Implementation of Histogram Based Image Fusion Technique for Underwater Image Enhancement in Reconfigurable Platform

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Abstract

Objectives: This paper proposes a novel histogram based image fusion method to refine the visibility of underwater images which are suffered from colour degradation and poor illumination due to ocean depth. **Methods/Statistical Analysis**: To improve the enhancement of underwater images, R channel is separately processed as red component attenuates heavily compared to blue and green component and is combined with histogram equalized original image. Then various weight maps, suitable for underwater images, were obtained from the single image and are processed before fusion is done. **Findings:** Automated Underwater Vehicles (AUV) is used for marine navigation, pipeline tracking, video mosaicking etc. Automation of video captured has to be used for various applications where image pre processing is necessary. Hardware implementation helps the automation process to be used in real time scenario. In this work Field Programmable Gate Array implementation (FPGA) of a novel algorithm for the underwater image enhancement is carried out. New weight maps suitable for underwater images were used for fusion as compared to existing methods and were compared with the existing methods. Altiumnano board was used for FPGA implementation. **Application/Improvements:** Degraded images need to be enhanced before processing it further applications. This work is mainly focussed on underwater images and can be used in AUVs and Remotely Operated Vehicles (ROV).

Keywords: Histogram, Image Fusion, Underwater, AUV, FPGA

1. Introduction

Submarine environment is rich in underwater cultural heritage. The Sea floor is rich in resources varying coral reefs, petroleum opulence, historical evidences etc. Therefore seafloor exploration has been an agreeable field of researchers. This is ranging from underwater archaeology, the biological life in sea floor and deeper ocean, geological nature, detection and investigation to find shipwrecks, study of ecology, and having a bird eye view in economical point etc.

The behaviour of light in underwater is dissimilar from the terrestrial. This is mainly due to the reciprocating phenomenon that is ranging from fragmentary level to macroscopic level extending throughout the ocean. Under these condition the inverse square law of light is no longer adhere to the straight line from the light source to the object. Hence the luminous intensity at any given point from a particular distance from the source cannot be predicted by the inverse square law[1].

The amount of light reaching the object either by direct illumination or diffuse illumination can be collectively called as total illumination. There are many challenges posed by the ocean in capturing the underwater life. The human activities and capturing images are limited to a small extend due to turbulent ocean nature.

Hence the underwater imaging is usually carried out by Underwater Vehicles (UV) The Autonomous Underwater vehicles[2] are equipped with navigation sensors are widely used for imaging in now a days.

The degradation of underwater images are mainly due to scattering, reflection, wavelength selective absorption and veiling light[3] By the Interaction with the water molecules and suspended particles in the underwater environment, the photons are scattered away from their path. Reflection is mainly due to the salinity structures and in homogeneity in the water. The image luminance is lost by the absorption of photons from the image field. The rate of absorption depends on the wavelength. The attenuation is maximum for the red channel whereas the blue and green channels are attenuated less as the depth increases. Another important factor that affects the underwater image is veiling light. This is the ambient irradiance that is scattered into the path between the object and the observer. Due to the scattering effect of the light in the aquatic environment, the artificial light source to be provided for adequate illumination[4]. Disastrously these artificial lightning tend to illuminate the scene in a non-uniform fashion. Hence colour correction needed to process the images captured with UVs.

Image processing is accorded with large data. FPGAs are an alternate solution for large data handling image processing applications due to its inherit parallelism. The logic blocks in FPGA are connected by the switching network provide re-programmability thereby permitting application specific hardware reconstruction[5]. Proper designing can utilize the temporal as well as the spatial parallelism therefore FPGA's are well suited as the platform for image processing applications. The parallelism which allows carrying out both reading from memory and writing to a memory at the same time[6]. FPGA outperforms other serial processors in terms of cost and performance. The reusable and reconfigurable platform make the FPGA implementation more suited for real time image processing. This work has been carried out in Xilinx Spartan 3 AN Nano board 3000.

The paper is organized follows; next chapter describes the previous works done in the area of underwater image enhancement. The brief description of behaviour of light rays in underwater is given, since it is essential for the study of underwater image enhancement algorithms. The next chapter dealt with the image enhancement algorithm that has been implemented in FPGA. Later the result and discussion is followed by the conclusion.

2. Related Works

As the advancement in the optical as well as the imaging technology has contributed a lot in the field of marine research. Hence underwater research drew attention in last decade. One of the main hurdles that faced by the researchers is degraded quality of underwater images. Therefore underwater image enhancement is been a consideration[7].

In[8] has discussed the intensity of a particular scene can be modified by changing the features of histogram equalization. The key feature of this method is the image is subdivided into two thereby increase the contrast by conserving the mean intensity of the scene.

Saibabu, et al. has proposed an algorithm for digital image enhancement. The images are seized under non uniform lighting condition. Different methods such as adaptive intensity enhancement of the given image, contrast improvement as well as colour restoration which were done independently to make the proposed algorithm more robust to the images taken under different characteristics. More over the algorithm become more extensile because of the adaptive of transfer function, which is depends on the mean of neighbouring pixels.

As the spreading of light increases more amount of light gets attenuated, this in turn reduces the clarity of images which are taken under water environment. The degree of light attenuation in underwater and air molecules varies to a great extent. A new underwater optical model was derived by[9] which clearly depicts the formation of images in the turbulent environment. Moreover they proposed an algorithm which effectively enhances the images by constructing a new underwater dark channel which estimates the scattering rate.

As the Underwater images are always blurred in nature, this restricts to get finer details present in the scene. A low complexity algorithm was proposed relayed on back channel prior model. The complexity is reduced by applying a median filter, to estimate the depth map of the scene[10]. Due to light scattering the contrast of the scene is poor, this has to be restored. An efficient colour correction method is also used to restore the contrast.

An algorithm[11] was proposed by for improving visual appearance of the image by contrast limited Adaptive Histogram Equalization. The CLAHE on RGB colour space and HSV colour space. These two are combined together using the concept of Euclidian Norm.

A fusion based method was proposed by[12] to enhance the underwater images. This method computes two

derived inputs and weights maps which extracts the features of the image. The derived inputs are computed by applying colour correction and contrast enhancement. The weight maps are designed in such a way to increase the visibility of objects that are far from capturing device.

3. Theory

As intermission increases the light rays may undergo double or multiple scattering which effectively reduces the amount of light waves reaching the bottom. Hence multiple scattering processes are to be modelled[13]. The amount of light wave propagating through under water is controlled by mechanisms such as absorption of light molecules, back scattering and reflection. The above condition can be well modelled by radiative transfer theory. The space can be divided into two homogenous planes, the air which above the ocean and water molecules below the horizontal line. The radiative transfer function can be mathematically expressed as in equation 1,

$$\cos\theta \frac{dL}{dz} = -cL + S + \int_0^{4\pi} L\beta d\Omega \qquad (1)$$

Where z is the perpendicular direction on water surface pointing downwards and is the polar angle between the direction of propagation of the beam and the vertical. The spectral radiance $L(z, \theta, \phi, \lambda)$ is defined as the amount of radiative energy travelling in the (θ, ϕ) direction.

While the underwater imaging is taken into consideration, the light wave from the image can be treated as the combination of two components, direct transmission and forward scattering. As the light rays advance through the water molecules from the object has to be captured towards the imaging device, a portion of energy is lost as a result of scattering and selective absorption. The amount of light rays that reach the camera is termed as the direct transmission. It can be expressed as in equation 2,

$$D(x, y) = L_0(x, y)e^{-cz} \qquad (2)$$

Where c is the attenuation coefficient, z is the distance between object and capturing device. This parameter depends on the pixel coordinate x and object radiance is denoted by Lo. The term c can be further expanded as the sum of absorption coefficient and total scattering coefficient of water molecules.

The light scattered forward at small angles from the Line of Sight propagation path is termed as the forward scattering. This component causes an image blur. The

veiling light the amount of light rays scattered from the surrounding illumination sources.

The scene irradiance at any pixel can be treated as the sum of direct signal, indirect signal and backscatter, as per equation 3.

$$E(x, y) = D(x, y) + A(x, y) + B(x, y) \qquad (3)$$

Where D(x, y) is the direct signal component, A(x, y) is the indirect signal component and B(x, y) is the backscatter.

Images are susceptible to noise; hence a pre-processing is required to eliminate undesirable pixel intensities existing in the scene. Median filtering is one of the simplest methods to eliminate this unwanted content. This is achieved by sliding the kernel along entire image in a pixel by pixel fashion and thereby replacing the pixel with the median of intensity value present in the window. One of the major issues posed by the medial filtering is the non-availability of boundary pixels. As the last and first values of the pixels are being missed, these pixels are to be repeated. Thereby doing it can preserve the edges and removes noise content to a greater extend.

4. Proposed Method

White balancing is the method of removing additional and unrealistic colour casts produced by the environment. In underwater environment due to scattering and wavelength selective absorption additional colour casts are introduced. In order to remove these effects, the white balancing methods are used. The most widely used and simplest white balancing algorithm is Grey World[14]. The GW algorithm is based on the property that average colour of the image is grey. This condition does not hold by the underwater images, because as the depth of the ocean increases the red channel is attenuated most. More over due to the poor light propagation results in poor illumination. Therefore the contrast of the scene is poor. Hence this method is failed in the case of underwater images. In order to obtain the colour cast free images, the gray World algorithm is slightly modified in this paper.

The mathematical representation of Grey World Algorithm is as follows,

Calculate Mean of each channel and increase the R-Channel component according to it as in equations 4 to 5.

$$R_{avg} = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} I_r(x, y) \qquad (4)$$

$$G_{avg} = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} I_g(x,y) \tag{5}$$

$$B_{avg} = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} I_b(x,y) \tag{6}$$

The major problem associated with enhancement of underwater image is that R channel component in the image is very low, hence colour correction becomes erroneous and enhancement of the image suffers due to this. In this paper we introduce a novel approach of augmenting the red channel by adding a mean value to the average red value using mean green and blue values. This is done by adding 45% of the mean of green and blue channel values to the red channel component. 45% is the optimum value chosen based on trial and error method as per equation 7.

$$R_{avg} = R_{avg} + 0.45 \times \frac{(G_{avg} + B_{avg})}{2} \tag{7}$$

Though white balancing removes additional and unrealistic colour casts, it alone cannot solve the problem of visibility, hence a colour corrected input id derived in addition to white balanced image.

Second derived input has to be computed from a noise free image. Underwater image is noisy by nature hence to obtain a noise free image; the noise needs to be eliminated using a suitable filter. In our work the pre-processing of image by removing noise is achieved by median filtering the white balanced input.

The median filtering is applied on input image, by doing so the property of edge preserving smoothing is exploited. This nonlinear operator arranges the intensity value of the local window image pixels and replaces the value in the output image pixel by the middle value. As the images lost its true colour due to channel absorption and scattering has to be restored. In order to regain the colour of the scene an additional colour correction has to be taken out in the noise reduced image.

4.1 Weight Maps

Different weight maps were proposed by[15] for image enhancement. The derived inputs such as the white balanced as well as colour corrected version of the image has some finer details. These finer details from each image have to be extracted out and fuse them together to form the enhanced image. Hence the weight maps are designed

to extract the finer* details. Image restoration is very crucial step which has to be carried out in such a way to extract the dominant features in the image.

4.2 Laplacian Weight Map

The main aim of this weight map is to assign a high value to the edges as well as the textures. This is done by processing the luminance channel of both the colour corrected and white balanced input. Laplacian filter is a better choice for edge preserving. Laplacian of an image accentuate the regions having abrupt or rapid intensity change. The second derivative measurements are very delicate to noise .Since the images are noise reduced hence further noise reduction is not needed. Even though it preserves edges, this weight map doesn't give the details of contrast since it can't discriminate the flat, valley or rapid regionsa in eqn. 8.

$$W_L = \sqrt{1/3 \left[(R^k - L^k)^2 + (G^k - L^k)^2 + (B^k - L^k)^2 \right]} \tag{8}$$

4.3 Saliency Weight Map

One of the main challenges in underwater image enhancement is that the objects within the image lose their visibility and hence discrimination of the objects from the background scene becomes difficult. The quality that makes the object distinctive relative to its neighbours is known as saliency. Saliency algorithm[16] is an algorithm which can be used to solve this problem. It is based on concept of centre-surround contrast wherein a saliency map is developed so that the contrast of the main object of interest is enhanced. Another main advantage of this approach is that the mid values of the image are not affected while applying this method as in equation 9.

$$S(x,y) = \| I_\mu - I_{\omega h c}(x,y) \| \tag{9}$$

where I_μ is the mean image feature vector and $I_{\omega h c}$ is the Gaussian blurred version of the luminance channel. A 5x5 separable kernel is used for image blurring.

4.4 Local Contrast Weight Map

In order to enhance the local contrast of the image under consideration, a local contrast weight map is used. To find the local contrast weight map, luminance channel of the image is first found out. Then the standard deviation between luminance level of each pixel and the average

surrounding region is computed. Equation (10) represents the equation for computing Local contrast weight Map, where I^k represents the luminance channel of the image and $I_{\omega hc}$ represents the high pass filtered luminance channel. The mathematical representation is as in equation 10 and 11,

$$W_{\downarrow}LC(x,y) = \|I^{\uparrow}k - \dashv | \vdash \square I_{\downarrow}\omega hc | {}^{\intercal}k)\dashv\|$$ (10)

4.5 Exposedness Weight Map

In an Underwater image the all the pixels will not be exposed. The regions where the light rays strikes reflect a portion of light according to the optical property of the object. Hence this weight map measures the exposedness of each pixel. By calculating the weight maps an idea about the local contrast. This weight map assigns a high value to the exposed pixels and vice versa.

$$W_E(x,y) = \exp\left(-\frac{I^k(x,y) - 0.5^2}{2\sigma^2}\right)$$ (11)

4.6 Image Fusion

Once the image weight maps are computed, the four weight maps (Laplacian weight map, Saliency Weight Map, Local contrast weight map, Exposedness weight map) and the two derived inputs (White balanced image input and colour corrected input) are combined together to obtain the final enhanced image. Firstly the effective weight map from the four weight maps are combined by averaging the weight map values as shown in equation (12). As a result of this operation, two weight maps will be obtained for each input. Then these weight maps will be normalized as shown in equation (13). Finally the equations are fused using the equation (14) to obtain the resulting enhanced image.

$$W_{Avg}^k = \frac{1}{N}\sum_{i=1} W_i^k$$ (12)

$$W_{Norm}^k = \frac{W^k}{\Sigma_{i=1}^{2} W^k}$$ (13)

$$g(x,y) = \sum_{k=1} W_{Norm}^k(x,y)I^k(x,y)$$ (14)

5. Hardware Implementation

The implementation of image processing algorithm is done using FPGA making use of its inherent parallelism.

This makes it possible to exploit the parallelism inherent in images as well. A Xilinx Spartan 3AN FPGA kit is used in this research work. A high level design of various modules implemented in FPGA is shown in the Figure 1. Each operation is implemented using a set of logic blocks which forms the very fabric of FPGA. The input image will be undergoing parallel through two sequential operations. Former being the white balancing along with the R channels pre-processing and its subsequent operations as in Figure 2. The latter being the colour correction and its subsequent operations. This will considerably reduce the execution time for processing of the entire image as these operations are independent of each other hence they can be executed in parallel. The processing time of each image is computed and it varies the minimum time required for the test images is 38 ms.
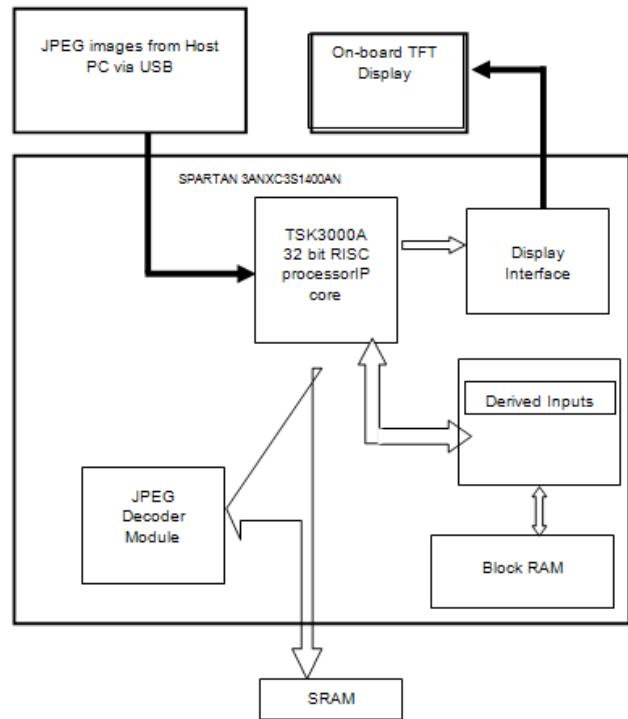

Figure 1. Hardware modules used in the FPGA development board.

6. Results and Discussion

Underwater image is enhanced using the proposed algorithm and is shown in Figure 3. Figure 4 shows white balanced and average of input image in Figure 3. Figure 5 shows normalized weight map for white balanced input and average input. Different underwater images are enhanced using the proposed algorithm and is shown in Figure 6.
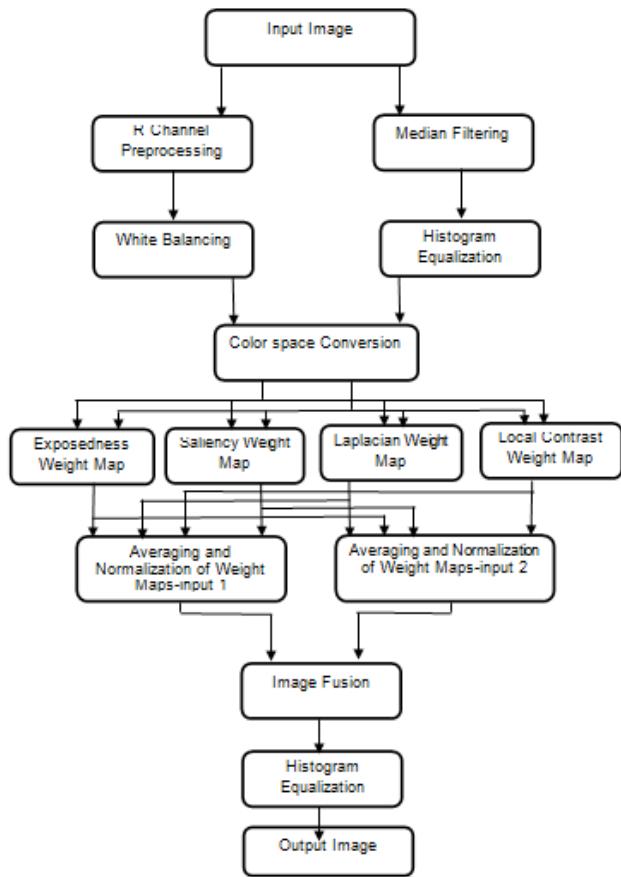
Figure 2. Block diagram of proposed algorithm.
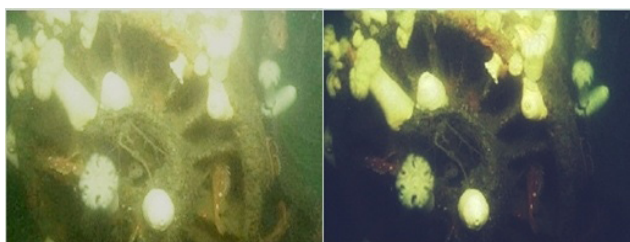

Figure 3. Input and Enhanced output image.

Figure 4. Input images after white balancing and averaging.

Objective image quality measurement parameters used in this work is the descriptors[17]. The parameter e

computes the ratio of new visible edges in the restored image as in Table 1. This descriptor computes the potential of the proposed algorithm to restore the edges; those edges were not visible in the original image. The quality of contrast restoration of the proposed algorithm can be measured by the parameter r. The number of pixels becomes saturated after restoration indicated by e. FPGA runtime for various test images are shown in Table 2.
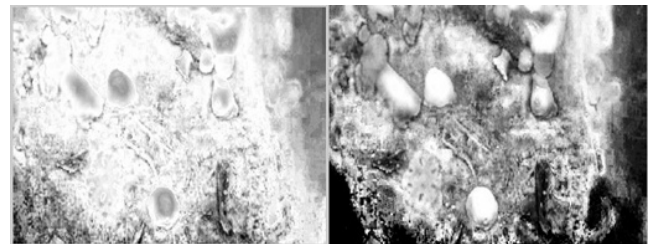

Figure 5. Normalized weight map for white balanced and average input.

Figure 6. Underwater input image and enhanced image.

Table 1. Image Enhancement parameters[17]

	E	Sigma	R
Image 1	0.60	0.129	1.56
Image 2	0.61	0.439	2.41
Image 3	0.09	0.003	1.28
Image 4	0.14	0.255	1.96

Table 2. FPGA run time for various test images

	Size	FPGA run time
Image 1	320x240	42 ms
Image 2	320x240	38 ms
Image 3	320x240	46 ms
Image 4	320x240	44 ms

7. Conclusion

Innovative fusion based under water image enhancement method is implemented in FPGA. The study of underwater imaging revealed that increase in depth of ocean results in attenuation of red colour. In this method R channel pre-processing is carried out to enhance the red components in the image. Hence the colour loss can be compensated to an extent. Colour correction methods are applied on the processed image to obtain details of scene which are degraded by absorption and scattering of light rays in water. The weight maps are aimed to extract the features of image. These extracted features are normalized to the range of input and combined using a fusion based strategy. Even though the resulted image is free from noise and unwanted colour shifts, additional enhancement is carried out to improve the visibility of low light regions. The parameters proposed by[17] are computed. The obtained result showed that the enhanced Image improves the visibility of areas which are affected by low light conditions as well as additional illumination provided by the underwater vehicles.

8. References

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