"UNDERWATER IMAGE ENHANCEMENT USING FUSION"

A DISSERTATION

Submitted in partial fulfilment of the
requirements for the award of the degree
of

INTEGRATED DUAL DEGREE

in

ELECTRONICS AND COMMUNICATION ENGINEERING
(With Specialization in Wireless Communication)

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DECEMBER, 2019

CANDIDATE DECLARATION

I declare that the work that is presented in this dissertation with the title "Underwater image enhancement" towards the partial fulfilment of the requirement for the awarding of dual degree of B.Tech/M.Tech submitted to Department of Electronics and Communication Engineering, Indian Institute of Technology, Roorkee is an accurate record of my own work carried out during the time from June 2019 to December 2019 under the supervision of Dr. Vinod Pankajakshan, Assistant Professor, Department of Electronics and Communication Engineering, IIT Roorkee.

The content of this dissertation has not been submitted by me for the award of any other degree of this or any other institute.

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CERTIFICATE

This is to certify that the statement above made by the candidate is correct to the best of my knowledge.

DATE: ....

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ACKNOWLEDGEMENT

First and foremost, I would like to express my utmost gratitude towards my guide Dr. Vinod Pankajakshan, Assistant Professor, Department of Electronics and Communication Engineering, IIT Roorkee for his constant support and invaluable guidance throughout my dissertation research. His wisdom, knowledge and commitment to the highest standards inspired and motivated me. His encouragement and motivation have always emboldened my resolve and helped me overcome difficulties. The support from my family has helped me a lot in getting to complete this report

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ABSTRACT

A method to enhance underwater images has been presented in this report. This method only utilizes the degraded image versions of a single image. It gets the inputs and weight measures only from a single test image. Both colour correction and contrast-enhancing of the original image are taken as the inputs. To increase the visibility of underwater images that are degraded by scattering and adsorption effects, weight maps are introduced which will used to enhance the image. Since this requires a single image it does not require complex hardware to capture images and does not depend on the underwater conditions. The enhanced output images have reduced noise level, improved global contrast, better illumination of the darkened regions while also maintaining a high enhancement in the fine details and edge details.

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1 INTRODUCTION

Digital image processing is a broad subject that may involve operations that can be complex but with a simple central idea. The data contained in an image is used to recognize, understand and interpret the information available and to infer the required information that we wish to know. Image enhancement is used to enhance an image's quality when observed with the human eye. Image enhancement techniques are used to get details that are obscure or to highlight the important parts of an image that are of interest by modifying the attributes of an image [1]. It has a lot of applications in many areas of science and engineering of which one in underwater imaging.

The Ocean is a vast place that remains a mystery to scientists. It is opined that we know more about the space than we do about oceans. Underwater imaging has a lot of applications in marine biology, archaeology, detection of underwater bedrocks, etc. Underwater imaging has different and complex hurdles than the imaging processing of objects in air. They are mainly because of absorption and scattering effects which cause attenuation of the propagated light [2]. Light energy is reduced by absorption effect and scattering effect changes the direction in which light propagates. This is why most underwater images are foggy and look very misty.

Objects that are farther from surface suffer more distortions because the composing wavelengths of light cannot travel all the way i.e the composition of light has different wavelengths that travel differently in different mediums. As depth increases, depending on wavelength, colours are lost in the order of red, orange, yellow, green and purple respectively. Since blue light has the shortest wavelength they travel the longest in water and hence underwater images are mostly in a bluish-green in colour. Disproportionate bluish-green colour is observed because the blue light travels longer against the attenuation. Variations in light sources will affect how we perceive the colour. These are the reasons behind the non-uniform colour cast characteristic of a typical underwater image. Colour cast is one of the reasons why traditional enhancing techniques like histogram equalization cannot be used to enhance an underwater image. The degeneration of underwater images is due to a combination of additive and multiplicative processes so an enhancement that addresses all these must be strategized. While there are some complex image enhancement algorithms that require multiple images and enormous computing power a computationally simple approach that could work with a single image and also gives good results is something that is needed.

This report presents a practical approach to remove colour cast and haze with just a single image that is taken with a non-specialised camera. It is based on the division of the image into multiple images by passing them through different algorithms and then fusing those multiple inputs to form an enhanced image so as to get a natural appearance of an underwater image

IMAGE ENHANCEMENT

The main aim of enhancement is to process an image so that the out-coming result is more desirable than the original image [1, 3]. Image enhancement techniques that are applied on an image basically depend upon the type of the image, mode of capturing device and application of the information obtained from the images. For example, a method which is used to enhance images of solar flares might not be useful to enhancing pictures of X-rays. Image enhancement can be considered a specialised branch which could be quite different depending on the areas which people choose to work with. The path to image enhancement can be divided into two main categories, Spatial domain methods and Frequency domain methods

1.1 Spatial Domain methods

Spatial domain implies the depiction of an image in a pixel format and the operations which are done directly on them are called spatial domain methods. A spatial domain process is denoted by

$$G(x, y) = T[f(x, y)] \tag{1}$$

where (x, y) is a neighbourhood, $f(x, y)$ is an input image, $G(x, y)$is the processed image and T is an operator which operates on $f(x, y)$ which is defined for all (x, y). In addition to that T can be operated on an image set like performing the pixel by pixel sum of all images for a noise reduction. A neighbourhood around a point (x, y) can be defined as a square/rectangular sub-image area centred at (x, y), which is shown below in figure 1. The sub-image centre is moved through each pixel starting at the top-left corner. For every location of (x, y) T operator is applied to get the corresponding output G.

The simplest instance of T is when the size of neighbourhood is 1x1 i.e a single pixel. In such cases, the value of G only depends on f's value at (x, y) while T can be defined as gray level (also known as mapping, intensity). The transformation function S which is of the form

$$S = T(r) \quad (2)$$

where r is the variable which denotes the gray level of $f(x, y)$ and S is the variable which denotes $G(x, y)$ at any point (x, y). An example of $T(r)$ is shown in figure which is in the form of eqn (2). The effect of this transformation will produce a higher contrast image than the original image by darkening the levels which are below m and brightening the levels which are above m of the original image. This process is known as contrast stretching and in this technique, the r values lower than m are compressed into a narrow range of S by the transformation function towards dark. For values of r above m the opposite effect takes place. In a special limiting case shown in figure 2, $T(r)$ gives us a two-level image (binary). This kind of mapping is also called as a thresholding function. Gray level at a point is the factor that affects the enhancement at that point. The techniques of this category are also called as point processing techniques

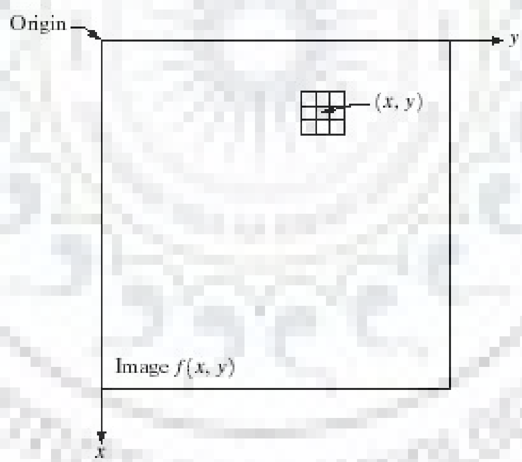
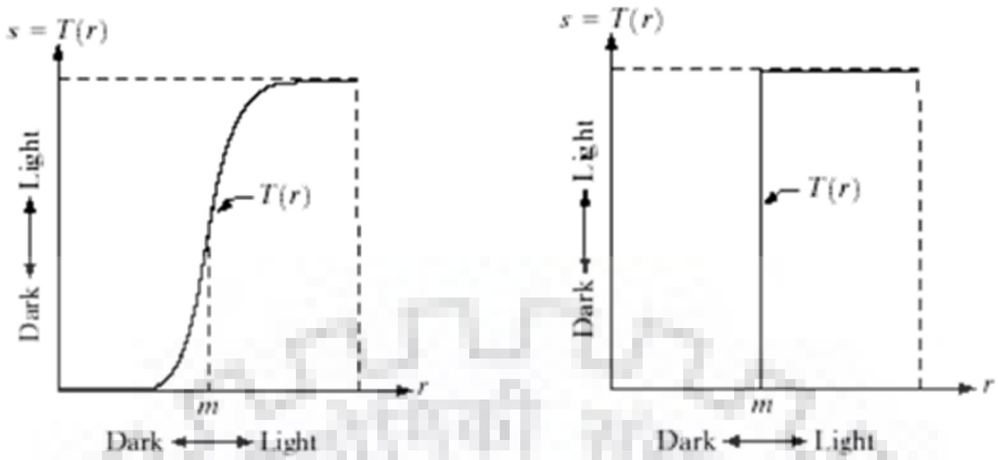


Figure 1: A 3x3 neighbourhood around point (x, y) in an image.



Contrast Stretching Thresholding

Figure 2: Contrast stretching Gray level transformation functions.

For point processing operations larger neighbourhoods allow more flexibility. Generally, a function which has a value of ‘f’ in a predefined neighbourhood (x, y) is used to determine g value at (x, y). The main approach in this is based on using arrays which are called masks (also called kernels, filters, templates, or windows). A mask is basically a small (for example 3x3) 2-D array, like the one shown in figure 1. The mask is exceptionally helpful because the mask coefficient values are those which determine the nature of a process implemented like image enhancement, sharpening techniques which use this type of approach are called as mask processing or filtering [1, 3].

In a broad way Spatial domain image enhancement can be classified into four main categories:

1. Point processing,

2. Image subtraction,

3. Image averaging

4. Spatial filtering.

Point processing is also divided into two types: Gray scale modification and Histogram processing

Similarly, gray scale modification falls into three categories: Log transformation, Piece-wise transformation, and Power law transformation.

and finally, Piecewise transformation can further be divided into contrast stretching, gray level slicing and bit plane slicing.

Spatial filtering can use Weiner filtering or Gabor filtering in spatial domain [4]. The different spatial domain techniques are shown below.

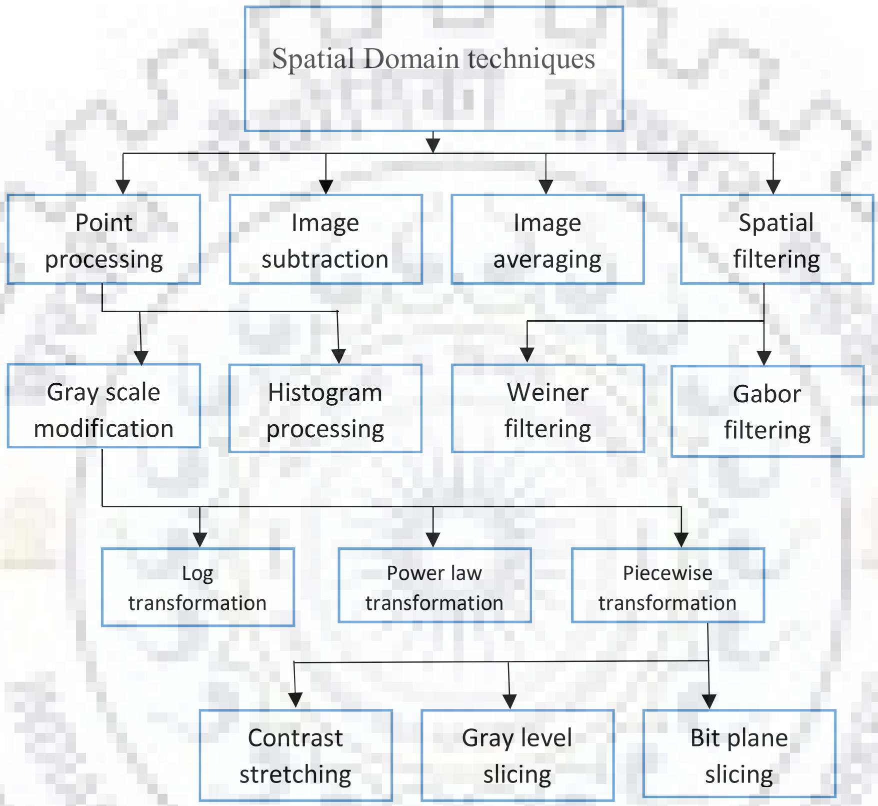


Figure 3: Spatial Domain Image Enhancement Techniques.

1.1.1 Histogram Equalization

Histogram equalization can be considered the basic block of image enhancement. A digital image's histogram shows the distribution of its pixel intensities [5]. The histogram of an image is a plot of the number of pixels in that image, shown in the vertical axis, whereas in the horizontal axis each of those pixels has a specified brightness value, as shown in figure 4

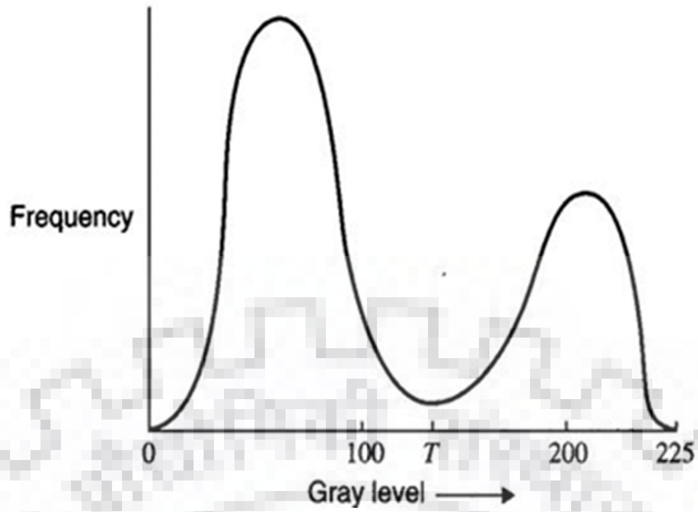


Figure 4: Histogram as number of pixels vs. intensity value.

Histogram equalization is quite a common technique almost seen in all aspects/fields in which image enhancement is used. The brightness of an image is caught easily just by looking at the histogram of an image. The predominantly dark part of the image will be towards the low end of the gray scale and so the image detail is highly compressed towards the darker ends of the histogram. In order to produce a clearer image, the gray levels are stretched out at the dark end which produces a uniformly distributed histogram. Histogram equalization is nothing but finding a transformation gray scale function that produces an output image with a uniform histogram [1, 3]. A transformation T must be found that maps the gray values r in the input image I to gray values S = T(r) in the transformed image TI.

The assumptions on T are that

(a) T is monotonically increasing, single-valued and
(b) for all $0 \leq r \leq 1$ it is taken as
$0 \leq T(r) \leq 1$

A standard example as to what happens to an image when it undergoes histogram equalization is shown in figure 5

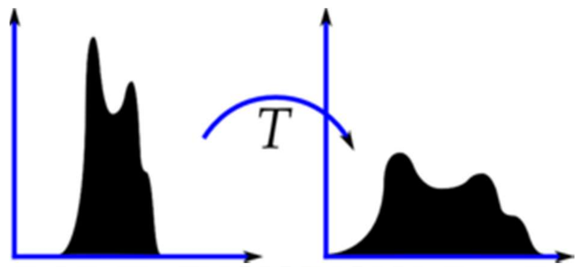


Figure 5: Histogram equalization

If one of the input images is subjected to histogram equalization method, then it produces the result shown in figure 6. The original image and its histogram are shown from left to right respectively.

Figure 6: Example of histogram equalization

While histogram equalization is a fine method for entry-level enhancement operations it alone is not capable of enhancing complex images which have many factors at play

1.2 Frequency domain methods

By modifying the FT (Fourier transform) of the image and then processing them through filter transfer functions we can perform manipulations on an image. These are called the Frequency domain methods. First, the Fourier transform of an image is calculated which then is passed through a filter transfer function. Then an inverse transform is used to get the enhanced/modified image. The main part of this is the filter transfer function which can include various types such as high pass filter, low pass filter and Butterworth filter. This method is much simpler because it only needs to have the Fourier transform which can be easily enhanced by multiplying with a filter (as opposed to convolution in spatial domain). It is then undergone through the reverse Fourier transform to get the enhanced image back.

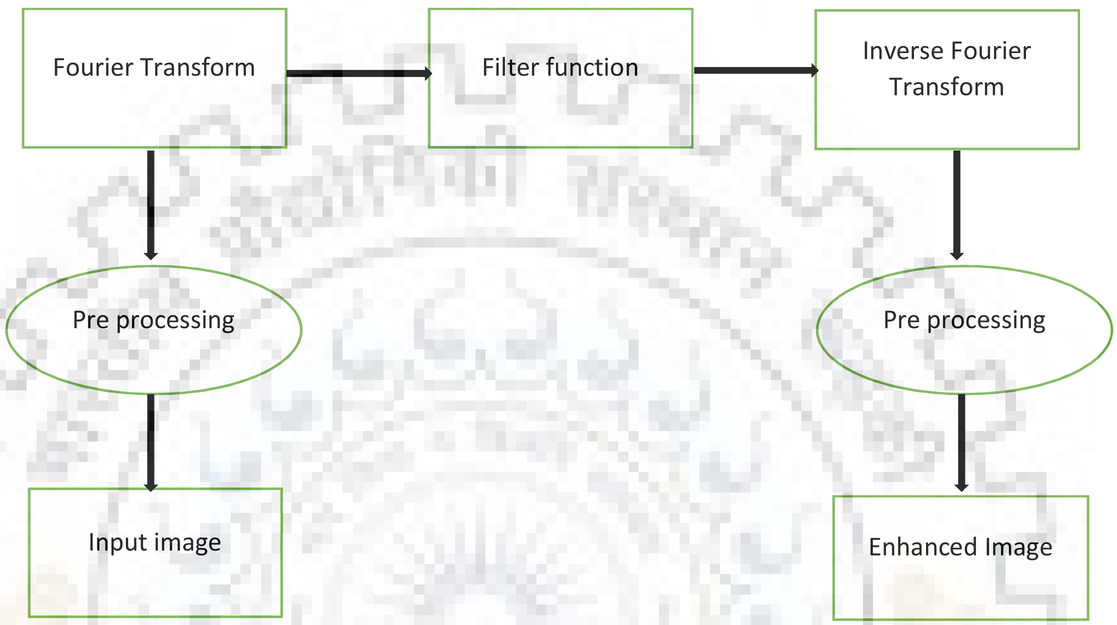


Figure 7: Image enhancement using Frequency-domain method

While it seems that blurring of an image by stripping it of all the high-frequency components or sharpening it by increasing its high-frequency components magnitude is easier, in practical situations, it is usually more efficient to implement these operations by small spatial filters [3].

The elimination of high-frequency components in an image is what low pass filtering gives. By passing through a low pass filter the image is blurred and there will be a reduction in the sharp transitions attributed to noise. Ideally passing through a low pass filter should retain its low-frequency components while eliminating its high-frequency components. Whereas in practice there are no ideal filters. The available filters have problems (i.e. blurring, ringing) which are caused because of available filter response, which have a large number of risings/ fallings, and is the culprit for the problems. In order to minimize the blurring, ringing filters which have smoother transitions such as Butterworth filter [6] are used and achieve better results

Images normally are consisting of reflected light from illuminated objects. In its basic form an image f(x, y) can be described by two components:

- The source light incident on the viewed image
- The amount light reflected by the objects present in the image.

These two components are called Illumination and reflectance, and they are denoted with i(x, y) and r(x, y) respectively. f is defined as their product (i.e.)

$$f(x, y) = i(x, y)r(x, y) \tag{3}$$

where $0 < i(x, y) < \infty$ and $0 < r(x, y) < 1$.

Homomorphic filtering can be applied to separately enhance these components in frequency domain. Image processing for colour image enhancement can also be achieved in frequency domain [1, 3].

The following four techniques of image enhancement in frequency domain are usually important

- Low pass filtering or smoothing domain filters,
- High pass filtering or sharpening domain filters,
- Homomorphic filtering, and
- Colour image enhancement.

Fourier transform can be used to convert images easily from spatial domain to frequency domain and vice versa.

At high frequency if an image has large values then the data (gray level), on a short distance scale, is changing rapidly (i.e.) a page in a textbook, noise, and edges. If it is found that an image has a large amount of low-frequency components it implies that picture has a large scale significance rather than in small parts (i.e.) a single object with a uniform surface which occupies a large part of the image. For colour images, frequency content depends on the colour components and their variation [7].

1.2.1 Filtering in Frequency Domain

Filtering in the frequency domain is a common technique that is used for image and signal processing operations [8]. The frequency domain is used because instead of the complexity of the spatial domain things can just be simply multiplied in the frequency domain which saves a lot of time. Filtering can smooth, de-blur, sharpen, and can restore some images. Essentially, filtering is the same as to convolute a function with a specific filter function that goes towards achieving the required result. Two functions are convolved by changing them into frequency domain then by multiplying them and then transforming them back to spatial domain. The whole filtering process can be summarized as

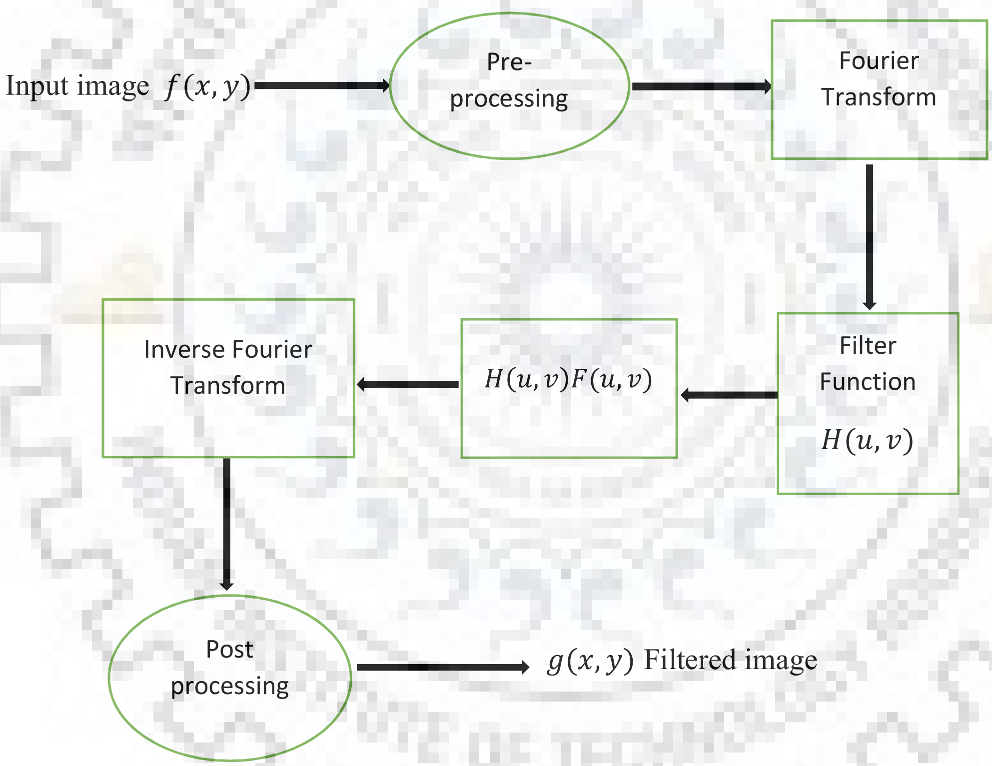


Figure 8: Filtering procedure in frequency domain

1.2.2 Importance of Frequency domain techniques

There is a great advantage of frequency domain operations while performing certain measurements or processes. In many cases operations in spatial domain can only be performed after much calculation effort/time whereas the frequency domain is easy to use.

Fourier transform, other forms of frequency-space transforms which are similar to Fourier transforms can be to 2-dimensional images. They might not always be for the enhancing visibility or the selecting features in structures for measurement. Sometimes Fourier transform methods are used in image compression to reduce the amount of data in the original image. They are also used for reducing data towards image compressing for better efficiency in transmission or storage. In such cases, reconstruction of the image (i.e.) can be done to bring it back from the frequency domain to the spatial domain for watching [1]. They have the ability to accomplish both the forward and reverse transform quickly and barely losing any image quality. Image quality is somewhat of an arbitrary definition that has certain assumptions and also includes the changing of brightness, colour levels/values, defining and locating feature boundaries, and introducing/removing of texture. As a general rule higher degree of compression means higher loss of image exactness. While speed is a constraint for any work, in image measurement speed is not that big of a concern since acquiring and analysing of the images takes time. The degradation of an image that can be tolerated by many visual applications of the compressed and restored images is usually more than what is accepted for image-analysis purposes. In a similar way, the amount of image compression which can be achieved with very low loss is very small. In many cases, image transmission from the point of capture to the analysis computer is not a big concern and can be assumed that the transfer of data is lossless even if there is no compression at all.

The transform is assumed to contain the image information completely and also reconstructed completely to have very high precision. The computers used for this are typically are better than image sensors.

1.3 Colour Image Enhancement

The process in which a colour image undergoes noise reduction and also enhanced by improving the visual quality of the output image is called colour image enhancement. In image data, noise reduces the perceptual quality and thereby limits the performance of an imaging system. High-quality colour image generation is important in many applications.

The enhancement process applied to colour images is required to

- Preserving of colour information
- Preserving of structural content (edges and fine details) and
- Removal of noise.

Colour image enhancement usually contains both the improvement of colour balance and colour contrast. Enhancement of colour images is often a difficult task because of the added complexity of the data and also the added complexity of colour perception [1, 3].

1.3.1 Basics of RGB Image

An RGB image is an array of colour pixels, in which a pixel is a triplet which corresponds to the basic colours of Red (R), Green (G) and Blue (B) at a certain spatial domain. It can be viewed as a stack of three gray scale images that can produce a colour image on a screen when fed into a monitor which has red, green, blue colour inputs. Light is electromagnetic energy that can be defined at a point, through its wavelength distribution, in the image plane. While there is electromagnetic radiation that is visible to the naked eye the human eye mostly cannot see all the wavelengths. Between 380 to 780 nm bandwidth is the visible portion of the light spectrum. The amalgamation of lights of different wavelengths is what is known as the visual sensation called "colour". Colour can be called a stimulus that is specified by visible radiant energy of certain intensity and spectral composition. Assigning names arbitrarily to all the different stimulus e.g. white, grey, black, red, green, and blue we make it easier to study the properties of the objects that display these light. The RGB model is based on a Cartesian coordinate system. The RGB colour space is used by computers, graphics cards, monitors and LCDs. It consists of three components red, green and blue, also called the base colours shown in figure 9

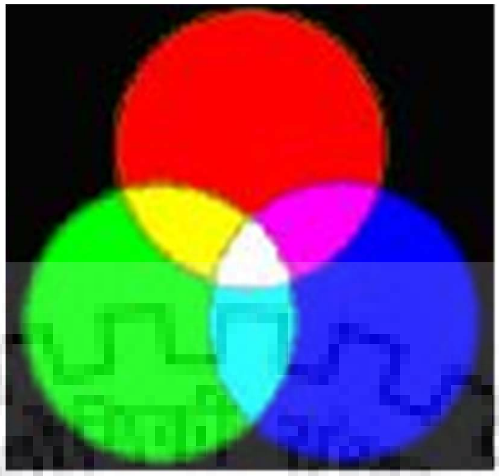


Figure 9: Three components of RGB colour image.

A colour can be obtained by mixing the three base colours. If red is mixed with green, it produces yellow. If red is mixed with blue, it produces Magenta etc. It depends on how much is taken from each base colour based on that it can create all the colours that a computer can display.

When a coloured image is viewed with a monochromatic camera which is equipped a RGB filter it produces a monochromatic image which has its intensity proportional to filter response. Repeating this process again and again with the other filters will produce three monochrome images that are the RGB components of the colour image. RGB colour image sensors usually integrate this process into a single device. The subspace of the cube shown in figure 11 is an area of interest in which RGB values are at three corners and the other three corners contain yellow, magenta, and cyan. Also Black and white are nearest and farthest to the origin. In this model, the gray scale extends from black to white through the line adjoining these points [1].

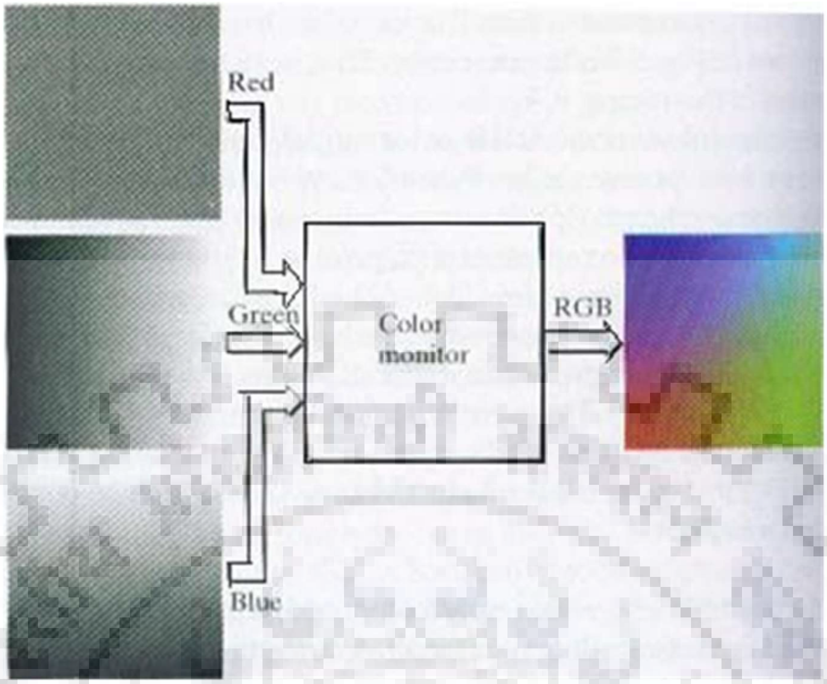


Figure 10: Generating the RGB image.

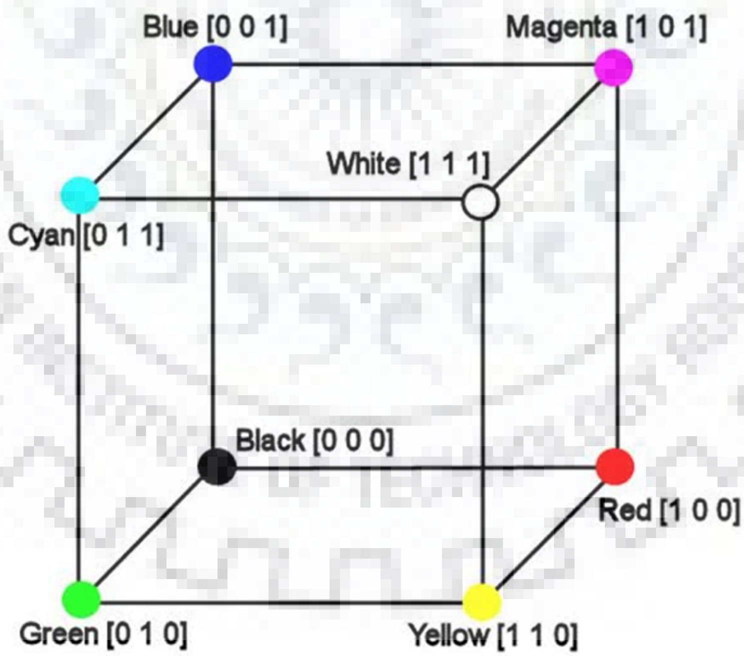


Figure 11: RGB colour cube.

Smoothing and Sharpening of Colour Images is done to enhance the RGB image once it is broken down to three components and required filters are applied to the components

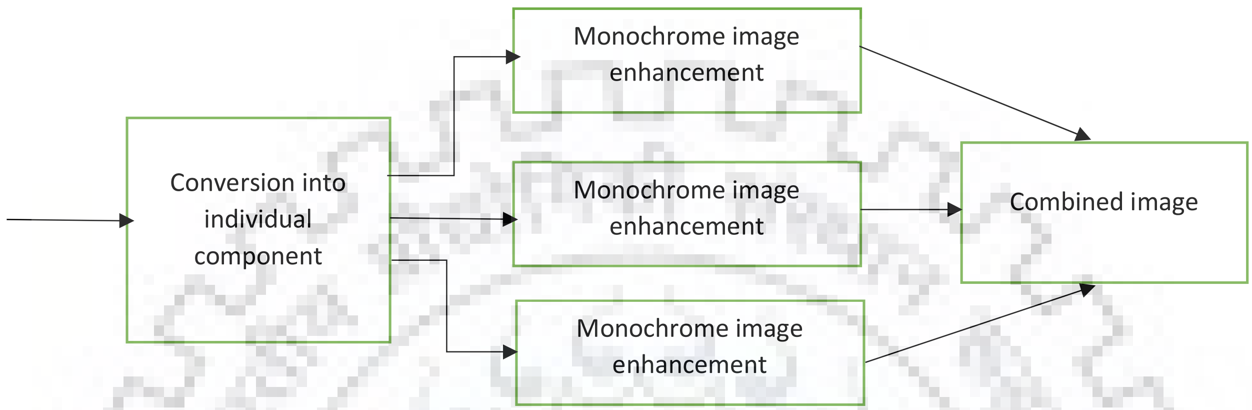


Figure 12: Enhancement of R, G, and B components of an RGB image.

1.3.2 Tone and Colour Correction

The general distribution of the colour intensities of an image is called the tonal range of the image. Images in which most of the information is concentrated at high (light) intensities are called high key images, whereas the images in which most of the information is concentrated at low intensities are known as low key images. The colour of high key images lies in high intensity while low key images lie in low intensities and the colour of middle key images lie in between [9].

A common method of improving the quality of an image is to use histogram contrast equalization. A histogram provides a global description of an image appearance by charting the number of pixels at each tone level. Contrast equalization involves increasing the dynamic range of an image by maximizing the spread between adjacent tone levels. While equalization extracts information in regions where tone levels are tightly compressed, equalization can also cause hue shifts and over-saturation. Consequently, there is a need for a method to automatically improve the quality of digital images without causing undesired hue shifts or degrading the characteristics of high-quality images. An overall stretch factor that is used to stretch the dynamic range of all the colours and is generated based on the standard deviation of the tone levels for the overall luminance of the image. A colour weighting factor is used to individually control the amount that the tone levels in each colour are altered. The colour weighting factor is based on the difference between the standard deviation of tone levels for the overall luminance of image and the standard deviation for tone levels of each colour [10]. The contrast enhancement method analyses image characteristics, such as the mean tone level and standard deviation for various tone levels on the overall luminance of the image and the standard deviations of the tone levels for the different colours to determine the level of improvement that can be applied to the image. A minimal dynamic range stretch may be performed if the image is saturated at one of the extreme tone levels for a colour or if there is a large variation in the standard deviations for the colours and the mean tone level for the luminance is near a mid-tone level [1, 8].

1.4 Underwater Image enhancement

Underwater imaging enhancement is more complex than simply enhancement of images taken in air. Since light attenuates through mediums it undergoes through a lot of different mediums, turbidity to reach the underwater object. Underwater imaging is difficult because different environments/mediums have different illumination properties. While there can be obstructions in air they are not as significant as the obstructions faced by light passing through water. Light propagation underwater decreases for increasing distance, depth due to scattering effects and attenuation effects of light. Due to scattering the direction in which light propagates is muddled which in turn blurs the captured image. The attenuation of the light is non-uniform due to ripples and particulate suspensions. This causes muddled appearance because the scattered light back-propagates contrast. At more than 10 meters almost nothing can be seen properly because of the haze and faded colours whose wavelengths are affected. All these factors affect the image quality and if taken the image is produced with poor contrast and is blurry and hazy.

To restore the degraded image there are several methods and strategies like restoration by using multiple images [1], specific hardware or usage of polarization filters [11]. Multiple image methods might require many images in various environmental conditions. Hardware techniques are expensive not cost-efficient for unknown explorative purposes. Polarization methods require several different degrees of polarized images. While underwater images can also be processed through a complex process which needs a self-correcting neural net they require enormous computation power and is not efficient on a lower number of images.

In order to find an efficient strategy that is based on a single image the approach should be simple and also can perform relatively fast on all occasions. Only fusion based approaches that can be used in many applications and only use a single image can be considered for this. They can have uses in defogging and HDR imaging [10]. The main advantage of this approach is that we only need a single image which can be processed by several enhancing techniques easily. All the relevant info pertaining to these techniques can be got from the degraded image [12]. Commonly used enhancement techniques like white balance [13], histogram equalization and colour correction show limitations [4] individually but by using all these techniques additively gets good results. The fusion technique's efficiency mainly depends on the input choice, the weights taken and also a bunch of operators that can achieve maximum clarity on the images that they operate on. While there can be the undesirable effects that occur because of processing through many layers it can be suppressed from the initial stored version of the image. This approach takes the use of many different weight maps. The weight maps of this algorithm gauge the image and its various aspects. In order to improve the quality of the images, these weights could assign higher values to pixels. Since this is a multi-additive process it can be immune to artefacts.

2 Framework for Underwater image enhancement

As presented in Ancuti, Ancuti et al [14] the steps to initiate underwater image enhancement encompasses the derivation of input from a distorted image and are merged by a multi scale fusion algorithm

Approach to the enhancement

It starts from a single distorted underwater image.

- It is undergone through white balance to collect the colour tone and the first input of the fusion is generated which is denoted as *img1*,
- Applying noise reduction method to this *img1* we get the second input of the fusion process which is denoted by *img2*
- Obtain the weights of these two inputs which are
    1. Laplacian contrast weight W_L
    2. Local contrast weight W_{LC}
    3. Saliency weight W_S and
    4. Exposedness weight W_E
- Now the multistage fusion is applied to the image to restore the image

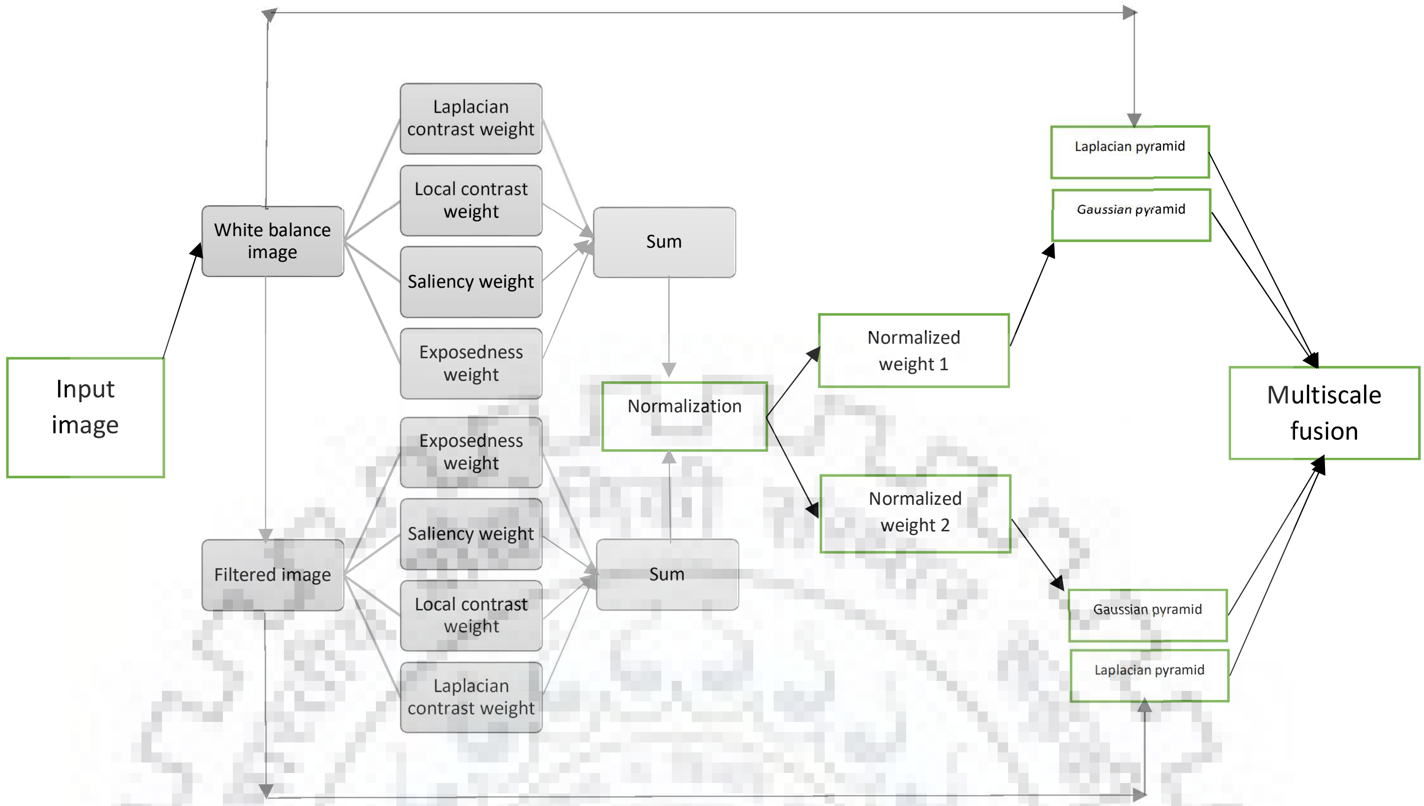


Figure 13: Multistage fusion

The weight maps ensure that the defining features of the image aren't lost because of the repetitive processing and hence preserves the image quality.

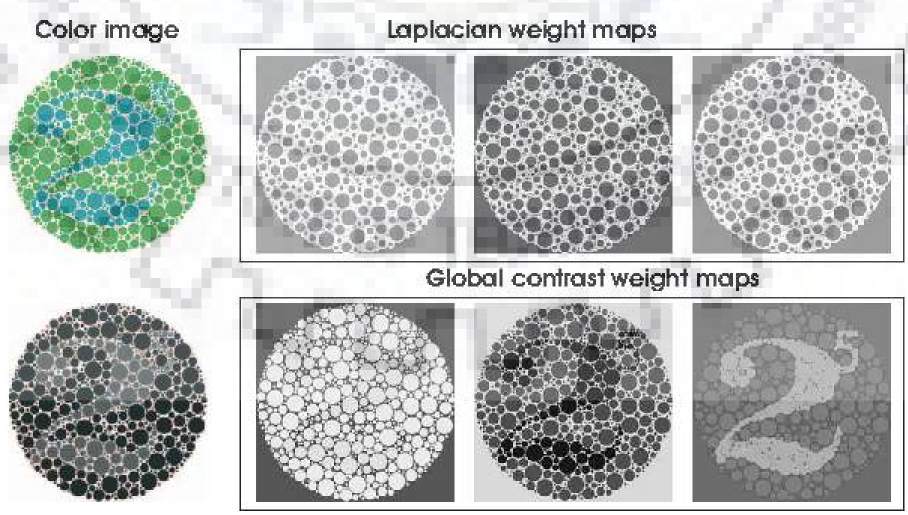


Figure 14: Laplacian and global contrast weight map

Figure 15: Saliency weight map

2.1 White Balancing

White balancing of an image simply means that removing unrealistic colour casts of the image (i.e) say an object is seen as white with our eye but when photographed the white perceived by the human eye looks different in that image. White balancing enhances the appearance of an image by removing unwanted colour casts [15], which are formed because of different illuminations and non-neutral colour sources. Underwater in depths more than 10 meters the white balance of an image suffers from attenuation of different colours. This is why most underwater images look bluish-green in colour because the other colours are attenuated before reaching them. When undergone through white balance the images are colour corrected and the accuracy of the white colour is preserved. It is done by introducing complementary colour to reduce the effect of colour cast. Since white balance describes the accuracy of the white colour generated by mixing RGB colours [13] we use it to retrieve the lost colour offset. All the image brightness values are normalized, compressed between [0, 1].

$$\mu_1 = 0.5 + \boldsymbol{\lambda}\mu_{1re} \qquad (4)$$

where μ_1 is the illumination of the scene, μ_{1ref} is the average reference and $\boldsymbol{\lambda}$ is a parameter

After this method, the difference between brightness values are reduced and the input image I_1 is obtained.

Figure 16(a): Original image

Figure 16(b): White balanced image

2.2 Global contrast enhancement

Contrast enhancement is a process that makes the image features stand out. To enhance images through contrast enhancement [4] histogram stretching is used. This amplifies the visibility in the haze but in the rest, it introduces some degradation. To avoid the degradation operating enhancers are used and the rest of degradation in the image can be avoided by applying better weight maps. The output from this method image I_2 which is the second input.

2.3 Weights

Weight maps are considered to recreate the original back because the different weight maps give us different images with different enhancements applied and the cumulative of them will give an enhanced image. For any image related to colour appearance, it is not feasible to integrate by per-pixel blending because the features like local/global contrast and exposedness are impossible to mix without getting any artefacts. In order to offset that large weight values are required to get a clear RGB image, generally to the white balance image. This is because the human eye is not taken into account for RGB which is basically a colour system for machinery. To explain the hue, saturation, contrast we use various weights like luminance weight map [16], saliency and chromatic weight map. They are used to find the information from the input image and integrated.

Chromatic weight map

In order to control the saturation gain in an image output Chromatic weight maps are used. Generally, the higher the saturation is, the more chance that the colour acquires the weight map. The distance between the saturation value and the max saturation range is calculated using the Gaussian curve

$$d = exp(-\frac{-(S-Smax)^2}{2\sigma^2}) \quad (5)$$

where S is saturation value and $Smax$ is the maximum saturation range and σ is the standard deviation. With the standard deviation σ =0.3, weights which are closer to zero gets assigned to pixels which have smaller saturation whereas the pixels with higher saturations have their weights almost equal to one.

Figure 17: Chromatic map

Luminance weight map

The luminance gain in an output image is the essential thing for this map. This is used in order to explain the standard deviation between different RGB colours and the luminance of each input pixel. From the RGB HSV space, the input images are regenerated for the luminance component V. This is used to preserve the balancing of brightness

Figure 18: Luminance map

2.3.1 Laplacian contrast weight

It deals with global contrast. Laplacian contrast gives us the primary regions which are highlighted in most cases this is the region of interest. It applies a Laplacian filter to each input channel and computes the final absolute value, it attributes higher values to edges and texture. This weight alone is not enough for underwater images because it cannot differentiate between a ramp and a flat region.

2.3.2 Local Contrast weight

The relation between a pixel and its neighbourhood average can be described as its local contrast weight. It is measured by computing the SD (i.e. standard deviation) among the pixel luminance level and the local average of the pixel's neighbourhood.

$$W_{LC}(\text{x, y}) = I^k - I^k_{whc} \tag{6}$$

where I^k represents the luminance channel of the input and I_{whc}^k denotes the low-passed version of it [4]. By introducing a small 5×5($\frac{1}{16}$[1, 4, 6, 4, 1]) separable binomial kernel which has ω_{hc}=$\frac{\pi}{2.75}$ where ω_{hc} is the value of cut off frequency. A small kernel is used because then it can be approximated as a binomial kernel instead of its Gaussian counterpart. This is done to strengthen the local contrast because local contrast favours the transitions in shadowed, highlighted parts of the second input

2.3.3 Saliency weight map

Saliency measures a property with respect to its neighbourhood regions [17]. Its main aim is to portray important information and recognize the areas of interest.

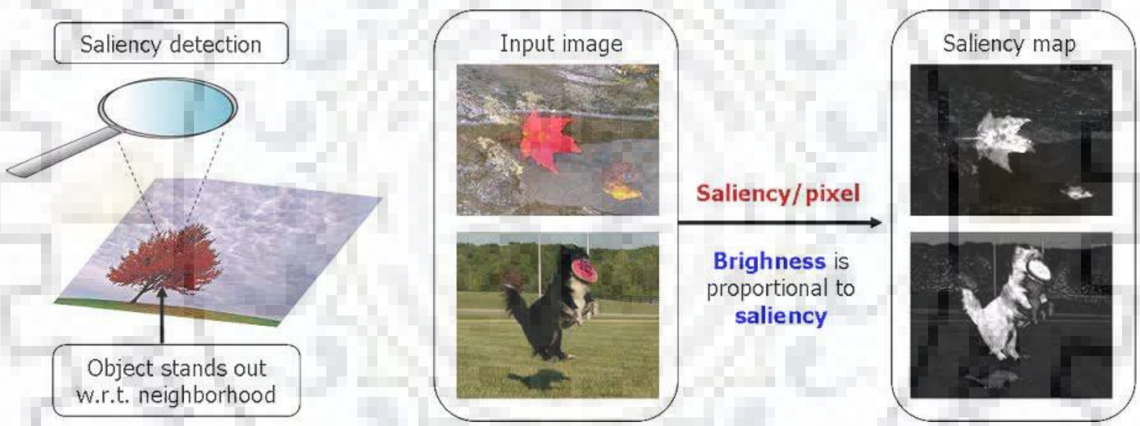


Figure 19: Saliency map

This is why a saliency map renders the main information of an image to some critical areas. It shows the difference between an area and its neighbouring region. If an area has more distinction then it will be easier to understand and can be focused on. In contrast with global contrast, saliency can make the edge of a map highlighted. In order to get our image's distinction enhanced we increase the equivalent weight value. Because saliency map favour highlighted areas, an exposedness map is introduced to protect mid-tones that might have been changed.

2.3.4 Exposedness weight

In order to preserve the appearance of a constant local contrast that is neither highlighted nor dulled an estimator is used. Exposedness weight provides the information for this estimator. Exposedness weight to put simply is the measure of how well a pixel is exposed. When pixels have their normalized values nearer to 0.5 they exhibit high exposed appearance. This weight map is a Gaussian-modelled distance [18] to the average normalized range value of (0.5):

$$W_E(x, y) = \exp(-\frac{(I^k(x,y)-0.5)^2}{2\sigma^2}) \quad (7)$$

where $I^k(x, y)$ is the pixel value at a location (x, y) of the input image I^k.The SD (i.e standard deviation) is set at σ=0.25. It is the reverse of the previous one (i. e) it assigns high values to the tones that have a distance closer to zero whereas the pixels which have larger distance values will be associated with overexposed and underexposed regions. This in effect acts like a counteract to the saliency map. Therefore the resulting fused image is well preserved

2.3.5 Naive fusion process

With all the normalized weight maps, the image reconstruction R(x, y) can be obtained by fusing the inputs with weight values at all the pixel locations (x, y) (i.e.)

$$R(x, y) = \sum_{k=1}^{K} W_K(x, y) I_K(x, y) \quad (8)$$

where I_K is the input that is weighted by normalized weight maps. Practically naive fusion is not desired because it gives halos

2.4 Multiscale Fusion

The enhanced image R(x, y) is obtained by fusing the predefined inputs with the weight measures at all pixel locations (x, y):

$$R(x, y) = \sum_{k=1}^{K} \bar{W}_K(x, y) I_K(x, y) \tag{9}$$

where I^k is the input (and k is the input index) that is weighted by the normalized weight maps [19]. $\bar{W}$ is the normalized weights that are found out by normalizing over k weight maps W under the condition that each pixel's value is to be constrained by unity. If the inputs and weights are fused directly we might get undesirable halos and so Gaussian pyramid decomposition for weight maps, Laplacian pyramid decomposition for inputs is introduced [20].

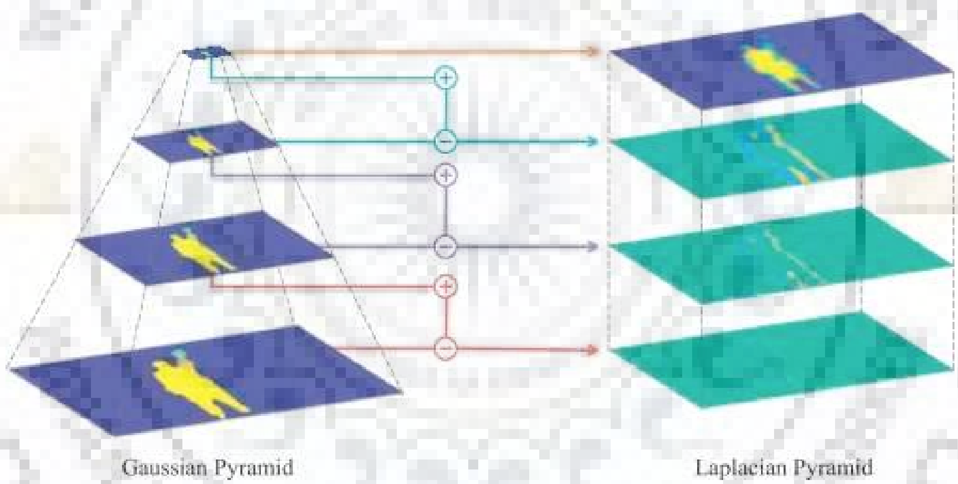


Figure 20: Laplacian and Gaussian Pyramid

Since Laplacian, Gaussian pyramids have the identical number of levels, mixing is done independently at each level which in turn gives the fused pyramid:

$$R^l(x, y) = \sum_{k=1}^{K} G^l\{\bar{W}^k(x, y)\} L^l\{I^l(x, y) \tag{10}$$

Where I is the number of pyramid levels which is 5 in this case, I^l is the Laplacian version of the image I and $G^l(\overline{W})$ is the normalized weight map in Gaussian form. This is done successively in a bottom-up manner. The restored output is calculated by adding all the fusions of the inputs. This method yields a good result because the potential artefacts due to sharp transitions are minimized at every level because there is a fusion process at every level.

3 Experimental results

Input and Output image sets

Figure 21(a): Original input image 1

Figure 21(b): Output image

Figure 22(a): Original input image 2

Figure 22(b): Output enhanced image

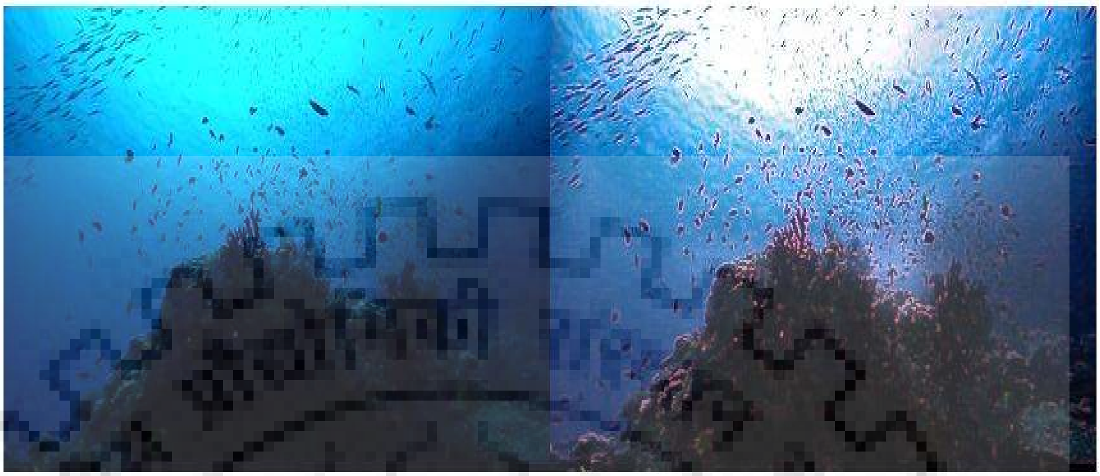


Figure 23: Output with a non-uniformly luminous input

By observing the output images in Figures 21, 22 it can be observed that the output image shows a good perceptual quality, discernible colour differences between different parts of the image a significant enhancement of global contrast. The limitations of this method can be seen in figure 23 which is a deep underwater image with non-uniform luminosity. It can be seen that output image is unclear with blurring and a presence of blueish tinge in the colour. These limitations are only for deep underwater images with insufficient illumination.

4 CONCLUSION AND FUTURE WORK

The output obtained is observed to yield results that did have enhanced global contrast. It can also be seen that the output images have more enhanced edges and the finer details are also more pronounced. It can be seen that this technique while dealing with images that are deep underwater and which have low luminosity, needs some corrections and appear with a high blueish tinge.

I will try to make a suitable approach so that in the future this method can enhance deep, non-luminous underwater images as well

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