Underwater Image Enhancement Model based on Termite Alate Optimization Algorithm

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***Abstract*—** Underwater images gain popularity in different applications, namely, marine engineering and exploring ocean resources. However, these images face hazing and color degradation effects due to improper light and absorption of color. To overcome these limitations, several underwater image enhancement models have been proposed in the literature. The existing models enhance the images at the same level without considering the image characteristics. However, in the real world, characteristics of the image vary for different images. Therefore, in this paper, we have designed an underwater image enhancement model based on the swarm intelligence termite alate optimization (TAO) algorithm. This algorithm determines the optimal parameters of the enhancement methods based on the image characteristics. The TAO algorithm provides better exploration, exploitation rate, and required minimum parameters over other optimization algorithms. Thus, it is chosen for the proposed model. The proposed model is categorized into two phases. In the first phase, the underwater image is read. Further, its RGB channels are extracted. The RGB channels are classified into three planes, namely, superior, inferior, and intermediate, based on the mean value of the image pixels. After that, the power law method is applied to the superior plane because this plane is used as a reference plane to enhance the other planes. In the second phase, the singular value decomposition (SVD) method is applied to inferior and intermediate planes based on superior plane characteristics. The optimal gamma and scaling values of the power law and SVD method are determined using the TAO algorithm. Besides that, exposure value and entropy are taken as the objective functions in these methods. Further, underwater standard dataset images are taken into consideration to validate the performance of the proposed underwater image enhancement model. Next, visual quality is checked using subjective analysis, and image characteristics are analyzed based on objective analysis. Finally, a comparative analysis is performed based on various parameters. The results show that the proposed model achieves better enhancement in terms of visual quality and entropy parameters.

Keywords: Enhancement; Gamma Value; Power Law; Scaling Value; Singular Value Decomposition; Termite Alate Optimization; Underwater Image.

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I. INTRODUCTION

The ocean is the largest part of the earth (approximately 70%), and it contains various natural resources.

Therefore, in the present time, it is explored to search these resources. However, exploring the ocean is a challenging task due to high turbidity, color distortion, and uneven illumination. To overcome these challenges, enhanced images are required [1]. To achieve this goal, researchers in the literature, have designed underwater image enhancement models. In the literature, numerous underwater image enhancement models have been proposed. The most popular models are histogram equalization [2], contrast stretching [3], contrast limited adaptive histogram equalization [4], and gamma correction using the power law method [5]. These models fall under the traditional underwater image enhancement model, which enhances the various images at the same level. However, in the real world, the characteristics of an image vary from image to image. To overcome this problem, swarm intelligence algorithms are taken into consideration by researchers for underwater image enhancement models [6–10]. Swarm intelligence algorithms are basically optimization algorithms that determine the optimal solution to any problem according to the requirements. In the underwater image enhancement model, these algorithms determine the optimal parameter values of the traditional models.

In this paper, we have taken Azmi et al.'s [11] work into consideration. In their work, initially, they differentiated the planes of the underwater image based on the mean value and characterized them as superior, inferior, and intermediate planes. After that, based on the superior plane, determine the gain factor to enhance the inferior and inferior planes. Finally, they have hybridized the power law method with the PSO algorithm to determine the optimal gamma value. The challenges of their method are that if the quality of the superior plane is not up to mark, then the appropriate gain factor is not determined. Besides that, the convergence rate of the PSO algorithm is lower for finding the optimal solution. These challenges are taken into consideration, and a new underwater model is designed that initially enhances the superior plane up to level. Therefore, an appropriate gain factor is determined. After that, we have chosen the recent swarm intelligence algorithm known as termite alate optimization, which provides a faster convergence rate than the other optimization algorithms, to find the optimal solution. The main contribution of this paper is summarized as follows.

- The image characteristics vary from image to image. Thus, the proposed underwater image enhancement model enhances the image based on its characteristics. The advantage of the proposed model is that, according to the required enhancement, it enhances the image up to that level. Thus, the proposed model is an adaptive model over the traditional models.
- The determination of the optimal parameter of the enhancement model enhances the image at an appropriate level. Therefore, in the proposed model, the optimal parameter values of the enhancement model are determined using the swarm intelligence termite alate optimization algorithm. This optimization algorithm provides a better exploration and exploitation rate [ref]. Thus, it quickly finds the optimal parameter value over the other optimizations. Besides that, this optimization algorithm requires minimum parameters to search the solution space for optimal parameter values.
- In the existing models, the image is classified into three planes, superior, inferior, and intermediate [11]. After that, based on the superior plane, the gain factors are determined for the intermediate and inferior planes, and based on them, these planes are enhanced [11]. However, in the real scenario, if the quality of the superior plane is not appropriate, then the appropriate gain factors are not determined. Therefore, in the proposed model, initially, the quality of the superior plane is enhanced, so appropriate gain factors are determined, and after that, other planes are enhanced based on it.

The remaining paper is organized into five sections. Section 2 explains the power law, SVD, and termite alate optimization. Section 3 illustrates that the proposed model is designed for underwater image enhancement. Section 4 shows the simulation results of the proposed underwater enhancement model.

Finally, conclusion and future scope are defined in Section 5.

II. RELATED WORK

In the proposed method, power law and SVD methods are taken into consideration to enhance the underwater image in a controllable manner. Hence, we have used the termite alate optimization algorithm to determine the optimal parameter of these methods. A brief overview of these methods and the TAO algorithm is given in this section.

2.1 Power Law Method

In the underwater image enhancement method, to control the brightness of the image, gamma correction is done [ref]. The brightness of the image is increased when the gamma value is less than 1, whereas it decreases when the gamma value is higher than 1. In the literature, numerous equations are proposed for gamma correction, and these equations are named the power law method by researchers [12–15]. We have used the following equation to correct the brightness of the underwater image:

$$I_B = P \times \left(\frac{I}{P}\right)^{\gamma} \quad (1)$$

In Eq. (1), P, γ, I_B, I denotes the peak value of the image (255 for the grey-scale images), gamma value, image brightness, and original image. In the Eq. (1), the determination of optimal gamma value enhances the brightness of the image in a controllable manner. Therefore, optimal gamma value is chosen using TAO algorithm.

2.2 Singular Value Decomposition (SVD) Method

The singular value decomposition (SVD) method is based on the linear algebra technique and is used in a number of image processing applications for compression, noise reduction, watermarking, and enhancement purposes [16–20]. We have used the watermarking application procedure to enhance the planes of the underwater image based on the reference plane. The basic equation of the SVD method for watermarking is given below [21].

$$I_o = I_o + sI_i \quad (2)$$

In Eq. (2), I_o, s, I_i denotes the output watermark image, scaling value, and input image, respectively. The scaling value is varied between 0-1. In the proposed method, optimal scaling value is determined using the TAO algorithm to enhance the inferior and intermediate planes based on the superior plane.

2.3 Termite Alate Optimization Algorithm

The termite alate optimization (TAO) algorithm was proposed by Arindam Majumder in 2021 [22]. It is based on the phototactic activities of the termites. In this activity, they follow two basic rules, as given below.

- Each alate in the group is attracted to the brightest alates, whereas it is repelled by the alate that is positioned in the darkest place.
- The alates, which are in the darkest area, either lose their wings or are preyed upon by birds. Therefore, in the optimization algorithm, these alates are substituted by new alates to search for the brightest alate in the group.

Due to these rules, termite alate optimization provides a better exploration and exploitation rate to find the optimal solution. The first rule explores new solutions in the solution space, whereas the second rule helps to avoid getting stuck in local optima problems in the solution space. Further, the brightest alate is differentiated from other alates based on its fitness function. The steps of the TAO algorithm are given below.

- Initialize the TAO algorithm parameters, namely, total number of alates, iterations, percentage of removing alates while searching the solution space, and adaption factor.
- In the second step, according to the given problem, the total number of alates is randomly initialized at the lower and upper limits.
- In the third step, the fitness evaluation of each alate is done based on the objective function.
- In the fourth step, based on the fitness evaluation, the best and worst alates from the total number of alates are determined.
- In the fifth step, a random alate is chosen from the total number of alates, and a new alate is generated based on the best and worst alates using Eq. (1).

$$a_{new} = a_i + r_1(a_b - a_i) - r_2(a_b - a_i) \quad (1)$$

In Eq. (1), $r_1 r_2 \in \{0 - 1\}$ are two uniform random number. On the other hand, a_i, a_b, a_w denotes the chosen, best, and worst alates.

- In the sixth step, the fitness evaluation of the new alate is done based on the objective function. According to the fitness evaluation, a fraction of the worst alates are replaced with the new alates.
- In the seventh step, the best alate is determined from the total number of alates and saved as an optimum solution.
- The fifth to seventh steps are iterated for a fixed number of iterations to explore the solution space and get the optimal solution in the output.

III. PROPOSED UNDERWATER ENHANCEENT MODEL

The proposed model enhances the underwater images in a controllable manner while considering the characteristics of the images. To achieve this goal, a swarm intelligence algorithm, namely, the termite alate optimization algorithm, is taken into consideration. The flowchart of the proposed model is shown in Figure 1. A detailed description of the proposed model is given below.

Initially, an underwater image is read. In the proposed model, the underwater enhancement benchmark dataset is taken into consideration [23]. This dataset is publicly available and contains a huge number of real-time images. After that, red-green-blue (RGB) channels are extracted and classified into superior (S), inferior (IF), and intermediate (IN) planes based on the mean value. The mean values of the plane are determined using Eq. (3).

$$M_{RGB} = \sum_{i=1}^{X} \sum_{j=1}^{Y} UI_{RGB} \quad (3)$$

In Eq. (3), M denotes the mean value, RGB denotes the red, green, blue channel, UI denotes the underwater image, XY denotes the resolution of the image in terms of row and column.

The plane that represents the highest mean is denoted as the superior plane, and the lowest mean is denoted as the inferior plane, respectively. The plane that denotes the mean value between the highest and lowest mean is denoted as the "intermediate plane. Next, the superior plane is enhanced using the power law method because this plane is used as a reference plane to enhance the remaining inferior and intermediate planes. The equation of the power law method taken into consideration is shown in Eq. (4).

$$S_E = 255 \times \left(\frac{S}{255}\right)^{\gamma} \quad (4)$$

In Eq. (4), S_E, S, γ denotes the superior enhanced plane, superior plane, and gamma value, respectively.

After enhancing the superior plane, the SVD method is applied to the inferior and intermediate planes for enhancement purposes. The equation of the SVD method taken into consideration is shown in Eqs. (5-6).

$$IF_E = IF + sS_E \quad (5)$$
$$IN_E = IN + sS_E \quad (6)$$

In Eqs. (5-6), IF_E, IN_E denotes the inferior and intermediate enhanced plane. On the other hand, s denotes the scaling value of the SVD method.

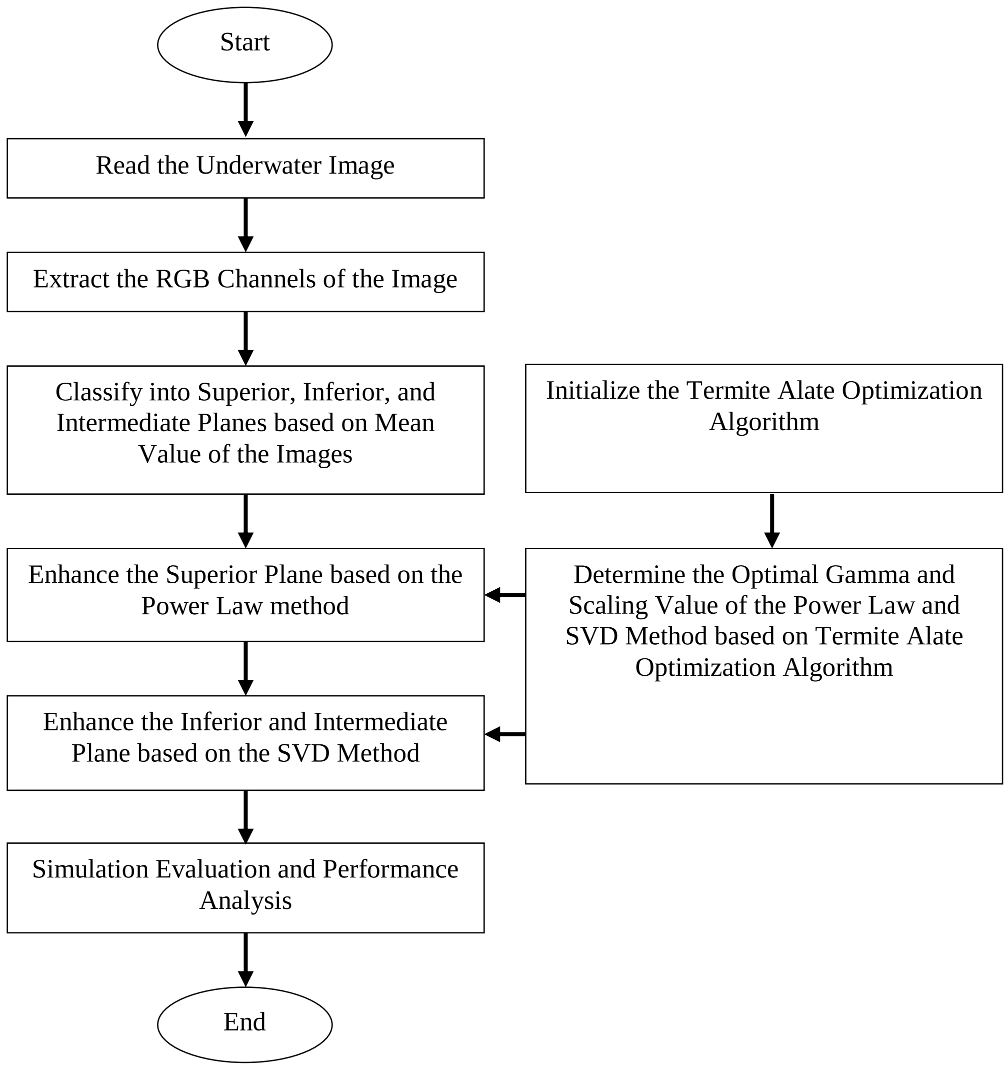


Figure 1 Flowchart of the Proposed Underwater Image Enhancement Model

The optimal gamma value and scaling value of the power law and SVD methods are determined using the termite alate optimization algorithm. To determine optimal values, the TAO algorithm is initialized. In the initialization, various parameters, namely, total alates (N), iterations (t_{max}), objective function (Of), and β, P_e are defined. We have taken exposure value as the objective function in the power law method, whereas entropy is the objective function in the proposed model. Next, according to the power law or SVD method, the lower and upper limits of the gamma/scaling value are defined. The TAO algorithm, based on these values, initialized the total alates $(N)$and fitness evaluations of each alate. Further, it determines the best and worst alates, which give the superior and inferior solutions. Next, new alates are generated based on the best and worst alates. The alates that are giving inferior solutions are replaced with new alates based on the fitness function and probability of eliminating them. In the last, which alate is given the superior performance is chosen as the best solution for power law and the SVD method. According to the best solution, the underwater image is enhanced. In the last section, the simulation evaluation and performance analysis of the proposed model are done and compared with the existing models.

IV. SIMULATION EVALUATION

The simulation evaluation is shown for the proposed model to evaluate its performance over the existing underwater enhancement models. Table 1 shows the simulation setup configuration defined for searching the optimal parameters of the proposed model using termite alate optimization. This table defines the important parameters, namely, population, iteration, objective function, and underwater image resolution.

Table 1 Simulation Setup Configuration for the Termite Alate Optimization Algorithm

Parameters	**Value**
Underwater Image Resolution	$[256 \times 256]$
Population	50
Iterations	30
Objective Function	Exposure Value and Entropy

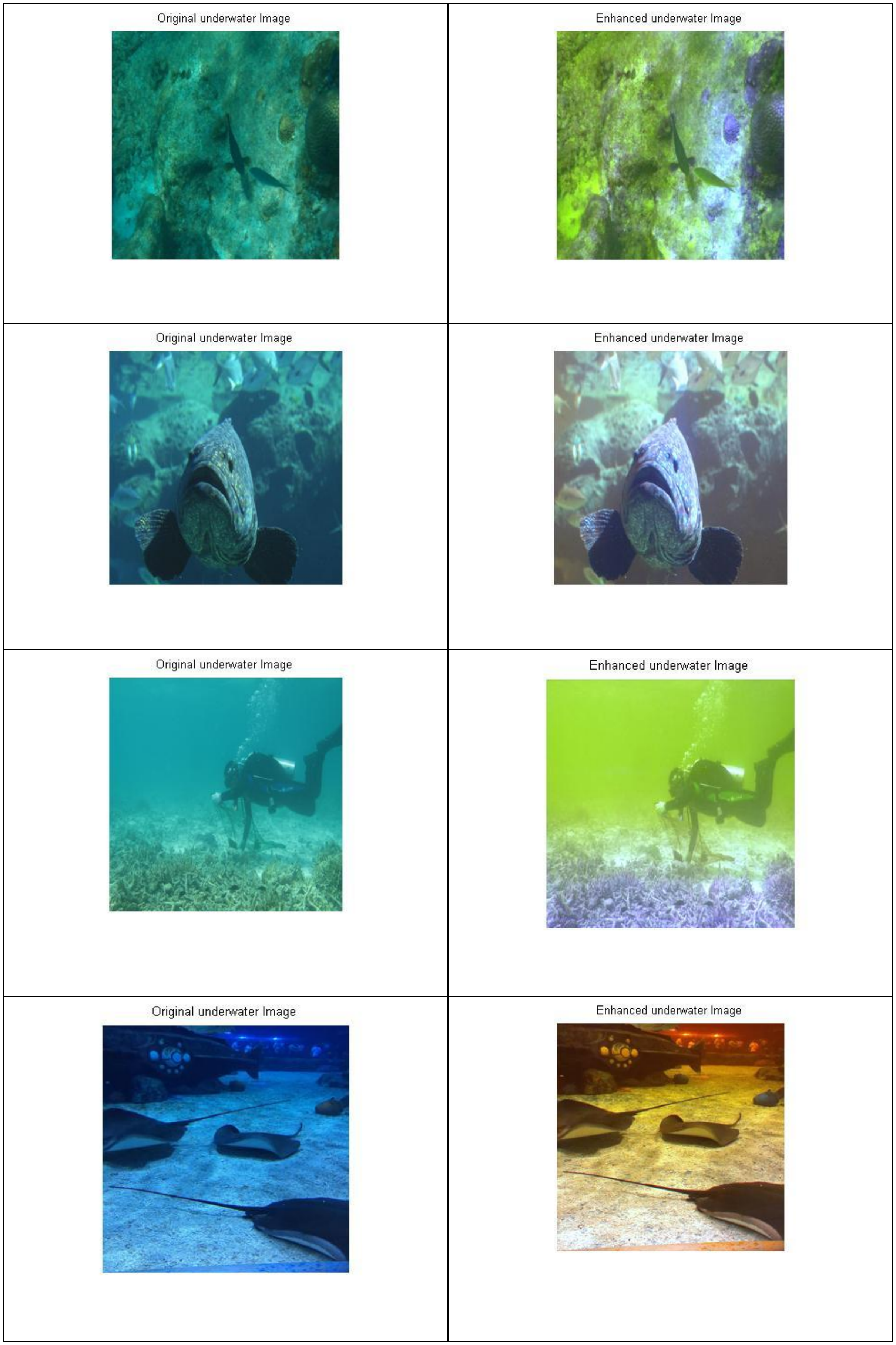
4.1 Performance Evaluation of the Proposed Underwater Enhancement Model

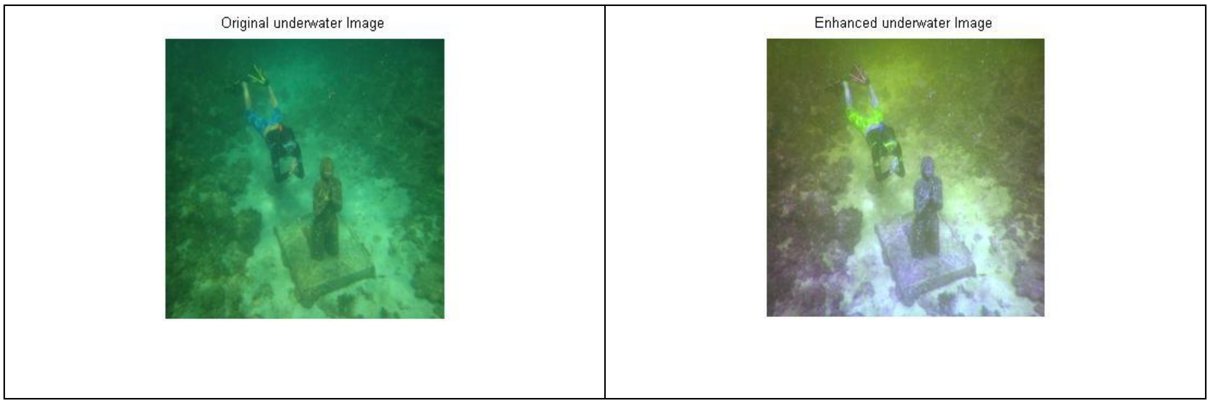
The performance evaluation of the proposed underwater enhancement model is done using subjective and objective analysis.

- **Subjective Analysis:** In this analysis, based on the visual quality, the input underwater image is compared with the output underwater image, which was generated after enhancement. Next, Table 2 shows the subjective analysis of the proposed model, which is designed for underwater image enhancement.

Table 2 Subjective Analysis of the Proposed Model

Input Underwater Image	Output Underwater Image


Original underwater Image
Enhanced underwater Image
Original underwater Image
Enhanced underwater Image
Original underwater Image
Enhanced underwater Image
Original underwater Image
Enhanced underwater Image



- **Objective Analysis:** In this analysis, various performance parameters are measured to analyze the image characteristics. The parameters taken into consideration in the proposed model are explained below [24–26].

1. Entropy: Entropy assesses image content and abundance. Entropy is the sum of the products of the outcome probability multiplied by the log of its inverse [27]. Entropy, H, is written as follows:

$$H = -\sum_{i=o}^{255} p_i \times \log_2(p_i) \quad (7)$$

2. Sobel Count: The sobel count parameter determines the total number of edges presented in the underwater image.
3. Execution Time: This parameter is used to determine how much time is spent on underwater enhancement using the proposed model. In MATLAB, *tic* and *toc* are the inbuilt functions used to determine the simulation time.
4. MSE: This parameter measures the mean square error between the input underwater image and the output image. It is determined using Eq. (8).

$$MSE = \frac{\sum_{i=1}^{A}\sum_{j=1}^{B}\{IU_{ij} - OU_{ij}\}^2}{A \times B} \quad (8)$$

In Eq. (3), the IU, OU denotes the input and output underwater image. On the other hand, AB denotes the dimension (row and column) of the image.

5. PSNR: This parameter measures the ratio between the maximum possible signal in the underwater image and the noise generated between the input and enhanced image due to the enhancement method. It is determined using Eq. (9).

$$PSNR = 10 \log_{10} \frac{P^2}{MSE} \quad (9)$$

Table 3 shows the objective analysis of the proposed underwater image enhancement model. The result shows that the output enhanced image achieves a better entropy, sobel count than the input image. Further, the proposed method achieves low entropy and better PSNR.

Table 3 Objective Analysis of the Proposed Underwater Image Enhancement Model

	Images				
Parameters	Image1	Image2	Image3	Image4	Image5
Input Entropy	6.5722	6.8441	6.2306	7.0192	6.6148
Output Entropy	7.2854	7.3844	6.7002	7.4960	7.3224
Input Sobel Count	5824	6261	9334	7385	6217

Output Sobel Count	5859	6320	9550	7119	6257
MSE	0.0052	0.0089	0.0044	0.0035	0.0018
PSNR (in dB)	71.3428	69.6334	71.6963	72.6901	75.6536
Execution Time (in Seconds)	8.291030	8.115823	9.537816	9.211359	8.056382

Finally, comparative analysis is performed with existing underwater enhancement models. The results reflect that the proposed model achieve entropy value of 7.3680 for diver image, 7.5952 for turtle image, 7.4960 for fishes image, and 7.6538 for coral beach.

Table 4 Comparative Analysis based on Entropy Parameter

	Images			
Methods	Diver	Turtle	Fishes	Coral Beach
Method [11]	6.6216	6.075	6.9833	6.2932
Method [26]	6.951	6.842	7.111	6.8476
Proposed Model	7.3680	7.5952	7.4960	7.6538

V. CONCLUSION

In this paper, we have designed an underwater image enhancement model that enhances the image based on its characteristics. To achieve this goal, two enhancement methods, namely, power law and singular value decomposition (SVD), are taken into consideration. Further, the optimal parameter values of these methods are determined using the swarm intelligence termite alate optimization algorithm based on the objective function. The objective function taken under deliberation is entropy. The simulation results are performed on the standard dataset images. Further, subjective, and objective analysis is done in the performance analysis. The result shows that the output images are enhanced over the input images in terms of visual quality. Besides that, the proposed model achieves better entropy and sobel counts over the input images. In the last section, comparative analysis shows that the proposed model achieves better entropy than the existing models, which are designed for underwater image enhancement.

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