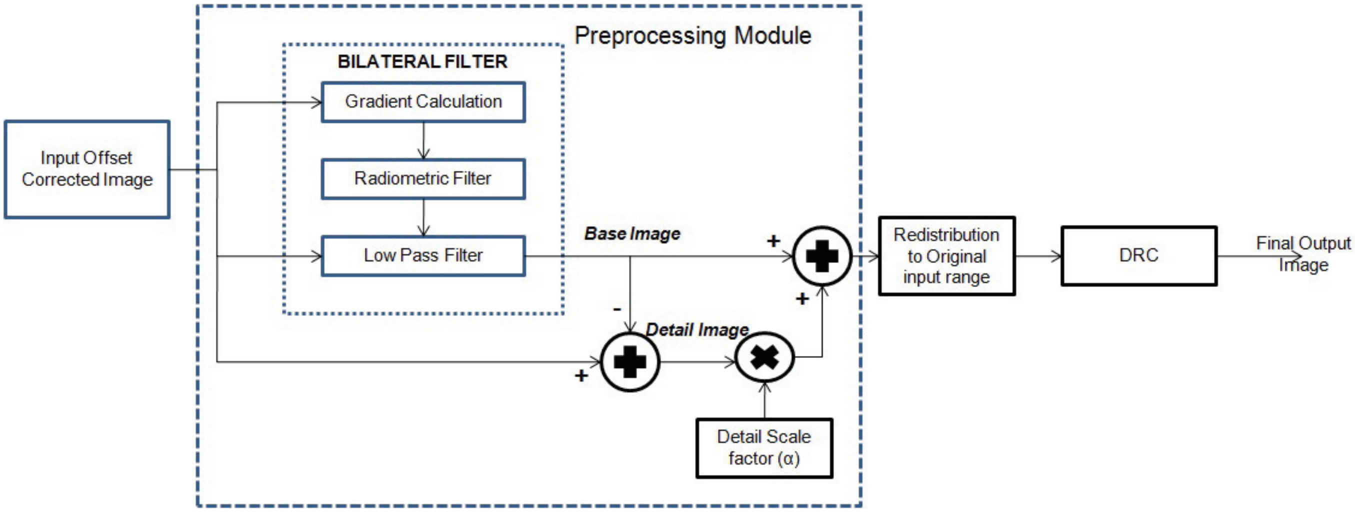

Fig. 1. Block Diagram of Proposed algorithm

where $H(y)$ is the occupancy count for the gray level y.
$Total\_Pixels$ is the total number of pixels
Using the above transfer function, the gray level mapping from input to output is calculated as

$$x^{'} = (2^n - 1)C(x) \tag{9}$$

where $x^{'}$ is the output gray level corresponding to the input gray level x.

3) Histogram Projection: In histogram projection [9] the output dynamic range is equally divided among all the valid gray levels present in the input image irrespective of their occupancy count. First, the histogram of the input image is binarized using a threshold **T**.

$$H(x) = \begin{cases} 0\, for\, \eta_x \leq \mathbf{T} \\ 1\, for\, \eta_x \geq \mathbf{T} \end{cases} \tag{10}$$

where η_x denotes the number of pixels occupying the gray level *x* . If η_x is more than the threshold **T**, it means the frequency of occurrence of gray level *x* is more in the original image and hence it must be preserved. Here the value of **T** decides the contrast of the image. Too small value of **T** results in very low contrast and very large value results in washed out appearance. Best results are obtained when **T** is chosen as 0.01% of the total number of pixels. The cumulative distribution function of *H(x)* is defined as

$$C(x) = \begin{cases} 0\; for\; x = 0 \\ \\ \dfrac{\sum_{y=0}^{x-1} H(y)}{\eta_{valid}}\; others \end{cases} \tag{11}$$

using this transform function gray level *x* is mapped onto the output dynamic range R using the equation R.C(*x*).

4) Adaptive Plateau Equalization: In Plateau equalization method, the histogram values forming the cumulative sum of pixels from the darkest intensity to the input intensity are truncated to a specified constant, known as "Plateau" value [10]. By removing the pixels above a certain "threshold or plateau" value in the histogram, the details of small objects against a wide background are preserved. If plateau value is one, it is called histogram projection, which yields minimum contrast enhancement. If plateau value is equal to highest pixel count in any histogram bin, then algorithm reduced to histogram equalization and it provides maximum contrast.

First, the histogram of grayscale value is generated. Then the cumulative addition of histogram bins is done from the darkest input intensity to the input intensity k

$$g_k(P) = \sum_{i=0}^{k} r_i \tag{12}$$

where r_i is the minimum of the two values: plateau parameter or the count of pixels at the particular gray level. The new grayscale value is calculated as

$$W_k = G * g_k(P)/g(P) \tag{13}$$

where G is maximum output range.
$g(P)$ is total cumulative addition of all pixels.

In adaptive plateau equalization algorithm, plateau value is adaptively calculated for each scene. It is given by

$$P_{nom} = \begin{cases} \dfrac{X\eta_A}{I_{inf,b} - I_{inf,a}} \; if(I_{99.99\%} - I_{inf,b}) > (I_{inf,a} - I_{1\%}) \\ \dfrac{X\eta_B}{I_{inf,b} - I_{inf,a}} \; if(I_{99.99\%} - I_{inf,b} \leq (I_{inf,a} - I_{1\%}) \end{cases} \tag{14}$$

where X represents the number of pixels in central area of the histogram and is given by

$$x = \frac{N - (\eta_A + \eta_B)}{\eta_A + \eta_B} \tag{15}$$

where N is the number of pixels in the image,
I_{min} is the grayscale that corresponds to the first histogram bin with a value greater than zero
I_{max} is the grayscale that corresponds to the last histogram bin with a value greater than zero
$I_{1\%}$ is the grayscale that corresponds to the location in CDF that is equal to 0.1% of total pixels
$I_{99.99\%}$ is the grayscale that corresponds to the location in CDF that is equal to 99.99% of total pixels
$I_{25\%}$ is the grayscale that corresponds to the location in CDF that is equal to 25% of total pixels
$I_{75\%}$ is the grayscale that corresponds to the location in CDF that is equal to 75% of total pixels
$I_{inf,a}$ is the first inflection point of the histogram
$I_{inf,b}$ is the last inflection point of the histogram
η_A is the number of pixels with a value less than $I_{inf,a}$
η_B is the number of pixels with a value greater than $I_{inf,b}$

III. HARDWARE IMPLEMENTATION

This section discusses the hardware implementation part of the algorithm and the corresponding block diagram is shown in Fig. 2. The processing board is based on Xilinx Virtex-4 FPGA (xcvlx100-10ff1148), takes input from Infrared sensor and gives processed output to the display.

The infrared sensor used is Cooled Mid Wave IR camera, with specifications as listed in Table I. The system clock for the FPGA device is 50MHz. The raw data coming from the sensor is stored in frame memory (SRAM) and given as input to Bad Pixel Replacement and Non Uniformity Correction (BPR & NUC) block. This will correct the bad pixels existing in the sensor and performs 2-point gain and offset correction to remove residual non uniformity of sensor. Then the corrected data is given as input to processing module, which performs Bilateral filtering and edge enhancement as discussed in this paper and gives enhanced image data with 15 bit resolution. The DRC block will compress the enhanced image output to display resolution (10 bit) and data will be stored in output frame memory (SRAM). Video encoder will encode the compressed data to analog video format(PAL) and given to display unit. The resource utilization of current algorithm is shown in Table II.

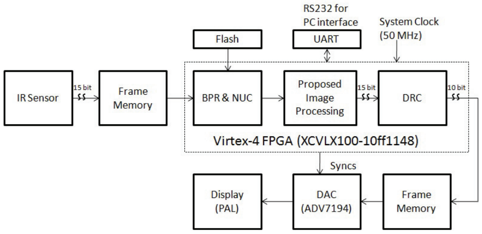

Fig. 2. Hardware Implementation of algorithm

IV. EXPERIMENTAL EVALUATION AND RESULTS

The experimental evaluation of the proposed approach is done using a Cooled Mid Wave IR (MWIR) camera whose specifications are given in Table I.

TABLE I
IR CAMERA SPECIFICATIONS

Sensor	InSb
Spectral Band	MWIR (3-5 μm)
Array Size	640x512
F#	5.5
Pixel Digital Resolution	15 bits

TABLE II
FPGA RESOURCE USAGE - XILINX VIRTEX-4 (XCVLX100-10FF1148) DEVICE

Resource	Used	Available	Percentage
Slices	10614	49152	21%
LUT 4	15809	98304	16%
FF	7013	98304	7%
RAMB 16	96	240	40%
DSP 48	33	96	34%
GCLKs	9	32	28%

The raw images captured from the detector, are NUC corrected with 2-point gain and offset to remove the residual non uniformity. The image is taken in "White Hot" polarity, that is hot objects appear white and the cold appear Black. The proposed preprocessing module is compared with the basic DRC methods, namely AGC, Classic Histogram equalization, Histogram Projection and Adaptive Plateau equalization. Experimental results shows that the DRC methods with preprocessing module gives better results compared to simple DRC methods.

In preprocessing module, we used σ_s=10 and σ_r=100 with a 5×5 filtering window. Optimal results were obtained at α=3. The resultant output image has 10 bit representation.

Fig. 3 is a high dynamic range input scenario with 16K resolution, a person sitting inside a room with the solder gun in hand. It is transformed to 1K resolution for LDR display using DRC methods and corresponding outputs are shown below. Fig. 4 represents output of AGC algorithm, 4(a) represents simple AGC output, 4(b) is with proposed preprocessing method. We can observe that, hair of the person and intensity of solder gun is better resolved in 4(b) compared to 4(a). Fig. 5 is output of Classical Histogram Equalization (HE), 5(a) is simple HE output where background is saturated and details are not clear, 5(b) is proposed output where background is less saturated and details are visible. Fig. 6 is output of Histogram Projection at threshold 36. 6(a) is simple projection output where image details are almost smooth and are clearly distinguished by the proposed preprocessing method output in 6(b). Adaptive Plateau Equalization (APE) results are shown in Fig. 7. Simple APE output is shown in 7(a) and APE with preprocessing module result in 7(b). It is clear that the figure 7(b) is better resolved compared to figure 7(a).

Fig. 3. Input Image

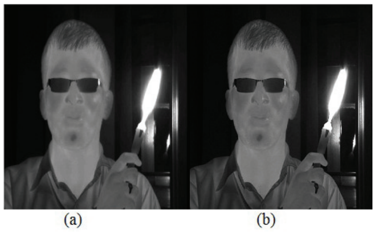

Fig. 4. AGC algorithm (a) without preprocessing (b) with preprocessing

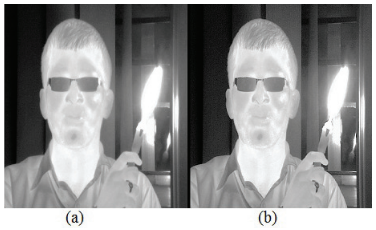

Fig. 5. HE algorithm (a) without preprocessing (b) with preprocessing

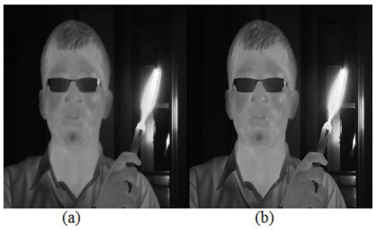

Fig. 6. Histogram Projection algorithm (a) without preprocessing (b) with preprocessing

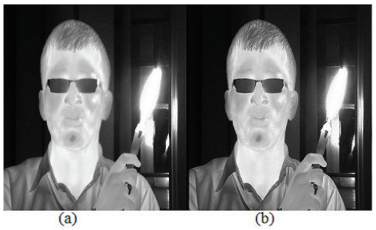

Fig. 7. Adaptive Plateau Equalization algorithm (a) without preprocessing (b) with preprocessing

Fig. 8. Input Image

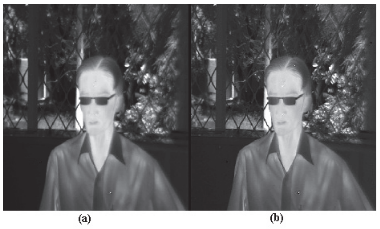

Fig. 9. AGC algorithm (a) without preprocessing (b) with preprocessing

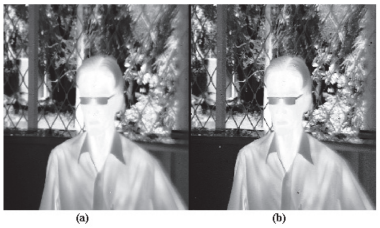

Fig. 10. HE algorithm (a) without preprocessing (b) with preprocessing

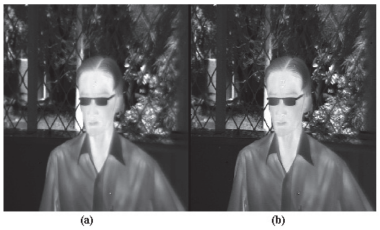

Fig. 11. Histogram Projection algorithm (a) without preprocessing (b) with preprocessing

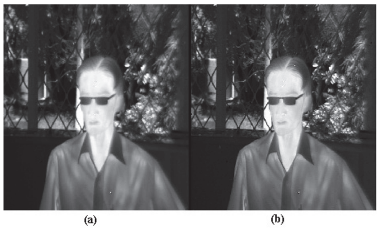

Fig. 12. Adaptive Plateau Equalization algorithm (a) without preprocessing (b) with preprocessing

Fig. 8 is another input high dynamic range scenario of 16K resolution and corresponding low dynamic range results obtained using DRC methods are shown in Fig. 9, 10, 11, 12 respectively. We can observe that the DRC method with preprocessing module gives better results (contrast and details of scenery) compared to DRC methods without preprocessing.

Thus the proposed method achieves better performance as far as detail enhancement and overall contrast is concerned. The phenomenon of adding back the details of the image to its base image makes it possible to improve the visibility of low contrast and high-frequency structures. And also the proposed method proves its robustness under different scenarios as well as for different DRC algorithms. The engineer has to choose the best DRC method suitable for his practical application.

We can still increase the details of the scenery by operating Detail Scale factor (α) variable, but consequently fixed pattern noise will build upon the resultant image.

V. CONCLUSION

A real time implementable detail enhancement algorithm for InfraRed images has been discussed. The detail enhancement is based on preprocessing module which relies on bilateral filtering to separate details from base component. The proposed method, DRC with preprocessing module significantly improves the overall contrast, image quality and details with minimal noise amplification. It was tested and implemented on Mid Wave IR (MWIR) detector and the experimental results validate that the current approach outperforms DRC methods without preprocessing module and its robustness is proved under different scenarios.

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