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AN INTEGRATED TECHNIQUE FOR UNDERWATER IMAGE ENHANCEMENT: COLOUR CORRECTION AND DEHAZING

SUKH SEHAJ SINGH, ROHIT SACHDEVA[1], AND RAJEEV SHARMA

ABSTRACT. In this paper, an integrated enhancement technique is designed for underwater images colour correction and dehazing. In the first step, pre-processing of the image is done and its RGB planes are extracted. Second step comprises the calculation of the exposure values for the Red, Green and Blue colour planes in order to determine the superior, intermediate, and the inferior planes. For the third step, inferior and intermediate planes are enhanced based on the exposure value of the superior plane. Fourth and the last step apply the power-law expression to the inferior channel. The gamma factor for the power-law expression is determined using cuckoo search algorithm. In addition, the cuckoo search algorithm gives multiple optimal gamma values in place of one. Thus, we got multiple optimal solutions in the output. The experimental results are performed on the standard dataset images. We have done the qualitative and quantitative analysis. The analysis shows that the proposed technique produces desired results for underwater image enhancement.

1. INTRODUCTION

The underwater images demand is increased in the marine system for monitoring the underwater pipes, cables, and aquaculture [1]. The underwater image processing is very difficult as compared to the normal images due to absorption and scattering effects [2]. These effects generated when light travels

[1]*corresponding author*

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through the water medium. The absorption effect degrades the colour wavelength and reduces the visible range [3]. The red colour has the longest wavelength and absorbed previously as compared to green and blue colour [4]. As a result, most of the captured underwater images are available with dominance of green and blue colours. On the other side, due to insufficient light available in the underwater environment, artificial lights are used during image capturing [5]. The artificial light provokes a non-uniform illumination. In addition, due to the absorption and scattering effect, hazy images are produced.

To overcome these issues as well as for improving the quality of image, the enhancement fields are used in the underwater images. In the literature, histogram equalization and histogram stretching were the most popular enhancement techniques [6, 7]. The main issue of this technique is over-enhancement. Further, the number of enhancement techniques are proposed such as integrated colour model (ICM), unsupervised colour correction (UCM), recursive histogram equalization [8–10]. The ICM technique stretches the RGB channel globally for enhancement purposes. Thus, the contrast is not improved significantly [8]. Next, while considering ICM as the base model, the UCM technique was proposed for colour balancing using the Von Kries hypothesis. This technique gives a greenish image in the output when the illumination of input images is a blue-green colour [9]. The recursive histogram equalization technique calculates the exposure value as basis to further determine whether the image is under-exposed or over-exposed. Subsequently, apply the histogram stretching based recursive operations to enhance the image. The output image came out to be over-stretched due to the recursion process [10]. Moreover, metaheuristic algorithms Genetic Algorithm (GA), Particle Swarm Optimization (PSO), algorithms have been used for image enhancement [11–13]. The GA algorithm generates an under or over-enhanced image if the selection of parent nodes is not appropriate. On the other side, the PSO algorithm gives better results as compared to GA but requires long computation time.

To overcome these challenges, we have designed an integrated enhancement technique that enhances the images in a controllable manner. The proposed technique determines the superior, intermediate, and inferior plane in the RGB image based on the exposure value. Thereafter, it enhances the intermediate and inferior channels based on the superior plane. In the last, the inferior plane enhanced using the power-law expression. In the power-law expression, the gamma adequate value is determined using a cuckoo search algorithm that gives multiple appropriate values of gamma for image enhancement. Implementation results signify that the proposed technique shows efficient results for both entropy and computational time. Also, the output image exhibits improved visualization in comparison with the original image when analysed qualitatively.

Remaining paper is as following: second section reviews the work already done. Third section outlines the proposed work. Fourth section represents the experimentation. Fifth section concludes the proposed work.

2. LITERATURE SURVEY

Azmi et al. [14] worked on the deformed underwater turbid images for improving contrast and colour distribution. Technique works on enhancing the colours of the red channel with respect to green and blue channel. The criteria used for enhancement is mean of the image pixels. Algorithm's focus is to refine the colour contrast for input image. For the validation, the results are performed on the 300 sample dataset images.

Sethi et al. [13] proposed the method for strengthening colour contrast of the image. This particular technique applies multiple applications of particle swarm optimization (PSO) to achieve more preferable results. This technique focuses on widening the application scope as a single conventional technique is suitable for processing only specific type of underwater images. Besides, limitation of the technique includes larger computational time requirement which is not preferred so as to process the real-time underwater images. 200 images are taken as a sample from Hope underwater videos and pictures database.

Prasath et al. [15] developed histogram based enhancement method for underwater image accompanied by cuckoo search for obtaining the optimal results. Course of action includes the global contrast enhancement followed by local. Nature-inspired cuckoo search method provides the optimal min, medium and max values for colour image histogram. Histogram is divided based on the intensity values. Further, the region based contrast stretching is applied on the histograms using CLAHE. Transformation of image from RGB-HSV takes place for subsequent processing. Again, the contrast correction is done by stretching the V (value or intensity) within specified range. The best solutions for contrast enhancement are selected by calculating and then sorting the absolute differences between the obtained and required (optimal) values. Sample images are taken from singh- stellwagen and boulder datasets, WHOI for quantitative analysis.

Wong et al. [16] presented an advanced technique for underwater image contrast and colour enhancement with the combination of distinctive histogram equalization and grey world assumption with additional featuring. Later includes examining local minima as well with respect to global minima. Results are compared with seven standard image restoration techniques to signify improvement both qualitatively and quantitatively. Dataset includes fish, reef, and ship images for validation.

Mathias et al. [17] discussed a technique for underwater image colour restoration. The working depends on the occurrence that one of the colour plane associated with image does not render actual white therefore, dark channel necessitates priority based processing. Flow of the technique includes extraction of the brighter region i.e. with high intensity and masking of the diffraction pattern for further processing. De-blurring operation is performed followed by final restoration of the dark colour channel with respect to the brighter ones. Transmission map is obtained to estimate the amount of distortion (scattering) corresponding to image colour channels. For experimentation purposes 500 frames are extracted from Bali diving HD video.

Ancuti et al. [18] provided a method to effectively distribute the colour across various channels. Colour transfer based strategy is adopted to recover the loss of the colour observed in the underwater image. Technique keeps under consideration the source image, target image and transfer image. The minutiae from the input image are added to the homogeneous grey component to achieve more preferred colour composition. To test for efficiency, results are obtained for more than 2000 sample images taken in unfriendly conditions with varying illuminations.

Pan et al. [19] presented a method for processing of underwater images to minimize the colour distortion and scattering effect. This method performs image de-blurring as well as edge enhancement. An iterative procedure based on the Artificial CNNs is implemented to find the transmission map i.e. to estimate the proportion of illumination reaching the camera without scattering. In addition, an automatic white balancing method is used to preserve the colour consistency in the image. It changes the pixel values to make the output image render actual white. 2000 images are collected as synthetic database for training the model.

Nnolim et al. [20] discussed an approach for colour correction for haze suspected underwater images. Multiple/variable scale based filters and global contrast enhancement methods are manipulated on the input image. Based on aforementioned, de-blurring operation is performed such that it dissipates the details lower than the value obtained by Gaussian blur. In addition, the technique accomplishes work to obtain the significant exposure values hence, prevents over-exposure and under-exposure image processing. For enhancement, the resultant images are fused based on the values of mean standard deviation. For experimentation, sample images are taken from Zhang Hao underwater image dataset.

3. Proposed technique

The proposed integrated enhancement technique requires simple operations, enhances the image in a controllable manner, and gives multiple resultant images in the output.

Initially, underwater input color image is read and its RGB plane is extracted. Next, the RGB plane exposure value is determined using Eq. (3.1), (3.2), (3.3).

$$Exposure_{red} = \frac{\sum_{k=0}^{L-1} h(k)k}{L\sum_{k=0}^{L-1} h(k)} \tag{3.1}$$

$$Exposure_{green} = \frac{\sum_{k=0}^{L-1} h(k)k}{L\sum_{k=0}^{L-1} h(k)} \tag{3.2}$$

$$Exposure_{blue} = \frac{\sum_{k=0}^{L-1} h(k)k}{L\sum_{k=0}^{L-1} h(k)} \tag{3.3}$$

where h denotes the histogram bin distribution, L denotes the total number of histogram bins and k is subscripted variable.

Flow diagram for the proposed technique is depicted in Figure 1.

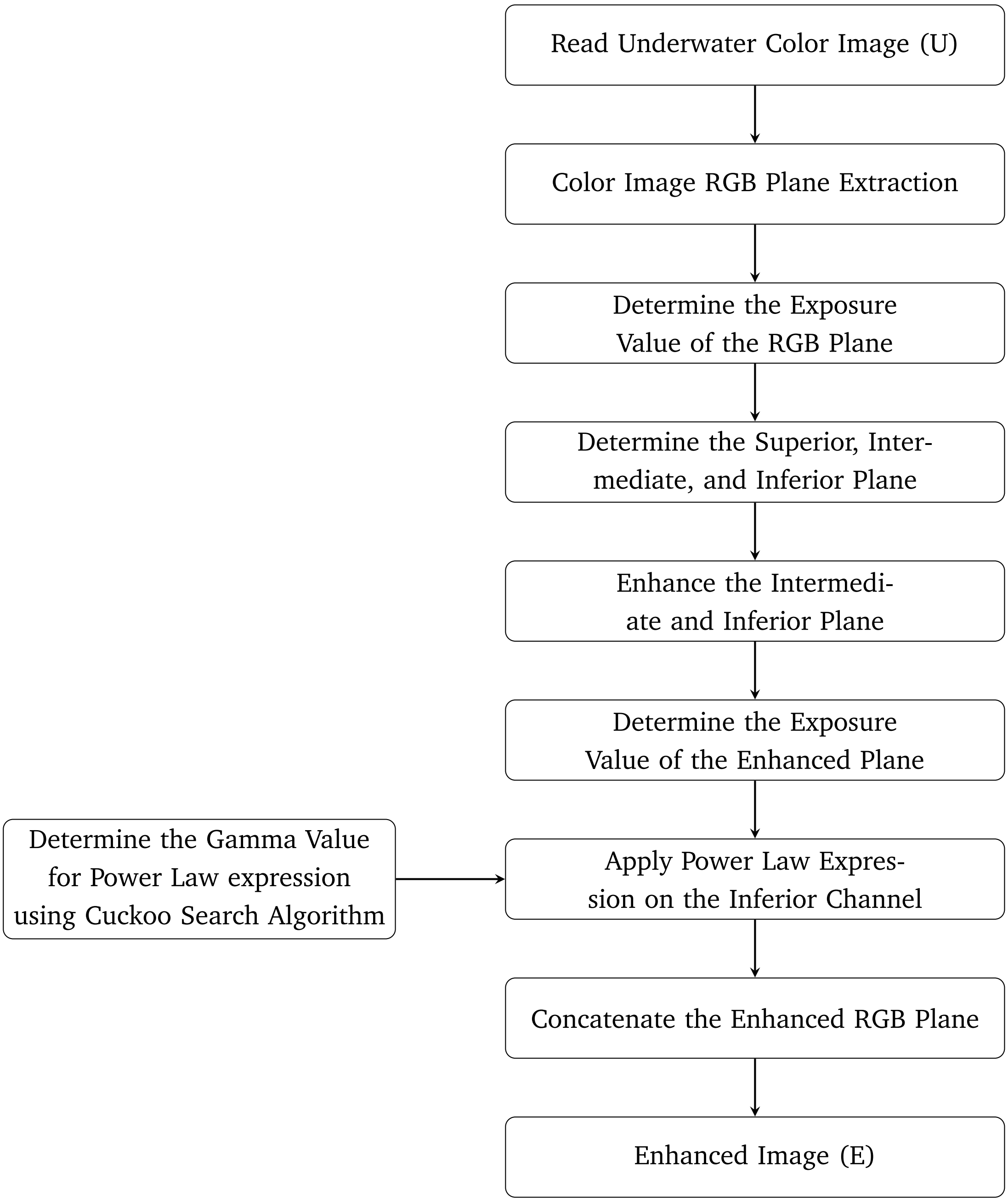

FIGURE 1. Proposed technique for underwater image enhancement

The exposure value tells the plane is under contrast, over contrast, or normal. Next, the exposure values of the RGB planes are compared and determined the superior, intermediate, and inferior plane using Eq. (3.4), (3.4), (3.4).

$$Superior = \max[Exposure_{red}\ Exposure_{green}\ Exposure_{blue}] \tag{3.4}$$

$$Inferior = \min[Exposure_{red}\ Exposure_{green}\ Exposure_{blue}] \tag{3.5}$$

$$Intermediate = \text{inter}[Exposure_{red}\ Exposure_{green}\ Exposure_{blue}] \tag{3.6}$$

The intermediate and inferior planes enhanced based on the superior plane using Eq. (3.7), (3.8).

$$P_{inferior} = P_{inferior} + (superior X P_{superior}) \tag{3.7}$$

$$P_{intermediate} = P_{intermediate} + (superior X P_{superior}) \tag{3.8}$$

The exposure value is calculated and the inferior plane is determined. On the inferior plane, the power-law expression is applied using Eq. (3.9).

$$P_{inferior} = 255\left(\frac{P_{inferior}}{255}\right)^{\gamma} \tag{3.9}$$

In the power-law expression, gamma values play an important role. The gamma value less than 1 increases the brightness and greater than 1 decreases the brightness. Thus, appropriate gamma value is calculated using the cuckoo search algorithm. The cuckoo search algorithm is inspired and based on the reproduction strategy of the cuckoos. The cuckoo birds correlate their eggs to the nest in the possible condition [15]. Only if they found the foreign egg in their nest, either they leave the nest or takes their egg to another nest. The same principle we have applied to search the optimal gamma value. The cuckoo search generates the multiple gamma values and based on the objective function to determine the number of gamma values suitable for image enhancement as shown in Figure 2. We have used the entropy as an objective function. In the cuckoo search algorithm, initially, gamma value is generated randomly within the range 0 to 1. Thereafter, apply the power law expression on the inferior channel based on the gamma value and determine the entropy. The gamma factors giving better results are sorted and stored respectively. The whole process is iterated for fixed number of times.

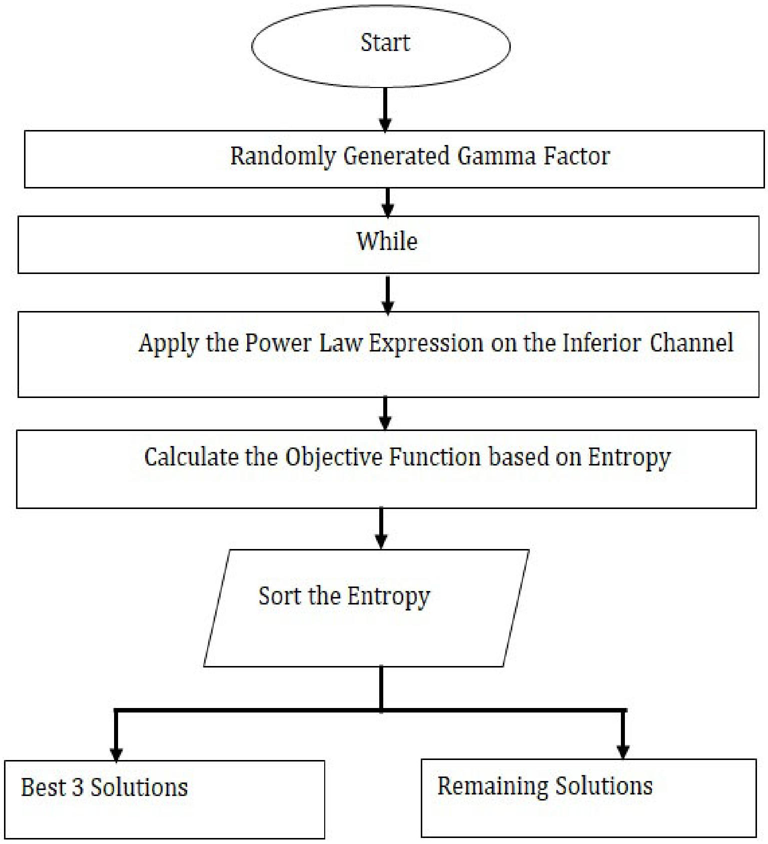

FIGURE 2. Determination of Optimal Gamma Factor based on Cuckoo Search Algorithm

4. EXPERIMENTAL RESULTS

For the validation of proposed technique on standard dataset images, experimental results are performed. The standard dataset images are downloaded from https://li-chongyi.github.io/proj-benchmark.html. The proposed technique is simulated in MATLAB 2013a. We have done the qualitative and quantitative analysis for the technique proposed, as explained below:

4.1. **Qualitative analysis.**

In the qualitative analysis, the visualization of enhanced images is compared with the original images. Table 1 shows the qualitative analysis for original and corresponding enhanced images.

TABLE 1. Qualitative Analysis for Original and Enhanced Images (Image 1-5)

Original Image	Enhanced Image
	
	
	
	
	

4.2. **Quantitative Analysis.** In the quantitative analysis, parameters such as entropy and computation time are measured as explained below.

4.2.1. *Entropy.* The richness of the image is determined using the entropy parameter in information theory. An image with higher value of entropy contains higher information [17]. This is calculated using equation (4.1).

$$Entropy = -\sum_{k=0}^{L-1} p\left(k\right) log_2 p\left(k\right) \tag{4.1}$$

where p represents the probability of the histogram bin.

TABLE 2. Entropy values corresponding to Enhanced Images

Original Image	Enhanced Image Entropy (Gamma-1)	Enhanced Image Entropy (Gamma-2)	Enhanced Image Entropy (Gamma-3)	Average Entropy
Image1	6.82	6.72	6.23	6.59
Image2	6.40	6.52	6.66	6.52
Image3	6.20	6.23	6.45	6.29
Image4	5.52	5.78	5.66	5.65
Image5	7.10	7.13	7.07	7.10

4.2.2. *Computation Time.* The total time required by an algorithm to produce the enhanced results is measured using this parameter.

4.3. **Comparative analysis with the existing techniques.** In this section, proposed technique is compared with the most popular existing techniques in terms of entropy (Table 4). Experimental results show that the proposed technique gives better entropy as compared to existing for the same dataset images.

5. CONCLUSION AND FUTURE WORK

In this paper, we have designed the integrated underwater image enhancement technique. The proposed technique enhances the RGB planes in a controllable manner. To achieve this goal, the exposure value of the channel is

TABLE 3. Computation rime required prior to the resultant enhanced images are obtained

Original Image	Enhanced Image Computation Time (seconds)	Enhanced Image Computation Time (seconds)	Enhanced Image Computation Time (seconds)
Image1	1.44	1.44	1.44
Image2	1.55	1.55	1.55
Image3	1.39	1.39	1.39
Image4	1.22	1.22	1.22
Image5	1.57	1.57	1.57

TABLE 4. Computation time required prior to the resultant enhanced images are obtained

Image	**Method**	**Entropy**
Artificial Coral Leef	Original	5.421
	ICM [8]	6.185
	UCM [9]	6.459
	Proposed Technique	6.484
Coral Stone	Original	6.025
	ICM [8]	7.145
	UCM [9]	7.157
	Proposed Technique	7.201
Fishes	Original	7.408
	ICM [8]	7.672
	UCM [9]	7.671
	Proposed Technique	7.701

calculated for determination of superior, intermediate, and inferior channels. Thereafter, the intermediate and inferior channels are enhanced based on the superior channel. In the last, the inferior quality channel enhanced using the power-law expression. The power-law expression gamma factor is found using a cuckoo search algorithm. The cuckoo search algorithm gives multiple optimal gamma values in the output. The experimental outcomes based on the quantitative parameters such as entropy and computation time show that the proposed technique gives appropriate results for enhancement. Proposed technique is compared with the most popular existing techniques on the basis of entropy and the improved results for enhancement are obtained.

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DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING
PUNJABI UNIVERSITY
PATIALA, PUNJAB, INDIA, 147002
Email address: sukhsehajsingh@yahoo.com

DEPARTMENT OF COMPUTER SCIENCE
MULTANI MAL MODI COLLEGE
PATIALA, PUNJAB, INDIA, 147001
Email address: rsachu.147@gmail.com

DEPARTMENT OF CHEMISTRY
MULTANI MAL MODI COLLEGE
PATIALA, PUNJAB, INDIA, 147001
Email address: rajeev.sharma00@yahoo.com