Underwater Image Enhancement using CLAHE in a Reconfigurable Platform

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***Abstract*— The main idea in adaptive histogram equalization is to find the mapping for each pixel based on it local (neighborhood) gray scale distribution. In this method the contrast enhancement mapping applied to a particular pixel is a function of the intensity values of pixels immediately surrounding the pixel. Hence the number of times that this calculation should be repeated is the same as the number of pixels in the image. This gives rise to an extensive computation requirement, which even with some modifications cannot be used for real time image enhancement. So here another form of adaptive histogram equalization is used which is a compromise between global histogram equalization and fully adaptive histogram equalization - regional histogram equalization. The noise is also suppressed by contrast limited enhancement. The design is implemented in Field Programmable Gate Array (FPGA) which is known to be a better choice for hardware implementation where parallel processing algorithms such as image processing is carried out.The algorithm is successfully implemented in Xilinx Spartan 3AN on Altium Nanoboard NB3000 board using Altium Designer.**

Keywords—FPGA, CLAHE, Underwater Image Enhancement,

I. INTRODUCTION

Histogram equalization is a technique used to improve the quality of an image captured under poor lighting conditions. Underwater images from scattering and propagation of light through water. Preprocessing these degraded images need to be done for further applications such as pipe line tracking, video mosaicking etc. Histogram equalization is one such image enhancement technique to be used for underwater image enhancement due to its ability to enhance contrast. The standard procedure in this case , is to re-map grayscales of the image so that the resultant histogram approximates that of uniform distribution. This procedure is based on the assumption that the image quality is uniform over all areas and one unique grayscale mapping provides similar enhancement for all regions of the image. However, when the distributions of grayscale change from one region to another, this assumption is not valid. In this case, an adaptive histogram equalization technique can significantly outperform the standard approach.

Adaptive histogram equalization used here involves many steps. Initially the whole image is divided into the necessary number of regions (two regions in this project since the screen size in FPGA monitor is 240X320) and histogram equalization is performed using the same algorithm to both regions. This algorithm involves finding and storing the cumulative distribution of every intensity value. Using this value, the new intensity value can be found out by applying the formula which is used for adaptive histogram equalization based on uniform distribution. After remapping the newly obtained intensity to its original location, the enhanced version of the input image is obtained.

II. RECENT WORK

Sapana and Vijaya [5] proposed that for image enhancement histogram method can be effectively used. In image processing histogram refers to the occurance of each intensity of the given image. In the case of histogram equalization, the dynamic range of histogram of that image is increased.

Gwanggil [1] proposed that histogram equalisation of colour images can be accomplished by transforming RGB images into different colour spaces and particular channels are applied histogram equalization process. In his paper, the different colour channels in the image is taken and luminosity conserving and contrast enhancing histogram equalization method is applied separately. The different colour spaces used for applying histogram equalization process was LAB, YIQ, YCbCr, and HSV. Histogram Equalization is applied to the luminance channels.

Rajesh kumar et al. [4] proposed that histogram stretching can not be used in applications where flat histogram is needed. Here histogram equalization can be used. One can make use of Contrast Limited Adaptive Histogram Equalization which is an improved version of AHE (Adaptive Histogram Equalization). AHE and CLAHE overcome the limitations of standard histogram equalization. So many variations of CLAHE are there that can be used for better performance. Adaptive Histogram Clip(AHC) is one such technique. In the case of AHC clipping level is automatically adjusted and moderates over enhancement of background regions of portal images.

Nikoletta and Constantine [2] proposed a novel color image histogram equalization approach. Here the correlation between color components is taken into account and it is enhanced by a multi-level smoothing technique borrowed from statistical language engineering. Multi-level smoothing aims at dealing efficiently with the problem of unseen color values, either considered independently or in combination with others. Here

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HSI color space is used and only intensity and saturation values are modified keeping hue value remain unchanged.

Rajesh Garg et al. [3] proposed that various techniques such as grey scale manipulation, filtering and Histogram Equalization (HE) can be effectively used to enhance an image. As Histogram equalization is simple and effective it became a popular technique for contrast enhancement.

Alex Stark [6] proposed a scheme which is based on the generalization of histogram equalization for adaptive image contrast enhancement. He points out that in many applications, HE is not effective. However, with minor modifications, one can attain dramatically different results. From the past suggestions for variations on histogram equalization, cumulation function plays a vital role and can be used to generate a grey level mapping from the local histogram.

III. ALGORITHM

Adaptive histogram equalization (AHE) can be used to improve contrast in images which suffers from poor lighting. Apart from ordinary histogram equalization the adaptive method computes several histograms, and these histograms correspond to distinct section of the image. Here the lightness value of the image is redistributed throughout the image. Hence the local contrast of the image is improvised.

The transformation technique used to transform all pixels in an image is same for an ordinary histogram equalization. This can work well when the image is similar without much grey level difference throughout the image. However, as there are significant lighter or darker regions in the image, this method is insufficient.

Adaptive histogram equalization (AHE) overcomes the limitations of ordinary histogram equalization by transforming each pixel with a transformation function derived from a neighbourhood region[7]. It was first developed for use in aircraft cockpit displays. Here each pixel is transformed based on the histogram of a square surrounding the pixel. The transformation function used her is same as that of ordinary histogram equalization. The transformation function is proportional to the cumulative distribution function (CDF) of pixel values in the neighbourhood.

One of the drawbacks of adaptive histogram equalization is that it has a tendency to over amplify noise in relatively homogeneous regions of an image. This limitation can be overcome by applying a variant of adaptive histogram equalization called contrast limited adaptive histogram equalization (CLAHE).

Histogram equalization maps grey levels 'r' of an image into gray levels 's' of an image in such a way that the gray levels 's' are uniform. This expands the range of gray levels (contrast) that are near the histogram maxima, and compresses the range of gray levels that are near the histogram minima. For most images, the contrast is usually expanded for most pixels, improving many image features. The transformation function that converts an original histogram into a flattened histogram is s = T(r). This transformation must satisfy the following two conditions:

- T(r) must be single valued and monotonically increasing in the interval $0 \leq r \leq 1$
- $0 \leq \mathrm{T(r)} \leq 1$ for $0 \leq \mathrm{r} \leq 1$

  i.e. $0 \leq s \leq 1$ for $0 \leq r \leq 1$

The requirement that T(r) must be single valued is needed to guarantee that the inverse transformation will exist and the monotonic condition preserves the increasing order from black to white in the output image.

A transformation function that is not monotonically increasing could result in at least a section of the intensity range being inverted, thus producing some inverted gray levels in the output image. The second condition guarantees that the output gray levels will be in the same range as the input levels. The inverse transformation from s back to r is denoted as in eqn. 1.

$$\mathrm{S} = \mathrm{T}^{-1}(\mathrm{s}) \qquad (1)$$

A transformation function that satisfies both the conditions is as shown in Fig. 1.

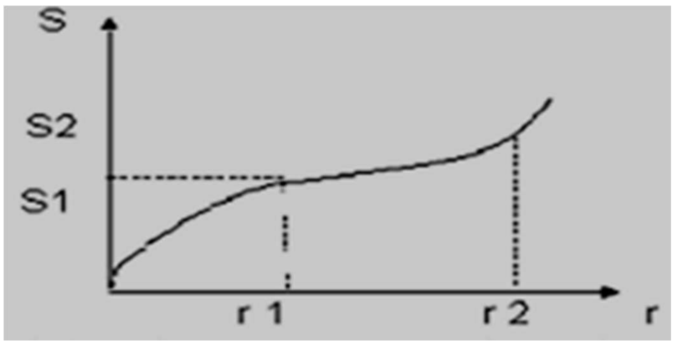


Fig.1 Single – Valued transformation function

The gray levels in an image may be viewed as random variables in the interval [0,1]. One of the most fundamental descriptors of random variables is its probability density function (PDF) is given by eqn. (2).

$$\mathrm{s} = \mathrm{T(r)} = \int_0^{\mathrm{r}} \mathrm{P(r)dr}\;;\; 0 \leq \mathrm{r} \leq 1 \qquad (2)$$

So the gray levels for continuous variables can be characterized by their probability density functions P(r) and P(s). The probability density of the transformed grey level is given as in eqn.3

$$P(s) = P(r)\frac{dr}{ds} \quad (3)$$

Cumulative density function, shown in fig. 2, is obtained by simply adding up all the Probability density functions (PDF). Since probability density functions are always positive and the integral of a function is the area under the function, the transformation function is single valued and monotonically increasing and satisfy the first condition. Similarly the integral of a probability density function for variables in the range [0,1] is also in the range [0,1] so the second condition is also satisfied. Differentiating transformation function T(r) with respect to ‘r’ gives the result as in eqn. 4.

$$\frac{ds}{dr} = P(r) \quad (4)$$

Thus P(s) can be written as in eqn. (5),

$$P(s) = [1] = 1\ ;\ 0 \leq s \leq 1 \quad (5)$$

Since P(s) is a probability density function, it follows that it must be zero outside the interval [0,1] in this case because its integral over all values of ‘s’ must equal to 1. So P(s) is a uniform probability density function.

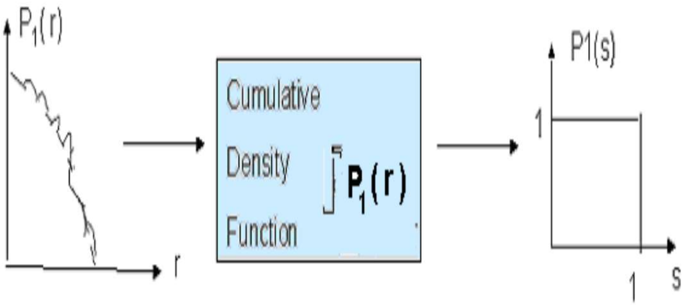


Fig. 2 Cumulative Density Function

For discrete values probabilities and summations are dealt with, instead of probability density functions and integral as given [8] in eqn. 6.

$$P(r) = \frac{n_k}{n}\ ;\ k = 0,1,2,\ldots,L-1 \quad (6)$$

And the discrete version of the transformation function is given by as per eqn. 7 and 8,

$$S_k = T(r,k) = \sum P(rj) \quad (7)$$

$$s_k = \sum P(r) = \frac{n_k}{n} k = 0,1,2,3,\ldots L-1 \quad (8)$$

Using Contrast Limited Adaptive Histogram Equalization, (CLAHE) which is an improved version of AHE, or Adaptive Histogram Equalization, sharp field edges can be maintained by selective enhancement within the field boundaries. Here field edge in a portal image is first obtained and then only processing those regions of the image that lie inside the field edge. By applying a combination of CLAHE, median filtration and edge sharpening, noise can be reduced while maintaining the high spatial frequency content of the image.

IV. HARDWARE IMPLEMENTATION

The CLAHE algorithm is implemented on Xilinx Spartan 3AN based Altium Designer’s nanoboard NB3000. The design consists of open bus document and schematic document as shown in fig. 3 and fig. 4. Open bus document describes the various components and their connections in altium designer in top level method. Schematic design shows the hardware components associated with design and the pins they are using for various connections.

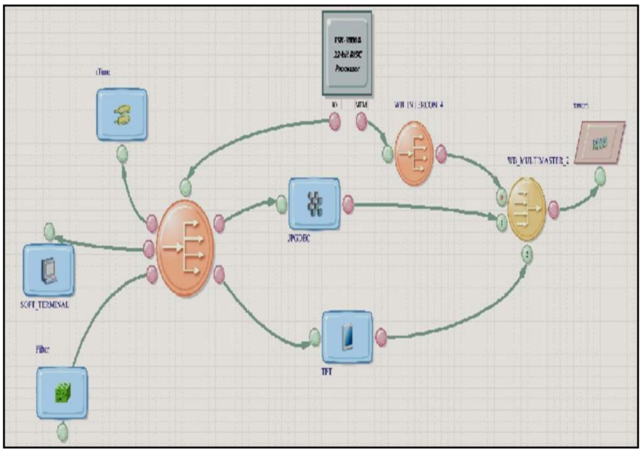


Fig 3. Open Bus Document

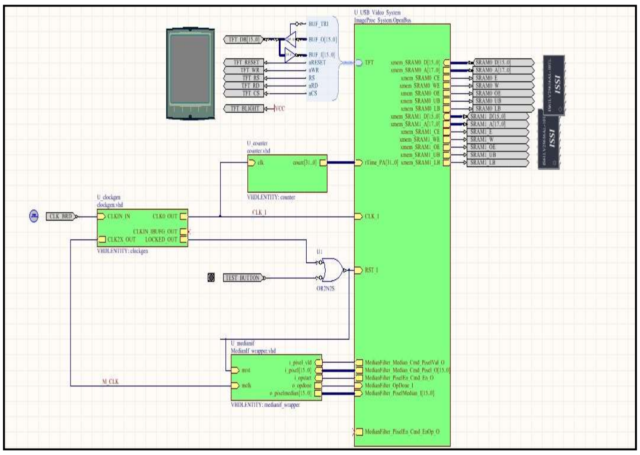


Fig 4. Schematic Document

V RESULTS

For grey scale image, the image is subdivided into 4 equal parts and the histogram equalizaion was implemented. For clipping, a threshold value of 0.032 was given. The output obtained was visibly brighter compared to the original underwater image. Fig. 5 shows original underwater image and fig. 6 shows ehanced underwater image.

In the case of colour image, the three colour components, RGB, were separated. This was done to separate the red, green and blue components. The components were separated by extracting the first 5, next 6 and last 5 bits of each pixel one after the other. The last 5 pixels were first separated by AND operation of the 16 bit pixel value with 1FH. These bits form the blue component. Then the pixel is shifted by 5 bits and then AND operation was carried out with 3FH to get the green component and again shifted by 6 bits. The final pixel value was the red component. Then RGB was converted to YCbCr color space. The algorithm was applied to Y component only and then recombined to get the enhanced image. Fig. 7 and 8 shows the original and enhanced images respectively.

The design was successfully implemented in Altium nanoboard NB3000. The resource utilisation of Xilinx Spartan 3AN is also shown in table 1.

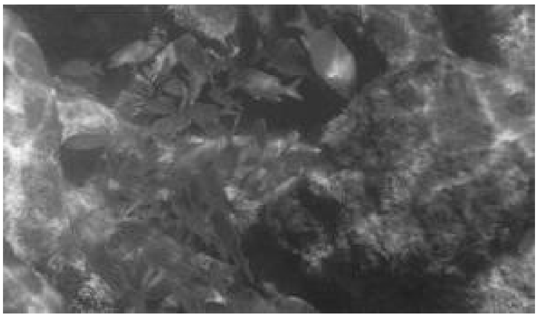


Fig 5. Input underwater image

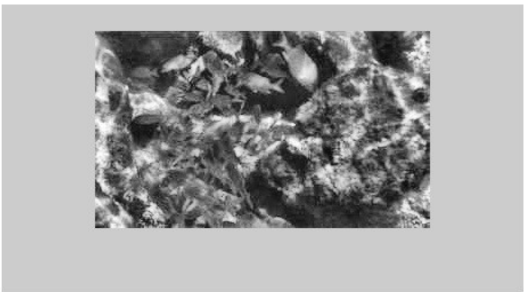
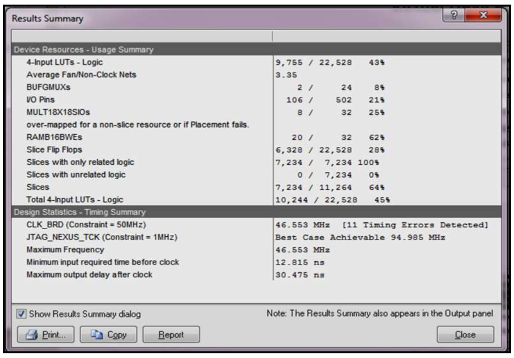


Fig 6. Enhanced underwater image

Fig 7. Input color image

Fig 8. Enhanced color image

Table 1. Resource utilization



Results Summary

Device Resources - Usage Summary	
4-Input LUTs - Logic	9,755 / 22,528 43%
Average Fan/Non-Clock Nets	3.35
BUFGMUXs	2 / 24 8%
I/O Pins	106 / 502 21%
MULT18X18SIOs	8 / 32 25%
over-mapped for a non-slice resource or if Placement fails.	
RAMB16BWEs	20 / 32 62%
Slice Flip Flops	6,328 / 22,528 28%
Slices with only related logic	7,234 / 7,234 100%
Slices with unrelated logic	0 / 7,234 0%
Slices	7,234 / 11,264 64%
Total 4-Input LUTs - Logic	10,244 / 22,528 45%
Design Statistics - Timing Summary	
CLK_BRD (Constraint = 50MHz)	46.553 MHz [11 Timing Errors Detected]
JTAG_NEXUS_TCK (Constraint = 1MHz)	Best Case Achievable 94.985 MHz
Maximum Frequency	46.553 MHz
Minimum input required time before clock	12.815 ns
Maximum output delay after clock	30.475 ns

Show Results Summary dialog — Note: The Results Summary also appears in the Output panel

Print... Copy Report Close

VI CONCLUSION

Successful implementation of contrast limited adaptive histogragam equalization on underwater images can be used in Autonomous Underwater Vehicles (AUV) for enhancing underwater images suffering from poor lighting. Thus the images can be preprocessed before being used for underwater applications such as pipeline tracking, video mosaicking, mine detection etc.

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