ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)

Volume 11 Issue 3 March 2024

Synergistic Approach to Enhance Underwater Images: CLAHE and DCP Fusion

[1] K. Abirami, [2] Mary Shalini J, [3] Rethika G

[1] [2] [3] ECE, Easwari Engineering College

Corresponding Author Email: [1] abirami.k@eec.srmrmp.edu.in, [2] maryshalini201202@gmail.com, [3] rethikag.2017@gmail.com

Abstract— Underwater imaging is an essential tool in various domains, including marine biology, underwater archaeology, and offshore inspection. However, underwater images often suffer from poor visibility, color distortion, and low contrast due to the absorption and scattering of light in water. To address these challenges, this paper proposes a novel underwater image enhancement method that combines Contrast Limited Adaptive Histogram Equalization (CLAHE) and the Dark Channel Prior (DCP) algorithm. The Contrast Limited Adaptive Histogram Equalization (CLAHE) technique enhances local contrast and mitigate the effects of uneven illumination, commonly encountered in underwater scenes. CLAHE adaptively equalizes the histogram of small image regions, preserving details and enhancing the overall image quality. The Dark Channel Prior (DCP) algorithm, leverages the statistical property of outdoor haze-free images to remove the inherent haze in underwater images. By effectively subtracting the underwater haze, DCP restores the image's original color and contrast. In our proposed method, CLAHE and DCP are integrated to harness their complementary strengths. First, CLAHE is applied to the underwater image to enhance local contrast and reduce uneven illumination effects. Then, the Dark Channel Prior is employed to estimate and remove the residual haze, further improving image clarity and color fidelity. The proposed method offers a valuable tool for improving the visibility and quality of underwater images, facilitating better understanding in various underwater applications.

Index Terms— Contrast Limited Adaptive Histogram Equalization (CLAHE), Dark Channel Prior (DCP), Image enhancement techniques, Underwater image enhancement.

I. INTRODUCTION

Underwater imaging is a vital tool in various fields, from marine biology and environmental monitoring to underwater archaeology and industrial inspection. However, capturing high-quality underwater images remains a formidable challenge due to the attenuation and scattering of light in aquatic environments. Consequently, underwater images often suffer from poor contrast, color distortion, and reduced visibility, hampering their utility for research and practical applications.

To address these challenges and unlock the full potential of underwater imagery, this research introduces an innovative approach that combines two powerful image enhancement techniques: Contrast Limited Adaptive Histogram Equalization (CLAHE) and the Dark Channel Prior (DCP) algorithm. By synergistically integrating these techniques, we aim to revolutionize the field of underwater image enhancement, offering a solution that significantly enhances image quality and helps researchers and professionals better analyze and interpret underwater scenes.

CLAHE is a powerful local contrast enhancement technique that adjusts the intensity distribution of small image regions independently. By adaptively equalizing the histograms of these regions, CLAHE can effectively enhance local contrast, reduce the effects of uneven illumination, and reveal hidden details in the image. It has found success in a wide range of image enhancement applications.

On the other hand, the Dark Channel Prior (DCP) algorithm was originally introduced for outdoor haze removal. It leverages the observation that haze-free outdoor images exhibit a remarkably dark channel in the outdoor scene's radiance. By estimating the transmission map using this dark channel prior, DCP can effectively remove the haze and restore the original colors and contrast of the image. Although DCP was designed for dehazing outdoor scenes, researchers have recognized its potential in enhancing underwater images by addressing the common issue of underwater haze.

In this paper, we propose a novel methodology that seamlessly integrates CLAHE and DCP to enhance underwater images. Our goal is to harness the complementary strengths of these two techniques. First, CLAHE is applied to the underwater image to address local contrast issues and alleviate uneven illumination. Following this, the Dark Channel Prior is employed to estimate and eliminate any residual haze, further enhancing image clarity, and color accuracy.

Our research contributes to the field of underwater imaging by offering a comprehensive and innovative solution that addresses the multiple challenges faced when working with underwater imagery. We present experimental results and comparative analyses to demonstrate the effectiveness of our approach, underscoring its potential to significantly improve the quality of underwater images across various applications.

In the subsequent sections, we will delve into the technical details of our proposed method, present experimental results to demonstrate its effectiveness, and discuss its potential implications in various underwater imaging scenarios. Through this research, we aim to contribute to the advancement of underwater image enhancement techniques, ultimately enhancing our ability to explore and understand the hidden beauty and mysteries of the underwater world.

II. RELATED WORKS

Underwater image processing is a specialized branch of computer vision and image analysis dedicated to the enhancement, analysis, and interpretation of visual data captured in aquatic environments. It plays a pivotal role in numerous sectors, including marine biology, oceanography, offshore engineering, environmental monitoring, and underwater archaeology. By leveraging cutting-edge techniques and algorithms, underwater image processing transforms raw underwater imagery into valuable insights and actionable information. The survey apprehended in [10] introduces a review of existing relatively mature and representative underwater image processing models, which are classified into seven categories including enhancement, fog removal, noise reduction, segmentation, salient object detection, color constancy and restoration.

Underwater image enhancement is a multidisciplinary endeavor that draws upon principles from computer vision, image processing, physics, and marine science. It leverages cutting-edge technology, including specialized cameras, lighting systems, and image processing software, to transform raw underwater imagery into valuable insights and actionable data. The work presented in the article [11] highlights the survey of underwater image enhancement algorithms. This work presents an overview of various underwater image enhancement techniques and their broad classifications. The methods under each classification are briefly discussed.

This paper presents a comprehensive perceptual study and analysis of underwater image enhancement using large-scale real-world images. In paper [1], an Underwater Image Enhancement Benchmark (UIEB) is constructed including 950 real world underwater images, 890 of which have the corresponding reference images. The rest 60 underwater images are constructed which cannot obtain satisfactory reference images as challenging data. Using this dataset, we conduct a comprehensive study of the state of-the-art underwater image enhancement algorithms qualitatively and quantitatively. In addition, we propose an underwater image enhancement network (called Water-Net) trained on this benchmark as a baseline, which indicates the generalization of the proposed UIEB for training Convolutional Neural Networks (CNNs).

Our purpose was to identify an algorithm that performs well in different environmental conditions. In journal [2], some algorithms from the state of the art have been selected and they have employed them to enhance a dataset of images produced in various underwater sites, representing different environmental and illumination conditions. These enhanced images have been evaluated through some quantitative metrics. By analyzing the results of these metrics, it is understood which of the selected algorithms performed better than the others. Another purpose of our research was to establish if a quantitative metric was enough to judge the behavior of an underwater image enhancement algorithm. We aim to demonstrate that, even if the metrics can provide an indicative estimation of image quality, they could lead to inconsistent or erroneous evaluations.

From the PDE-based and variational Retinex method, a novel approach based on underwater image formation model combining underwater dark channel prior (UDCP) is being proposed in the paper [5]. Here in this, the proposed method can achieve a good performance on dehazing, contrast enhancement, edge preservation, and noise suppression. The contributions of the paper are summarized as follows: (i) A novel total variation method for underwater image restoration is proposed based on the underwater dark channel prior, in which we successfully integrate the underwater image formation model into the variational framework. (ii) Rather than estimating the TM directly using the traditional dark channel prior, we present a UDCP method to improve the estimation of the TM. Moreover, we determine the global background light from the candidate pixels estimated from the brightest regions. (iii) In order to reduce the complexity of solving the proposed underwater total variation (UTV) model, we design a fast algorithm based on the alternating direction method of multipliers (ADMM) to accelerate the whole progress. (iv) Compared with previous methods, the proposed underwater variational method can achieve a good performance on dehazing, denoising, and improving contrast simultaneously.

According to the characteristics of foggy images, such as high noise, low resolution, and uneven illumination, an improved foggy image enhancement method based on dark channel priority is proposed in paper [3]. First, the new algorithm refines the transmittance and optimizes the atmospheric light value and converts the restored image to HSV space. Second, the brightness *V* component is enhanced and improved by bilateral filtering, and the saturation S is improved by adaptive stretching algorithm. Finally, the image is converted from HSV space to complete image enhancement. The new method solves the problems of that the color of large area is uneven and the overall color of the image is dark when the traditional dark channel prior method is used to remove fog. The experimental results show that from subjective evaluation and quantitative analysis the new algorithm overcomes the shortcomings of noise amplification and edge blur when the conventional enhancement algorithm enhances the image. It can improve image darkening and avoid image distortion in JPEG, BMP, GIF, PNG, PSD, and

TIFF formats.

Conditions of the underwater environment have its challenges in the underwater vision research process. Some things that make underwater imagery difficult is that light can be scattered by particles in the sea, besides that light can be absorbed by seawater, as well as the turbidity level of seawater, so special techniques are needed to get clear underwater imagery. In underwater environmental conditions, the images obtained are usually of very poor quality. Backlight and attenuation will occur. Image matching techniques to determine the key points of image pairs are needed in three-dimensional reconstruction research. In paper [6], a solution is provided through Speeded Up Robust features (SURF), which is an image matching technique where the matching results are very dependent on the image quality. This study proposes the Contrast Limited Adaptive Histogram Equalization (CLAHE) method to increase the number of matching images with SURF. The results of the experiment showed that image matching increased by an average of 76.8 %.

The scattering of light reduces color contrast. An improved method for underwater image enhancement based on the fusion method that is capable to restore accurately underwater images is discussed in paper [8]. The proposed work takes a single image as the input and a sequence of operations such as white balancing, gamma correction, sharpening, manipulating weight maps are performed on the input image. Finally multiscale image fusion of the inputs is done to obtain the resultant output. In the initial stage, color distorted input image is white balanced to remove the color casts maintaining a realistic subsea image. In the second stage, CLAHE is performed on the gamma corrected image. CLAHE plays a significant role in luminance enhancement of underwater images. At the same time, histogram equalization is performed on the sharpened image.

Various researchers have proposed different solutions to overcome all the mentioned problems. Dark channel prior (DCP) is one of the most used techniques which produces a better Peak Signal to Noise Ratio (PSNR) value. However, DCP has some issues such as it tends to darken images, reduce contrast, and produce halo effects. The proposed method in paper [7] solves these issues with the help of Adaptive Color Correction Method. The measure of entropy (MOE), Measure of Enhancement (EME), Mean Square Error (MSE), and PSNR opted as performance measures during experiments. The values of MSE and PSNR achieved by the proposed framework are 0.26 and 32 respectively which shows better results.

Thus, as discussed above, poor visibility to the captured underwater images is caused due to scattering and absorption. In the paper [9], a hybrid framework for underwater image enhancement is proposed, which unifies underwater white balance and variational contrast and saturation enhancement. In this framework, the improved underwater white balance (UWB) algorithm is integrated with histogram stretching, aiming to better compensate the attenuation difference along the propagation path and remove undesired color castings. In addition, a variational contrast and saturation enhancement (VCSE) model is developed based on the enhanced result obtained from UWB. The advantages of VCSE model lie in the improvements of contrast and saturation as well as the elimination of hazy appearance induced by scattering. Moreover, a fast Gaussian pyramid-based algorithm is designed here to speed up the solving of VCSE model. The improvements achieved by this method include the more effectiveness in color correction, haze removal and detail clarification. Extensive qualitative and quantitative assessments demonstrate that the proposed approach obtains high quality outcomes, which outperforms several state-of-the-art methods. Application tests further verify the effectiveness and broad application prospects of our proposed method.

III. DCP AND CLAHE ALGORITHM

A. Haze removal using Dark Channel Prior (DCP)

DCP is used to obtain a natural Haze free image. This method is generally used in the process of underwater image enhancement. The presence of water particles as well as scattering of light cause haze in the image which can be removed by DCP method. A hazy image can be characterized by using a function S(x) is given by

$$S(X)=Z(X)T(X) + A(1-T(X)) \quad (1)$$

where S(x) is the haze mixed intensity of the image, Z(x) is the haze free image, t(x) is the transmission map (medium transmission) and A is the global atmospheric light.

The main aim of this Dark Channel Prior is to find the haze free image Z(x) from the haze containing image S(x).

There are 4 steps in the dehazing process which includes

(i) Estimation of atmospheric light
(ii) Transmission Map Estimation
(iii) Transmission Map Refinement
(iv) Image reconstruction.

DCP proposes that most of the local regions in the background of the image often have some pixels which have a very low intensity in one of the three channels of the (RGB). It can be denoted as (x) and it is considered as the dark channel at x can be denoted as:

$$z^{dark}(x) = \min_{c \in RGB} \min_{y \in \Omega(x)} z^{c}(y) \quad (2)$$

In the above equation, Z^c is one of the RGB channels of Z and Ω(x) is a square region with center x. If x doesn't belong to local regions, then Z^{dark} (x) is a low value and it tends to zero. Thus, it's named as dark channel. S(x) is an image whose intensity is mixed up with the atmospheric light. So, the dark channel of S (x) has a high value as compare with Z

IFERP
connecting engineers... developing research
ISSN (Online) 2394-2320
International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)
Volume 11 Issue 3 March 2024

(x) and that is the distinction which helps to remove haze. First of all, global atmospheric light A is estimated and then the medium transmission t(x). t(x) is calculated by dividing the equation (1) by A.

$$\min_{c\epsilon RGB} \min_{y\epsilon\Omega(x)} S^c(y) / A^c = \min_{c\epsilon RGB} \min_{y\epsilon\Omega(x)} Z^c(y) / A^c + [1-t(x)] \quad (3)$$

According to the DCP, the dark channel of the image tends to zero, so we have the below equation:

$$\min_{c\epsilon RGB} \min_{y\epsilon\Omega(x)} Z^c(y) / A^c = 0 \quad (4)$$

Combining Equation (3) and Equation (4), we get:

$$t(x) = 1 - \min_{c\epsilon RGB} \min_{y\epsilon\Omega(x)} S^c(y) / A^c \quad (5)$$

A factor 'w' is introduced in Equation (5) to keep a small amount of haze in the image to perceive the depth of the image. So, the medium transmission t(x) is:

$$t(x) = 1 - w \min_{c\epsilon RGB} \min_{y\epsilon\Omega(x)} S^c(y) / A^c \quad (6)$$

Then, a soft matting algorithm is applied to refine the medium transmission t(x), and to find the accurate medium transmission. Now, Z(x) can be calculated as:

$$Z(x) = [S(x) - A / \max (t(x), t_0)] + A \quad (7)$$

where, t_0 is a threshold value applied to avoid a low value of the denominator.

B. Drawbacks in DCP process

DCP has major drawbacks. In general, an image has two grounds. One is foreground which is the main focus. The second one is background which is actually considered. DCP technique has major drawbacks in the background enhancement. Firstly, after DCP when there is removal of haze the image contains only small background area with low contrast, which will cause poor result on dark background with very low contrast. This is because the image background may also be mixed with thick haze and thus this method reduces the contrast of the local regions.

Secondly, the Z(x)t(x) of equation (1), which is called direct attenuation has a nonlinearity along with the image intensity. So, the result implemented by DCP has a low contrast than the haze free image. [1-t(x)] represents the thickness of haze. Different intensities of foreground irradiance (A) passing through same thickness of haze having same degree of attenuation results in a low contrast of image. The drawbacks mentioned here have little effect on haze removal, but if the haze image has a larger background area and low contrast, the DCP causes poor results and reduces the contrast of foreground. This is overcome by adding adaptive histogram equalization (CLAHE) to the result.

C. Contrast Adaptive Histogram Equalization (CLAHE)

Adaptive histogram equalization (AHE) is a technique where image processing is used to enhance the contrast in images. It is slightly different from ordinary histogram equalization. This method estimates several histograms, each of which corresponds to different sections of the image and this is used to redistribute the lightness values of the image. Thus, local contrast is enhanced. However, AHE amplifies noise in relatively similar regions of the image.

A development of AHE called Contrast Limited Adaptive Histogram Equalization (CLAHE) limits the amplification. CLAHE is a generalization of Adaptive Histogram Equalization where contrast of the image is kept contrast. The image is divided into tiles. CLAHE color models are specifically developed for enhancement of images. Especially, it operates on the tiles of the image. Tiles are nothing but the small regions of the image that is divided according to a particular grid. It enhances the contrast of each tile. To remove the induced artificial boundaries, the nearby tiles are combined by using bilinear interpolation. Thus, the contrast is limited to avoid amplifying any noise particularly in homogeneous areas in the image. The amplification is mainly limited by clipping the histogram at a value called as clip limit. This clip limit finds the amount of noise to be removed and the contrast level of the output image.

IV. PROPOSED METHODOLOGY

In this part we look into the proposed algorithm so as to obtain a more enhanced, haze free and also a visually pleasing image of the underwater scenery. The process is explained in the figure 1 for good incorporation of the working principle. As a first step, underwater image is obtained. Here, almost all the images suffer from the haze effect which is caused due to the variations in the light conditions and depth of the underwater scenery. So, the haze has to be eliminated for which the image is subjected to haze removing algorithm called DCP. But, on removal the result of the image is obtained with the contrast of the image reduced and darkened. To mitigate the disadvantage of DCP, the image is subjected further to CLAHE. This method enhances the contrast of the image. Here, the image is separated into tiles and for each tile the contrast is improved individually and these tiles are rejoined by the process of interpolation. After the enhancement of the contrast of the image, the image is further subjected to color correlation technique to get a more visually pleasing and refined image. The main purpose for doing this is to get a better enhanced image of the object and better refinement of the image.

In this Color Correlation technique, the Mean Square Error (MSE) and the mean value in each of the RGB channels of the image (Z) are computed. The maximum and minimum value in each Channel is given below:

$$Z^c(max) = Z^c(mean) + Z^c(var)$$
$$Z^c(min) = Z^c(mean) - Z^c(var)$$

Where C indicates the (R, G, B); $Z^c(mean)$ implies the mean value and $Z^c(var)$ implies the Mean Square Error. The color corrected image is computed by:

$$Z(cr) = [Z^c = Z^c(min/Z^c(max) - Z^c(min)] * 255$$

IFERP
connecting engineers... developing research

ISSN (Online) 2394-2320

International Journal of Engineering Research in Computer Science and Engineering (IJERCSE)

Volume 11 Issue 3 March 2024

Here, Z(cr) represents the color corrected image that is more refined, a visually pleasing image, a haze free image and an image with better contrast distinction.

BLOCK DIAGRAM OF THE PROPOSED ALGORITHM

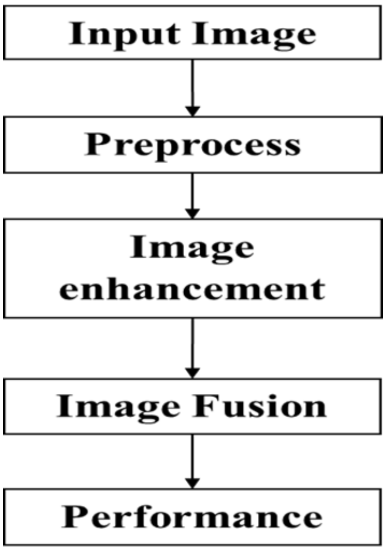

Fig. 1

FLOW DIAGRAM OF THE PROPOSED ALGORITHM

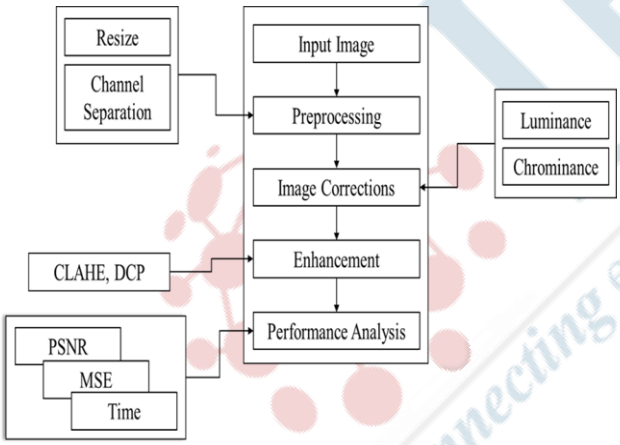

Fig. 2

V. RESULTS AND DISCUSSION

While the final arbiter of image quality is the human viewer, efforts have been made to create objective measures of quality. This can be useful for many applications. Many objective measures of quality require the existence of a distortion-free copy of an image, called the reference image that can be used for comparison with the image whose quality is to be measured. The dimensions of the reference image matrix and the dimensions of the degraded image matrix must be identical. The Image Processing Toolbox provides several functions that can be used to measure quality:

PSNR — The Peak Signal-to-Noise Ratio (PSNR) measure of quality works by first calculating the mean squared error (MSE) and then dividing the maximum range of the data type by the MSE. This measure is simple to calculate but sometimes doesn't align well with perceived quality by humans.

SSIM — The Structural Similarity Index (SSIM) measure of quality works by measuring the structural similarity that compares local patterns of pixel intensities that have been normalized for luminance and contrast. This quality metric is based on the principle that the human visual system is good for extracting information based on structure.

MSE — The Mean Squared Error (MSE) of an estimator measures the average of the squares of the errors, that is, the average squared difference between the estimated values and what is estimated. MSE is also calculated by comparing the original image and the noisy (compressed image) which produced results for MSE. MSE is also known as the risk function that corresponds to the expected value of squared error loss. MSE always remains positive and not zero is mainly due to randomness. Minimum the value of MSE shows minimum error.

We have used MATLAB 2019b version to simulate our proposed algorithm. The images shown in the figures consist of a segment of 480×640 pixels. In this experiment, the enhanced image is obtained by DCP method followed by CLAHE, White Balance and Color correction methods.

Fig.3 shows Enhancement of input image in steps. In the figure initially the image is converted to grayscale and then DCP is applied to it and after that CLAHE is applied to the resultant image. This resultant image is now white balanced and sharpened to have better features and finally, color correction is applied to it to obtain a better output image. To estimate and measure the performance of the proposed framework at each step, the results are measured after each step which is presented in Table 1.

Fig 3. (a) Input Underwater Image

Fig 3. (b) White Balance Input

Fig 3. (c) Initial Enhance Input

Fig 3. (d) Output Image

Table I. Measurements of Parameters

IMAGES	PSNR	MSE	SSIM	ELAPSED TIME (Secs)
1	43.3596	3	0.0016	6.310014
2	42.6769	3	0.0112	7.1004
3	44.5642	3	0.0010	6.0634

VI. CONCLUSION

The evaluation of the diverse existing methods and algorithms is done to enhance the quality of underwater images. But it is found that they have some disadvantages and gaps in the literature survey. These were looked into and based on that an integrated and combined approach of DCP and CLAHE techniques is proposed for better quality of the underwater images.

DCP method removes the haze present in the image. Along with this, DCP darkens the image and results in poor contrast of the image. So, in order to enhance the contrast of the image, it was subjected to CLAHE and a better contrast was obtained. Finally, a more visually pleasing image is obtained.

With proper simulation for various images and comparison of various different parameters like PSNR and MSE, it was concluded that the integrated approach is favorable to get the result. As we have concluded, this process is well efficient for underwater image enhancement and yields a better result and lossless data from the image.

REFERENCES

[1] C. Li et al. "An Underwater Image Enhancement Benchmark Dataset and Beyond," in IEEE Transactions on Image Processing, vol. 29, pp. 4376-4389, 2020.

[2] M. Mangeruga, M. Cozza, and F. Bruno, “Evaluation of Underwater Image Enhancement Algorithms under Different Environmental Conditions,” Journal of Marine Science and Engineering, vol. 6, no. 1, p. 10, Jan. 2018.

[3] D. Li, J. Sun, H. Wang, H. Shi, W. Liu, and L. Wang, “Research on Haze Image Enhancement based on Dark Channel Prior Algorithm in Machine Vision,” Journal of Environmental and Public Health, vol. 2022, Article ID 3887426, 12 pages, 2022.

[4] Deperlioglu, Omer, and Utku Kose, "Underwater Image Enhancement with Dark Channel Prior Based Image Dehazing and Histogram Equalization”, UMYMK-ICAIAME’19, 20-22 Nisan, 2019.

[5] G. Hou, J. Li, G. Wang, H. Yang, B. Huang, Z. Pan, A Novel Dark Channel Prior Guided Variational Framework for Underwater Image Restoration, Journal of Visual Communication and Image Representation, Volume 66, 2019.

[6] Suharyanto et al, “Contrast Limited Adaptive Histogram Equalization for Underwater Image Matching Optimization use SURF”, Journal of Physics: Conference Series, Volume 1803, 2020.

[7] Alhajlah, Mousa, "Underwater Image Enhancement Using Customized CLAHE and Adaptive Color Correction" Computers, Materials & Continua 74, no. 3, 2023.

[8] Sangeetha Mohan, Philomina Simon, “Underwater Image Enhancement based on Histogram Manipulation and Multiscale Fusion”, Procedia Computer Science, Volume 171, Pages 941-950, ISSN 1877-0509, 2020.

[9] Li, Xinjie, et al. "A hybrid framework for underwater image enhancement." IEEE Access 8, 197448-197462, 2020. Muwei Jian, Xiangyu Liu, Hanjiang Luo, Xiangwei Lu, Hui Yu, Junyu Dong, "Underwater image processing and analysis: A review", Signal Processing: Image Communication, Volume 91, 116088, ISSN 0923-5965, 2021.

[10] Raveendran, S., Patil, M.D. & Birajdar, G.K. "Underwater image enhancement: a comprehensive review, recent trends, challenges and applications", Artificial Intelligence Rev 54, 5413–5467, 2021.