IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 9 September 2023, accepted 26 September 2023, date of publication 5 October 2023, date of current version 16 October 2023.

Digital Object Identifier 10.1109/ACCESS.2023.3322153

TOPICAL REVIEW

A Review on Image Enhancement and Restoration Techniques for Underwater Optical Imaging Applications

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ABSTRACT Underwater image processing always a challenging problem in oceanic engineering applications. Images captured in underwater are commonly suffers due to color distortion, detail blur, bluish or greenish tone, and low contrast to light scattering and absorption in the water medium. The image visibility is affected drastically during capturing caused by the degradation of light absorption and scattering effect. Hence, the effective Underwater Image Enhancement(UIE) and restoration techniques are primarily required for the underwater ecological study applications. Various UIE techniques are studied for different data sets, and applications. However, the selection of suitable method for particular applications among available techniques is still a challenging task. In this paper, an overview of recent UIE and restoration techniques and classification methods are elaborated with data sets and applications. The UIE techniques are grouped under various category such as spatial domain, transform domain, color constancy based method, retinex based approach. Similarly, the image restoration techniques are grouped under underwater optical imaging technique, polarization based approach, prior knowledge and convolutional neural networks. Finally, we review the research process of the underwater image enhancement and restoration with the essential background of the water images and recognize challenges.

INDEX TERMS Underwater image enhancement, restoration, dark channel prior, fusion based method, Rayleigh scattering, underwater network, Rayleigh distribution, adaptive histogram equalization.

I. INTRODUCTION

Underwater imaging is becoming increasingly important to a range of applications, including monitoring of underwater structures and studying various aquarium life forms like fishes, and coral reefs, other life forms, mineral resources present in water bodies, and robot inspection, deep underwater archaeology. While taking a picture in good quality images from the underwater environment is not an easy task using the dedicated hardware. Nowadays, underwater study has become more active because of appliance demands, wreckage exploration, and marine species, underwater cables, and pipelines, mapping offshore seabed among others. However, the environment of underwater optical images is complex due to atmospheric scattering and absorption of water medium. Enhancing images is remaking the digital images that the results gave a better display. Image enhancement deals with sharpening image features like edges, contrast, minimizing the ring artifacts, and boundaries. While capturing an image or video in a water environment, the image or video quality reduced due to scattering and amalgamation. Also the images are suffering from more strong absorption, noise and low contrast, and poor visibility and also the video. However, underwater images are widely used in fields of spatial domain enhancement, transform domain enhancement, color constancy, and underwater applications. Suitable methods are required to enhance the quality of the image for processing.

The associate editor coordinating the review of this manuscript and approving it for publication was Yiming Tang.

The quality degradation range of underwater images are reflected by the medium transmission that is processing the percentage of radiance reaching the camera. Usually, an underwater image initiates procedures that are affected by a plethora that are usually ignored in a picture captured water surface. According here discussing the image enhancement and image restoration methodology and related sample water image Fig.4. The main goal of the image enhancement is to produce visually appealing images without relying on the physical model. In enhancement model [1] to create the many visually appealing images and also image enhancement employs qualitative, subjective in certain criteria on the physical water characteristics model and this model more fast and easier the convolution techniques. Based on fusion enhancement algorithm [2] presented the multi scale fusion algorithm to enhance the water images and videos, by the contrast-enhanced image and color-corrected image which process the multi scale fusion strategy level in image enhancement. Image restoration method, used of image formation process to reconstruct the degraded image in water environment. Sometimes, the model uses the optical effect of water image, camera to the object distance and as they give the response function by camera-specific information. Meanwhile, the techniques described underwater image color correction and contrast. A few researchers of image restoration are trying to restore the deteriorated image by using the model of degradation. To proposed [3] stretched the pixel range in red, blue, green for color space and contrast and saturation of underwater images improved by a HSV color space. Meanwhile, Rayleigh distribution processes are reduced, enhancing the region by shaping and stretching. Dual-image rayleigh-stretched [4] contrast limited adaptive histograms help to correct the global and local contrast of underwater images. In CLAHE (Contrast-Limited Adaptive Histogram Equalization) [5] methods reduce the noise amplification and it includes the grayscale image building as in Histogram Equalization methods. They also applied the contrast limiting method and noise reduction. However, expanding the noise signal is changed by threshold to the image histogram equalization. The original image formation approaches the large number of parameters [6] such as diffusion coefficient that describe water turbidity are available with a lot of restored image and required parameter in object distance from camera; it also referred to the depth of the image in many cases. Prior blurriness [7] has formed the assumed deeper the sight depth it also more dim or dull in submarine object image. The prior blurriness that view as depth level to completed the image renovation. Underwater dark channel prior algorithm part of an original dark channel prior(DCP), [8] it's also introducing the defog idea of natural image to underwater images. Based on dark channel prior [9] to proposed novel underwater image restoration algorithm guided by variational framework. Meanwhile, restoration algorithms are not used for all scenes underwater because they depend on assumption of prior information. To estimate the more accurate background light and scene depth underwater is available [10] propose the image blurring and light absorption and Blurriness-Prior, to restore the water image undergoing various types of complex scenes. Underwater image restoration presented a red channel algorithm, [11] which compensated for the attenuation of the red channel. Different underwater dataset is discussed about the image synthesis and depth map estimation. Huge number dataset in enhancement and restoration part that used for test performance, at same time some problems happen by fish detection datasets and segmentation process. Meanwhile, collecting the large number of dataset from different positions and locations in water images and it also establishes the quality level of surface in water images. In the real world underwater [12] have a large scale dataset, which includes the images with different degree and quality of reference images. While corresponding dataset are developed in enhancement and evaluation process, it synthesizes the physical model and properties of water scenes. Set of images are patched on a backscattering range that gives a result as a parameter and its assumed effects are identical [13]. In a trained dataset in a fusion network that builds up the underwater images, it includes input like gamma image, white balance picture and contrast. Underwater network (UW-Net) contained 1030 blue and 1050 green images from sunlight, around 1600 images for the tested D-Hazy dataset. It's taken 128×128 patches as a train and testing set. Background light estimation of underwater images contains 800 images, at different locations and levels of standard background light [14]. They used paired and unpaired image dataset from different location and scene [15], GAN [16], OUC vision [17], CNN [18], video record from the different cameras. In Fig. 1 shows a underwater image model, camera received light from the object. The back scattering reflects the light toward the camera in underwater vehicle, which light reached to the object in underwater. Some natural illumination occurs in undersea, it differ from water ranges and it viewed by underwater autonomous vehicle. In this paper overview of underwater enhancement and restoration techniques and different approaches and classification methods are elaborated. First, we discussed the image enhancement approaches with various methods. Next, we introduce the image restoration method, which analyzes the sub-objective and also discusses multiple datasets and quality evaluation metrics in the paper. From this paper, we point out future research in areas like restoration and evaluation metrics. Finally, we review the research process of the underwater image enhancement and restoration with the essential background of the water images and recognize challenges.

II. BIBLIOMETRIC DATA EXTRACTION

Obtaining data from issued research was essential for attaining the study's goals because it helped determine which scholarly works would be used to draw any inferences based on findings. We chose the databases for this study given that, in comparison to other data sources like Google Scholar, Web of Science (WOS), and PubMed, they cover a wider

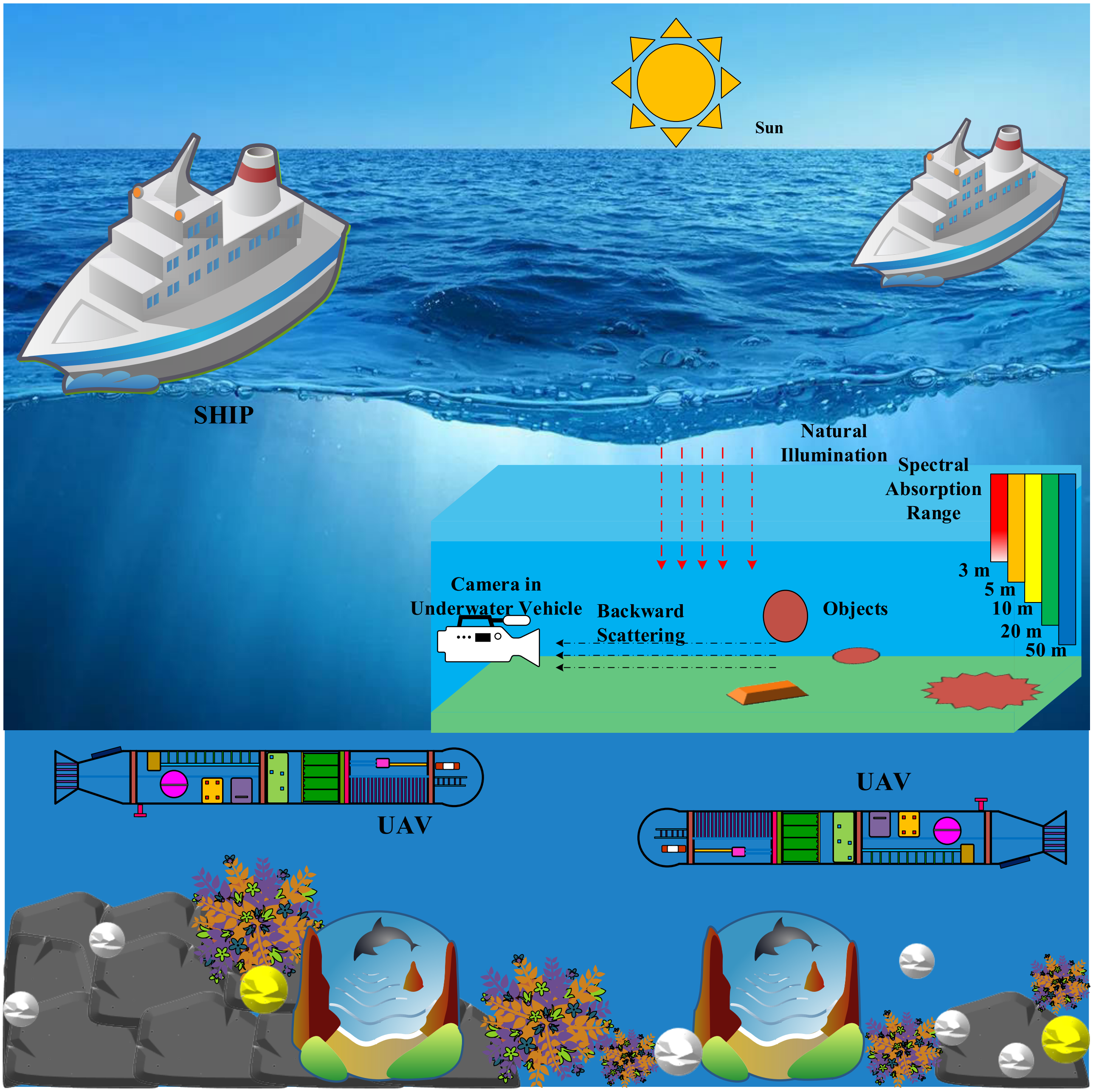

FIGURE 1. Underwater image capturing environment model.

range of research. In PubMed, there is a better alternative for disciplinary areas of research, such that it discusses the same coverage as WOS and SCOPUS. In the search for underwater images and the underwater image enhancement process, keywords were used through the PubMed database for a complete research publication in the English language. Keywords such as 'Image Enhancement,' 'Image Dehazing,' 'Image Restoration,' 'Contrast Enhancement,' and 'Color Correction' were retrieved from the PubMed database. A total of five thousand three hundred (5300) records were covered in underwater image and underwater image enhancement, listed as keywords. The records were retrieved based on the keyword presence in the title, abstract, and keyword section in the PubMed database. Many keywords indicate the content of the issued documents and the PubMed study within the domain. Keywords occur in many study topics that do not change over time. VOSviewer uses a zone viewpoint to depict each node by the average year in different literature (see Fig. 2). Bibliographic records contain information about the authors, organization affiliations, and the identification of prominent scholars in the field for mapping the issued collaborations.

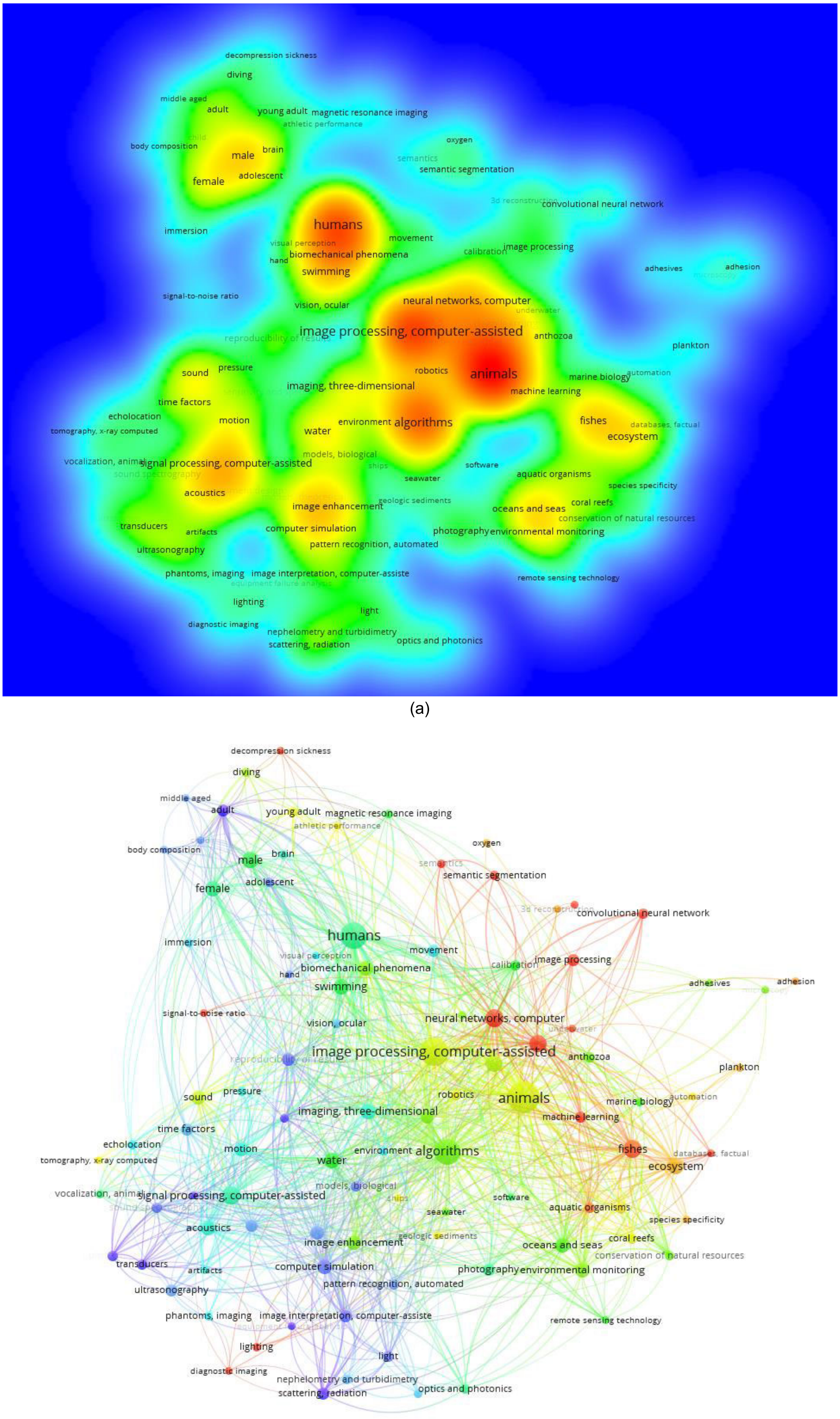

FIGURE 2. Visualization density of author keywords in underwater image processing.

VOSviewer creates co-authorship networks and can analyze the scientific knowledge captured in underwater images. In the scientometric model of underwater images, it covers the hidden significance of a large amount of data and also utilizes Excel along with VOSviewer to create various graphs. In network density visualization, the author network represents collaborations in author publications. In their analysis, Hung-Yu Yang had the highest citation count, but their strength score was low. Yanwei Pang had the strongest links but a low citation count. Most documents were produced by [author name]. They also indicate authors' citations who collaborated through co-authorship (see Fig. 3).

III. UNDERWATER IMAGE ENHANCEMENT

The underwater image's nature can be improved to extract data for future research. Quality of an image can be improved by use of restoration or enhancement. Image Enhancement works to clear the appearance of an image from a human point of view. Several researchers have developed various methods and algorithms for underwater images. An underwater image enhancement technology that combines dual intensity pictures with Rayleigh stretching involves the correction and stretching. Depending on Rayleigh distribution, the images are converting the images into separate average values of intensity. This method raises the underwater environment contrast, enhances images in detail and reduces noise [19]. To developed a low pass filter approach for enhancing deterioration of water image, which measures point spread in physical features of underwater photos. Its impact from artificial sources of light and red channel attenuation for underwater image data [20]. As part of a single underwater images enhancement, three-step are proposed [21]: a simple and effective color correction strategy, a variation RB 'Residual block' framework, and also an additional data preprocessing process on fuzz and underexposure. An underwater blue-green effect and amplified noise can be efficiently reduced and removed with a technique. Reference [22] 'Dynamic histogram Equalization' DHE and 'Acoustic gravity wave' AGW are presented as a combination, but both strategies were effective at the same time. The adaptive gray world approach removes the image's color cast and improves the image contrast by detaching the image's color cast. The parallel structure greatly improves the underwater image in good quality. The DHE is ideal for an image with low contrast, but it gives poor results when the contrast is high. To proposed the unique qualities of light propagation in water and quality of under-the-water photographs is poor.

Due to various circumstances, especially the waves, absence of light, [23] biological stuff is melted in water and photos taken by the closed range, any type of operation performed by pre-processing, a variety of filtering algorithms are available. The filters used to improve image quality, limit noise, maintain image corners, and smoothen and enhance an image are effective.

A. ENHANCEMENT PROCESS-SPATIAL-DOMAIN

Based on the gray mapping principle, the spatial domain of enhancement approaches sort out the histogram intensity of the redistribution by extending the gray scales. Color scheme have different part CIE-laboratory, Red-Green-blue color process has one thing and same time saturation intensity and value has taken main step for processing the image enhancement process are all common color models. It separates spatial domain image improvement approaches into single color model (SCM)-based and Multiple color model (MCM) based image enhancement based on whether a SCM or MCM is employed in the histogram redistribution process.

1) SINGLE COLOR MODEL

The global clarity has mirror light different in image, which in Histogram Equalization process and it regular approaches by enhancement contrast. Color model also have the process of correction in gamma, CLAHE, GUM 'Generalized-unsharp-masking'. A traditional color-correcting procedure such as white balancing, gray world Assumption, or Gray-Edge Assumption is used to change the color and contrast of the image. Based on fusion image enhancement procedure almost in modern addition. While it's in indirect operation method of traditional, combination concern the method for single manner. Numerous wave is beginning image and improvement of fuse process by the help of fusion methods. They chose over the network of neural method and it reduce duration and there is zero demand for more database for trained process. In multiscale fusion has proved one of the best performance which blend in the direction of image appropriate remove the artifact, it not build in domain. Sometime it compressing images to provoke the weighting of pyramid and the result of pyramid to form the blend image. The above paper explores a minor method that are include the scale of multi fusion figure in enhancement of different domains. In contrast enhancement techniques use fusion with the non-linear models. Using an algorithm based on retinex has separate framework to build the server picture which connect to the channel of Y with color model has YUV, enhanced channel as fused to build the Y phase. The path of numerous channel combines to Y based to another channel which has been enhance the images. To suggest the method discrete transform is utilized the figure to alternate band in various components which in the method use filter of homo-morphism process to use the brightness of over the images [24]. Because of deciding the parameter for channel transform and homo-morphism mechanism and it assumed result of various output from fusion part which achieved the parameter. Power Law Transform(PLT), and because of the parameter uses in Power-law Transform, several picture have numerous value of parameter are joined and it produce the enlarge images [25]. In preference of enlarging method to use the illumination picture are weakly arrange based fusion process [26]. On behalf of the modification in development the picture to delamination than the retinex process which to boosts the method of removing the

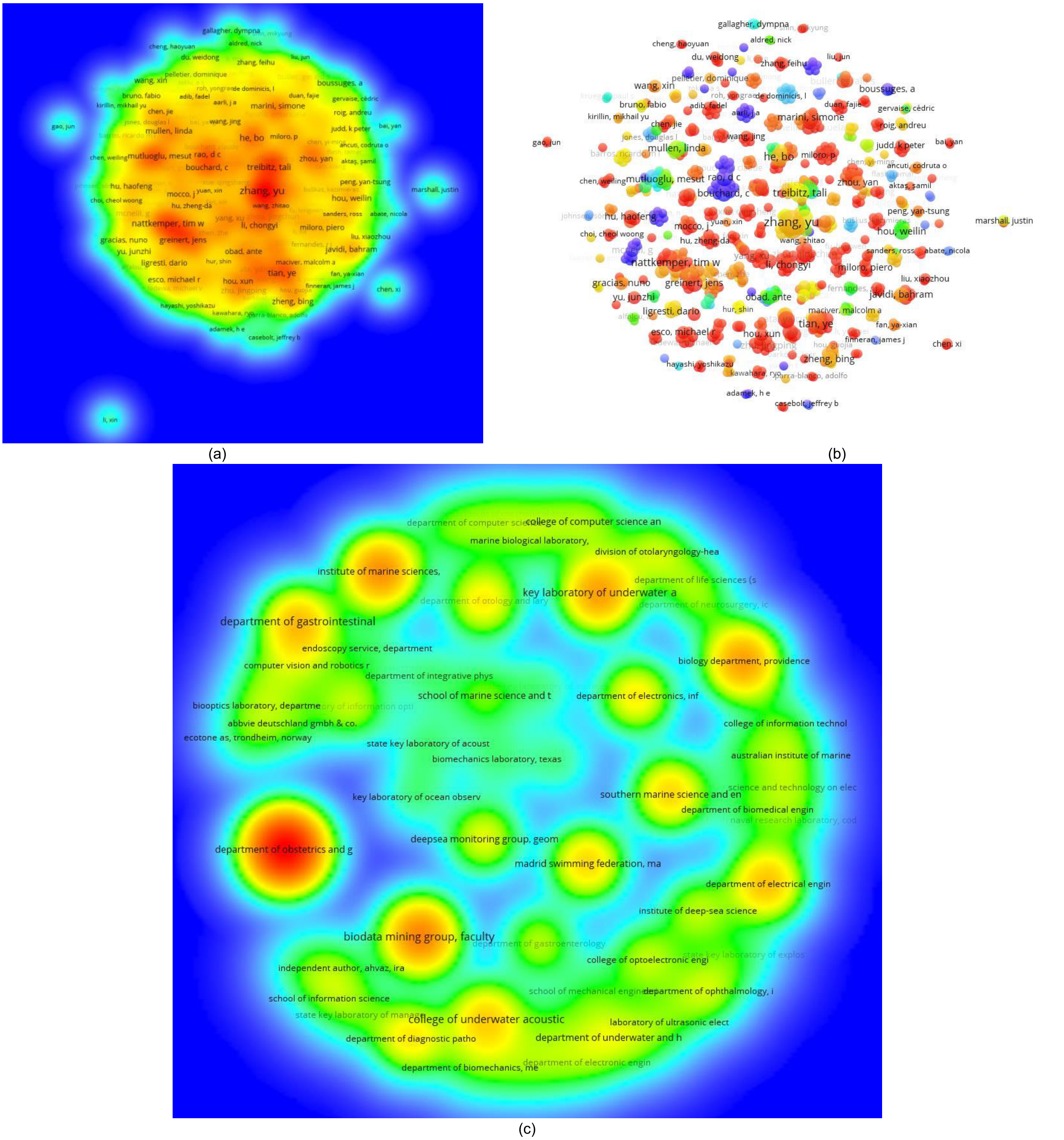

FIGURE 3. Bibliometric data (a) Authors related of underwater images density plot (b) Authors related of underwater images network plot (c) Institute related search for underwater image processing.

noise with help of amplification, reducing the congestion of the picture [27]. Meanwhile to calculate the process in image by the help of version in gamma, it contains the long term brightness of picture. Using a series of energy function minimize the part of illumination and reflectance. As of now research use the process to enrichment the image in fusion based method. And they have introduced the image improve by the fusion based multi scale process. Some difficulty are local and overall variation improvement the fusion based methodology is omitted to use the localization process are scale multi fusion and large enlarge of picture. The global, local improvement of contrast of equalization and adaptive, misadjust function, adaptive histogram equalization [28]. Techniques adaptive histogram equalization process quality for removing waste elaboration noise related to AHE (Adaptive-Histogram-Equalization) [29]. A detailed application of BBHE (Brightness-preserving-bi-Histogram-Equalization) is better for the brightness of the enhancement of contrast. From the input image [30], create the double fusion picture: beginning process to adjusting the white color balance, and another process to improve the histogram equalization process. The fused figure of brightness, salient feature to apply the computing fourth weight of fusion. At the end, approach of fusion based model of multi scale purpose and same time dual fusion picture is define the weight to provide an enhanced image with better contrariety and information in detail. The beginning approach to color the balance submarine images. The suggested underwater white balancing, to focus for adjusting the cast of color to induced away of light to contains the attenuation process of correcting gamma and to enhancing the yield to form fusion of images which is related to map weight and use standard technique for multi-scale. While proposed the global contrast, edges sharpness that to enhancing the images, taped featured the good illumination part are dark. To proposed [31] method of given data riddled into various layers by the shortage constraint method DSNMF are focused image is segmented into small section, for every channel of a local block is been restored in the green red blue image matrix. Component is bright using final part of matrix factorization and picture are modified by the use of sparse constraints, normal part of block illumination are original image are to calculate the later factorization. In method of bright enhancement process not in rule picture [32]. In trained image are arranged, which is important to area of contrast and also affected by surroundings.

2) MIDDLE COLOR MODEL

Markov Random field is being used to illustrate the correlated between the undersea image before, after distortion, posteriori enhancement intensity are used the color to picture. When calculate similarity and dissimilarity of picture patches, they are converted to lab CIE color capacity perceive various to equal magnitude. The preliminary database to collect from numerous submarine picture to enhancing approach on the ICM. Starting stage, the RCB color part had high attenuate channel of GB here it also draw across the hole range on zero to 255 [33]. To modifies the color model of HIS, component of S and I had clear stretch process using the histogram to improve the result images of sliding, stretching process are saturation and brightness. Contrast raise it careful for stretching in histogram are worked and also it corrects the color value by using unsupervised proposed on Von Kries hypothesis. An excellent way to eliminate greenish and blue cast and improve the variation in low power component of brightness [34]. Rayleigh distribution function to reorganize the given image have variety to combined of UCM-Unsupervised color correction method, ICM 'Integrated-color-method' which increasing the picture range to minimizing the complete saturation, enhancement region and introduce noise for improvement [35]. In the process to proposed the improve the original intensity performance the onward recursive adaptive histogram modification, it changes the under the water image brightness and saturation of HSV 'Hue-Saturation value' intensity model through distribution of Rayleigh as it work on system as visual of human view and they converting the strengthen picture to RGB model [36]. To proposed the 'CIE-Lab' model of color and RGB process has RGHS. Pre-Processing image, which are created using theory gray-world, utilized histogram stretching process RGB color distribution and light generating of selective attenuation beneath water. In the final stage, 'CIE-Lab' has intensity proposed brightness and color of part from a, b is optimized linearly, adaptively, simultaneously. To remove blind enhancement features of undersea images and histogram stretching could enhance observable effect the image while retaining the information [37]. In underwater image proposed to scheme on enhancement technique in wavelet. DWT Discrete-wavelet-transform works on the channels of RGB to decay levels, then collect approximate, collect the full response the part to construct the scale picture on red green blue channel being to change the wavelet of coefficient sign to lead a modification of water image [38]. In, Table 1 show about the parameter work and methodology to achieve in underwater scene.

B. TRANSFORM-DOMAIN IMAGE ENHANCEMENT

The region and pixel values corresponding to edges that contain the high number of image section, its low density of background image field are represented flat [39]. As of same in transform domain images to using the enhancement, [40] methodology are commonly work on the transform of the spatial domain images provides into frequency domains with the example of Fourier transform domains, [41] it continues to raise the image quality of water images by the help of amplified the high frequency block, simultaneously it suppress the with low-frequency parts. The difference between high-frequency parts is corresponding to the edge level and its display in the framework region of image is very short [42]. To improve the smoothing, non-uniform illumination of water image by the help of anisotropic and homomorphic filters. In the end, adaptive wavelets of sub band thresholding which modify the base shrink function are used to implement the de-noising [43]. In underwater images, use the enhancement methodology has been used in the wavelet transformation process are worked on recently. Wavelet-based fusion approaches are proposed to enhance the hazy image underwater and address low contrast images, color alteration issues occur. In the process, original images produce the two fusion images by stretching the value parts over the perfect values the HSV color model, enhancing the CLA Histogram Equalization. Wavelet fusion based on the consisting to the arrangement in high and low pass filter is clear away high, low recurrence presenting the picture, get information belonging to separately to creating a method of

TABLE 1. Spatial-domain image enhancement.

Reference	Methods	Objective	Parameter	Advantage
[19]	Rayleigh-stretched in RCB color model	Increase the water picture variation, develop the image to modified the histogram	Histogram	Histogram image is over-saturated and reddish.
[20]	Image dehazing and it properly restores the water images.	Dark channel process prior to proving value of qualification light, communication.	DCP(Dark Channel Prior)	It performs in underwater images with clear scenes and brilliant colors.
[21]	Retinex enhancing	Effective color correction and decomposed the reflectance and illumination	Retinex	Variation retinex model with optimization algorithm to decomposition.
[22]	Histogram equalization and adaptive gray level form	The visibility of water images increased and better quantitative scores	Gray-Levels Histogram Equalization	Increasing the colorfulness of the image
[23]	CLAHE methods	BRISQUE, Edge are estimate the element	Noise ratio and square error	Improve the visibility of water using CLAHE enhancement methods
[24]	YUV color space in retinex algorithm	Dynamic range to achieved good enhancement effect without color distortion	Contrast value	Not enhancing the dull areas but compress the brightness of highlight area
[25]	Low-illuminated image enhancement	Nighttime and backlighting images are effectively enhanced images.	Fusion based methods	Image fusion have various enhancement method
[27]	Variational optimization based retinex algorithm	Illumination and gamma corrected version	Bregman penalization	To restore the color component to estimate the color assignment
[31]	Fusion framework are straightforward	Visual quality and noise are reduced	Attenuation Single and backscattering	Performance level are low light conditions
[28]	Traditional enhancement of multi resolution fashion	Local and global enhancement and visual assessment	Fusion component	Using fusion method using different quality metrics
[26]	Fusion based framework	Week illumination to extract luminance and naturalness	Contrast Illumination	Different mature enhancing for fusion framework
[2]	Fusion principle	Reduce noise level, better exposedness of dark range	Analysis the density and color histogram levels.	Image matching the feature point and image dehazing
[33]	Markov random field	Color depleted and color image	Belief propagation	Feasibility of environmental condition
[35]	Modification of color model like RCB and HSV	Improve the contrast and reduce in images	CLAHE-Mix and CLAHS.	Reduce blue-green effect and minimized the enhanced areas
[36]	Recursive adaptive histogram modification	Modify histogram column and saturation and brightness	Attenuation and scattering	Highest measure of enhancement
[37]	Global histogram has relative to stretching	Color correction, contrast correction	Adaptive parameter acquisition	Perceptual quality is good with less noise
[34]	Unsupervised color correction method	Color cast reduce, contrast correction, saturation and intensity component	Calibration apply Bee law to estimate	Gray world, white patch and Histogram Equalization
[38]	Autonomous underwater	Vary depth of qualitative and quantitative metrics	Quality Metric	Remove the color cast and improving the contrast

fusion convenience. In this article proposed about the perspective view of enhancement methodology in water scene, [38]. Result of undesirable modification images that have been transformed, the RGB images channel, changes the coefficient wavelet to build a level of fragmentation. The collection of estimation, reports the detailed parts of grayscale images for Red green blue channels. Whereas, increased the accuracy level of water vision by the method of tracking and detection process test by a lot. Table 2 has also covered the domain image of enhancing process, parameter approach with advantage for water images. Even though techniques of transform domain images give results as visibility regions and better hazy images, amplification of noise and color distortion.

C. COLOR-CONSTANCY-BASED METHOD

To approach color distortion and blur of an underwater method, the TM estimation using color constancy for new proposes. They estimate the background length, calculate the map of transmission in constancy and correction are proposed in underwater enhancement. According to reinex theory, to determine the object color while its own reflection and own illumination. White balance and retinex are two of the most important aspects of color consistency. While addressing the issue of color by the white balance and the object has various conditions of light. In automatic application theory a color constancy which allows a human identify the particular light condition in the world. The core theory of retinex use the eye of human perceive color, bright for the point no more depending of simple light, it entering eye of person, however the color, bright enclosing few areas. Function process on retinex on kernel Gaussian, it works on a single scale retinex method. In equation for divide image in luminance and reflectance parts of equation:

$$\log(L\,(y,z) + \log(R\,(y,z) = \log(S\,(y,z)) \qquad (1)$$

On above Eqn.(1) has observed image like $S(y, z)$, which also the part of luminance L and reflection R. As the final execution of the equation was stored in linear feature part. Retinex applies in image defogging and image enhancement. In retinex-based methods used in recent years have applied underwater image enhancement. In particular causes as concerns on distortion color fog, the undersea damaged figure were investigated, improve the image by the help of retinex. Although the subaquatic image giving viewable effect has upgraded, limited effect of enhance [44]. An utilization retinex of subaquatic image enrichment proposed to analysis has problem from the image of three in the water image distortion color, draw of illumination, and optical fuzzy. Even if upgraded undersea image had exceeding visual outcome, more exact for recovery of color shown on Fig.2, it took 4-6 iterations and was more time-consuming [21]. In this paper, the channel of L to improve the filter of MSR (Multi-scale-retinex) the mutual filter, channel of A and B has to enhance in MSR of were enhanced by the MSR of the ternary filter after damaged underwater images were modified from RGB to LAB color space. To achieve the final enhanced picture for LAB glow of enhanced to fused and transformed into RGB color zone [45]. After converting the deteriorated image undersea from RGB and HSV color distance, retinex uses a decomposed channel of V into the flame layer and detailed the enhance layer which used in numerous methods.

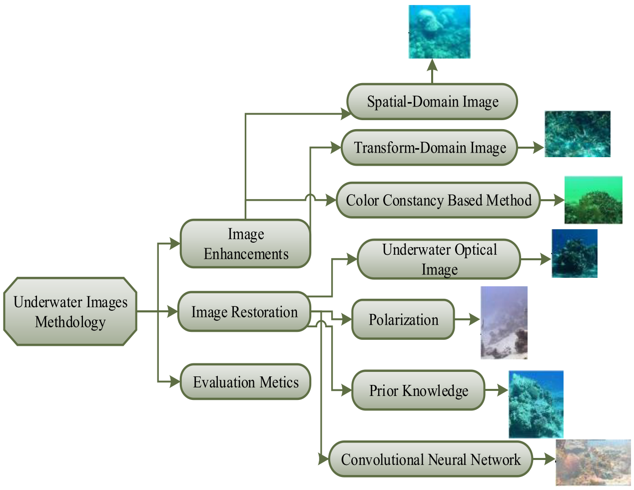

FIGURE 4. Fundamental of underwater images methodology.

To obtain final upgrade image, the enhancing H,V,S channels are translated into RGB color space [46]. The defog Multi-scale-retinex-color-restoration (MSRCR) image approach, which fixed on different channel to convolution and has been outstanding used for subaquatic picture improvement, was proposed [47]. In granted is based on the subaquatic retinex picture, taped enhancement method which is reasonable for submarine images that have numerous scenes, however, the filtering, processing part are wasteful [48]. On this research of network has number of progressive interleaved process from the representation of reclamation, resolution [49], have two major modules of PFDM(Progressive-Frequency-domain-module) and CGM (Convolution-guided-module). PFDM learned different explicitly and intensity features damage, CGM obtained the convolution blocks. Fig. 5 displays the raw image underwater and it shows the color difference in background and image visibility scene. In shown Table 3, discussion about the constancy method which estimates part of color range and level of raw image to resulted images. While the image has use different method like MSR and channel range.

D. RETINEX BASED METHOD

In retinex based methods, according to color constancy, a true picture of the real representation of the scene by removing the irradiation component glow of the things in water, which clear the irregular brightness. Proposed the explain in review manner to the automatic intensity of algorithm, featuring a various algorithm on application ACE 'Automatic-color-equalization' in the space of undersea scene [48]. In research on retinex for numerous range of enhancement algorithm and color. Applied the underwater images in retinex theory is used to enhance degradation. But the enhancement is limited because the visual effects of water images are improved. The alternating-direction optimization to solve the illumination and added intensity correction to eliminate the trouble to underexposure and muddy, constant optimization final output

TABLE 2. Transform domain model.

Author	Method	objective	Parameter	Advantage
[39]	Contour-let transform	Sigmoid function and tan-h function which suffering from low illumination	color distortion and halo effects	Low-level frequency
[40]	Autonomous imaging and video system	Image quality metric are automatically optimize	Optimal processing	Color measure as faster in runtime of image application
[42]	Transmittance correction	Effectively enhance the object of high or low depolarization degree	Transmittance correction	Depolarization degree of the object is high or low
[41]	Parameter selection and parameter optimization	Image quality metrics are designed for color images	Optimal Operating	Automatically select optimal operating parameter
[43]	De-noising method on peak signal to noise ratio	Removing the additive noise present in images	Diffusion coefficient for water turbidity	Poor smoothing level
[42]	Manually annotated background light (MABLs)	Histogram distribution of image of dark channel prior	Wavelet transformation process contrast based enhancement	Estimated the background light

TABLE 3. Color constancy methods.

Author	Method	Objective	Parameter	Advantages
[44]	different-angle retinex	Synthesizes the dynamic range compression	Dynamic range compression	Color distortion
[21]	retinex-based enhancing approach	Increasing the contrast and color of the image and enhancing edges	Image Dynamic	Time complexity level high
[45]	OUC-VISION underwater database	The frontal, opposite, left, right view	Multi scale retinex	Different sources of variation, spatial location
[46]	Interactive histogram equalization	Detail layer of images and illumination layer images	S-shade function and illumination Layer image	Visual effect observably in enhancement algorithm
[47]	Multi-channel convolution	Global contrast information and restoration	Residual function	Outperform qualitative and quantitative comparisons
[48]	Efficient enhancement method	Pixel distribution, the dominating color	Offset and gain for linear transformation and color correction	Image condition preserved by inverted gray

in high complication [21]. To propose [50] for glow correction of subaquatic figure view using intensity space, while improving the image contrast by luminance component for stretching. Underwater image enhancement method occurs in different scale of retinex, to suppress the mutual, trilateral filtering in radiance phenomenon. The contrast enhancement is not obvious and time consuming in the trilateral filter. It also reversed the color loss, that problem over the irregular illumination. The enhanced image of intensity to reach the peak of intensity region and also combined with MSRCR algorithm to correct the method based on histogram quantization of every color channel.

IV. RESTORATION METHODS

The method of image degradation process as build environment of an image quality; effect of hazy underwater image is removed. While the restoration explores the methodology, fundamental of light producing, to observe the parameter of method like prior and to restore the picture by order of satisfaction processing. Several methods work on underwater images.

A. OPTICAL IMAGING-BASED METHODS

To estimate the optimal process which has to be clean and realistic of water images by displaying the approach of optical

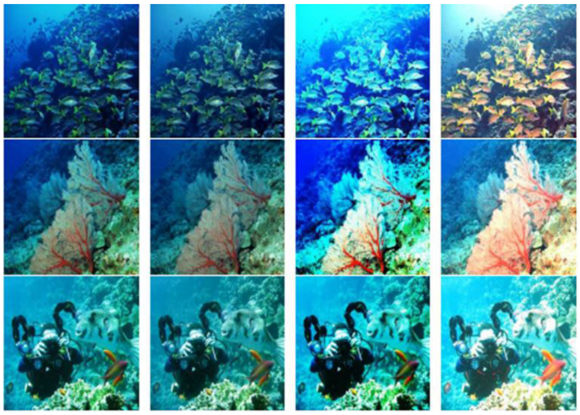

FIGURE 5. Comparison of color-constancy based method result of underwater images.

image to rate process for degradation. Based on the reduced Jaffe-McGlamery underwater optical image model, provided a self-tuning of image restoration method. The two classic expectations: undersea scene act illuminated and Forward Scattering 'FS' was present. Despite the fact that the method reduced the influence of light pour on submarine scenes, outer surrounding effects are limited because of anticipated action [51]. In the reclamation process of submarine images, the blur picture has induced the scatter of submerged water and particles attached [52]. In the support subaquatic optical picture to effect of spectral deconvolution on the underwater color scene and it reconstruct the glow. As of now, newly undersea optical image, scattering rate, and background light are estimated [53]. discovered that deteriorated underwater photos were caused by water optical properties. The medium transmission of undersea images has obtained the surrounding color of aqua images and the inversion process obtained the clear underwater image [54]. While applying the submarine optical image to underwater vehicles, increasing the accuracy of water target detection [55]. Table 4 show the method of enhancing process and parameter. While it performs the color rendering for UWE images.

B. POLARIZATION METHODS

The polarization method is manufactured to acquirement images at the equal time as reducing the noise. The passive technique in polarization the images are area-gated in an active image and radiation image system in muddy water. Laser image systems are contiguous to light origin and target after in a turbid medium for source. Flash gate closed the blocking of backscatter and from the object of reflected light are selecting the system operates. The laser image method has the drawback of environment and complex device settings. Fluorescence techniques used to reclaim the undersea scene, it detects microorganisms in coral reefs by use of the fluorescence image. To remove the artificial light using the fusion method, estimate the detectable coefficient to reclaim the undersea images and real time algorithm assembled the stereo-images and it applied AUVs. In a method of polarization, restoration images have an important advantage of scattering, avoiding absorbing light. By detecting the radiation image is received to expressed as

FIGURE 6. Comparison of polarized images on submarine.

$$D(a, b) + B(a, b) = I(a, b) \tag{2}$$

The target signal $D(a, b)$ irradiance, dark medium reduce scattering, absorption. Particles in water caused by $B(a, b)$ backscatter is represent on Eqn.(2). In frequent years, widely they use single method of polarization to apply the submarine image restoration process. Degradation of undersea images is based on light polarization [56]. Artificial light has adjusted more images from surrounding light which has the same scene. The 3D information has collected more difficult photographs and reclaim the method for polarizer [57]. Impact of legitimate light and unequal illumination came from numerous orders of contrast reduction in the submarine images. Meanwhile the illumination of artificial light is proposed undersea image for non-uniform illumination issues, which clear the artificial bright [58]. Flashing source and obtaining the squared image for polarization dealt with backscatter. The method estimated and introduced a point transmission, which resulted in edge preserving to restore the image [57]. Method of rebuilding process to correct the low transmittance for polarization. The methodology can improve the aspect of the picture which has a low and high depolarization substance [59]. Backscatter and polarization to estimate the rate of strength in several locations of the picture which fixed the discussion on illumination of non-uniform [60]. In rehabilitation model has worked on the optimization of bio-inspire which has the zero reference picture of attribute measured as cost activity. The methodology process gave a best applicability to restoration of water intensity but the amount was problematic [61]. Proposed an undersea enrichment methodology to operate the unpaired illumination [62]. Meanwhile it compares the model polarization picture and it can make sure that the effective original light is ignored show on Fig. 6. In Table 5 Absorption light in the underwater image is viewed as blue-green, it occurs in submarine water of muddy substance which applies the scatter effect to reduce the variation.

C. PRIOR KNOWLEDGE METHODS

In the environment field of undersea images is identical through the misty images, dark channel prior holds to implement the restoration submarine images. Prior data computes

TABLE 4. Object imaging-based method.

Author	Method	Objective	Parameter	Advantages
[51]	Optimizing a quality criterion on global contrast	It perform various of image condition	Inverse Filtering Process	Classifier detecting the man-made object in sea images
[52]	Restoration approach to incorporating optical function	Image quality metric and Effectiveness optical	Spatial Frequency	Imagery-derived and optimization are estimate their proof
[53]	Color restoration	Simulating correct color rendering was crucial	Color render to simulate the images	Simulation improve the color rendering to reconstruction
[54]	Effective enhancement algorithm	Difference of light attenuation of atmosphere and water	Derived and estimate the scattering rate	Captured from turbid water
[55]	Autonomous underwater vehicles	Seafloor creature and material for physical contact	It reduce the density information and loss of data's	Reduce problem in acoustic communication

TABLE 5. Polarization models.

Author	Method	Objective	Parameter	Advantages
[56]	Degradation effects of polarization of light	Polarizer at different orientation of couple image	Empirical constants	Doubling the underwater visibility range
[57]	3D information of enhancement	Restored the image and 3D information	Noise sensitivity are limited	Photographic parts are difficult
[58]	Illumination of effect	Several directions of illumination and natural effect can do contrast reduction	Visibility frames are too little because of shadow contrast	Removed inference of artificial light
[59]	Polarization effect in object of image quality	Focused on transmission	Estimate the global and key images	Low depolarization object and low Visual quality image
[60]	Backscatter effect work on several location	Non uniform illumination	Estimate the strength of various location	Scatter image visibility clearance
[61]	Rehabilitation work on optimization process	Zero level of bio-inspire	Cost activity are measured	Water intensity are good applicability
[62]	Enrichment process of undersea	Illumination are unpaired process	Visibility of original picture	Effective light are removed

the medium of transmission outline, depending on prior information. To reduce the transmission process to clear significance of depth range, as contributed the original light turned into clean significance at the depth. Reference [63] Is often used to dehaze images. Among hazy outside image and undersea image, the channel of dark prior caused defogging approach is used to apply submarine image restoration. Undersea reclamation methodology minimizes the intricacy of execution. They apply color recovery to improve the contradiction and flashing are to recover the images, which restore the smooth carpeting with median cleaning to part image depth knowledge [64]. Both wavelength and picture are mud to clear the fabricate bright, adjust ternary channel along several depletion characters; some work has a response of dimness [65]. In [66] join DCP(Dark Channel Prior) which has quick joint analytical filtering to disparity exhaustion somewhere forward the manipulation path. To reduce scattering and hue cast, along with to increase picture edge information, contrast, joint analytical filtering could be increasing the estimative value to the traditional dark channel prior. The backdrop glow of undersea picture is based on subaquatic inherent optical properties derived by IFM (Image-formation-model). Relational both inherent optical BL and inherent optical properties, to reveal the coefficients of the three color channels. In The TMs of GB(Green-Blue) channel was derived from R channel, same as traditional DCP uses to estimate the R channels and they are the exponential connection between the attenuation coefficients [67]. The 0.1 high percent flashing picture element in DC (Dark channel), select the moderate range corresponding depth as shown in final background light of the input image [7]. The underwater image recovered by use of DCP and cleaned the scattering of the underwater image, simultaneously [68]. While comparing the original image suffered by more color distortion, it restored the images display as a limited improvement. Higher value of Red, Green, Blue channels was different, with the no more lowest directly selected in DCP. Channel R is strong attenuation, which method achieved an excellent performance. Proposed the restoration technique wavelength and Dark channel prior [69]. By the guidance of the trigonometric bilateral filter and color correction methodology to address the light scattering and color correction [70]. Reference [66] To increase the dark hazard section to overall contrast. DCP of underwater images used dehazing methodology with trilateral filters. Proposed a self-moving channel red in undersea image restoration approach that cut down attenuation and AI influence on transmission estimate. Thereby only G and B channels method which that R channel in serious attenuation. DCP and MDCP(multi dark-channel-prior) are compared for better recovery performance, but reliability and robustness are limiting the assumptions [11]. Using DCP Classical for color correction in underwater images. while calculating the depth of water scene to proposed the restoration methodology to create the blurriness and light absorption [10]. They introduced intensity difference prior set on (UDC) undersea-data-center by use of a new subaquatic picture model information [50]. The light of ambient has to determine the intensity of depth to dependent on glow changes, both intensity and ambient light was estimated to calculate the image of transmission by the restoration technique to analyze the DCP [71]. To estimate the attenuate ratio of green and red glow channel it relate to blue, which reduce the dedicate to one image de-haze images [72]. Using a color line model of restoration technique, produced a high-quality image of underwater natural color appearance [73]. They have several real-world submarine picture with numerous quality, number of locations is preferred for original undersea databases [74]. Proposed the two various schedule for water synthesis and calculate the depth location in aquatic. It has one big achievement to convert the dark air from RGB image of D channels that are different-model to synthetic of undersea pictures, object, structure get from input dataset images [3]. To clear up the drawback in the loss of the channel(red) in that after its process the glow correcting and also its information of picture are estimated in the kernel (fuzzy) of the concluded image to restored [75]. Table 6 shows the prior knowledge method different in recent years of research, its evaluation parameter suggests an estimation level of results.

D. CONVOLUTIONAL NEURAL NETWORK-RESTORATION

Convolutional neural network part of the network based methods, it's made up certain stacked layers. In output and input layer double the layer are between the input and output passage limited process of database has more layer connected. In Convolution neural network (CNN) could be automatic structure driven learning proceed using the table of unreal undersea picture. Increase the overall appearance of undersea picture while using the white balance algorithm. Among the balance of white of the CNN is use environment light range to calculate the intermediate of transmission map and last to restore the submerged picture. The multiscale deep neural network is improved network for calculate the map of depth and ambient light energy and consisting the rough stacked CNN models. To produce the good quality, the restored underwater images and then other prevailing based on IFM in restoration algorithm. Using restoration methods to measure the surrounding light, TM (Transmission maps), with fast development of deep learning restoration methods. By research they have already importantly changed the parameter selection of artificial optimization models to automatic trained models that are used to current data to feature vector parts. Original underwater images gave good quality by applying the new white balance algorithm, then it accepted the traditional (CNN) convolutional neural network that are used to valuation the backlight and (TM) transmission map of color correction, as well as end of an image is restored on IFM. Since preprocessing an image through color correction loses the characters of the sea environment, the restored image could be over-saturated and enhanced [76]. Proposed a multi-scale deep network was stacked to assess CNN network and refined network that are predicted scene depth map and also estimated the background light. This method claims better results than using the existing IFM-based restoration method [69]. Proposed to build up the optical quality of image in absence of field truth and image glow, based on the CNN method by setting the image clearance metric by the guidance of the restoration process rather than ground truth data [77] and Fig.7 show the low quality of underwater images use of parameter calculation of convolutional process with transmitted to restoration process with finally give the quality enhanced image from the given images. To increase the optical quality of the water appearance, their edges have persevered. To calculate the map transmission of data-driven constructing the driven knowledge process of image has production residual process of ocean balance of illumination and to investigate the basic distribution of correct color [78]. Necessary to research the image quality evaluation for enhancement and restoration process.

Through feature learning of BLs or depth map are estimated image restoration processes of CNN, which perform the network scheme, trained item due to manufactured the image and possible defect of architecture in deep

TABLE 6. Prior knowledge methods.

Author	Method	Objective	Parameter	Advantage
[63]	Dark channel prior	Haze and recover high factor of image	Recover the aspect of haze free picture and estimate the thickness of the images	Haze removal the high quality depth map
[64]	Enhancement of dark channel prior	Color contrast to enhance	Effective enhance while in execution time	Reduce the Navigation in real time
[65]	Attenuation discrepancy propagation path	Light scattering and color distortion	Ratio of color patches and it estimate the different color channels	Wavelength compensation and image dehazing of truth color patches
[67]	Image formation model	Camera are recover and enhance image	Depth different and pixel blurriness	Different lighting condition while enhancing
[68]	Heavy fog using DCP	Local patches in water image	Estimate the local patches in water image, which as low intensities	turbid water removed and clarity of image
[66]	Scattered and absorbed of wavelength	To produce the gradient artifact problem in trilateral filters	Exposure the dark region and reduce the noise level	Evaluation of quantitative not covered
[10]	Image blurriness and light adsorption	Handle naturally illumination areas	Estimate illustration in each patch for each factorization	Need more information about the images.
[50]	Adaptive transmission fusion	Visual image are not restored	Optical image to calculate the surrounding light ,TM.	Backlogs of robustness
[72]	Light attenuation prior	Depth estimate using image blur and absorption	Optimization the default values in Max depth and min depth	Both estimates are difficult
[73]	Blurred image formation	Display the properties of color-lines prior	Gain and offset of linear transformation	Use more optimization parameters

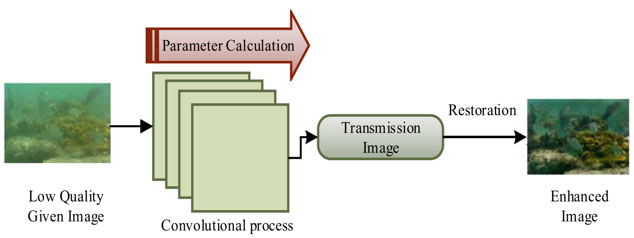

FIGURE 7. Flowchart of low quality picture extract of transmission range to enhanced image.

learning(DL) and trained networks adapt the few aquatic images. Using the DL methodology expend time intensity of the restoration environment by both models physical and non-physical.

V. DATASET

The underwater database is an enhancement substance, natural database in Deep Learning training images, it tests algorithm performance for underwater image and video for enhancement. Several well-known datasets have been developed in the work of several researchers. Water-GAN was used to create the database of Royal port [79]. In vison of datasets are created by taking images of several poses and situations undersea [17]. The collection images item of various area, measure water levels that developed evidence annotation to expand the SQUID (Stereo Quantitative underwater image dataset) file items [74]. Founded a large-scale of original water image increase benchmark data, which contains undersea images with varying degrees of decline as well as high-quality reference images [12]. The natural submarine image enhancement is established and used to begin the varied-view undersea figure. Image range set, submarine glow deviation part, which has different leading mission operator are included [16]. While recording the ocean video from several cameras and networks, which manufactured the EUVP (Enhancing Underwater visual perception) dataset of paired (12000) and unpaired (8000) images shown in Fig. 8 [15]. The five hundred images of various scenes and color exaggeration levels are standard named as environment light and estimated as the underwater images [14]. To proposed an image enhancement dataset available for the experiment, which contained an infinite variety of images. If images are used only in testing processing rather than training purposes, the required dataset may have better result in enhancement methods [80]. Enhancement methods have three steps to preserve the information in the natural appearance of dual image

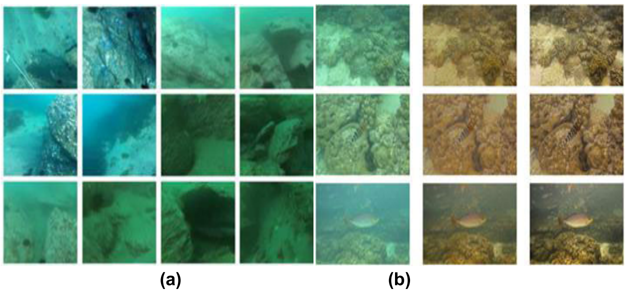

FIGURE 8. Underwater image of sample respected a) real underwater image and b) raw image the result of enhancement image [74].

wavelet fusion in edge and also it covers the homomorphic filtering [81]. The collection of paired and unpaired dataset of image are (11,000 and 9000) in Fig. 9, [15] that are gather the capture picture from different digital cameras, various clarity conditions using human robot and internet underwater image and video by enhancing underwater visual perception. Images from different locations and various water quality ranges have made data observations. It depends on the water surface and covers the 3D structure with different scenes. Moreover, the growth of 3D structure [74] which has been calculated from the stereo images. Restored images have different types of lead images and use of the parameter in global attenuation ratio, automatically chosen the color distribution. Datasets of underwater images for training set are 1004 green, 1030 blue images from the sun, chosen randomly images from dataset 1600 hazy images, shown in Fig. 10. In deep learning methods reach lower perceptual scores to higher perceptual scores from input to output. As among the color deviation in SQUID, non-reference image quality level, dataset for undersea shown in Table 7. Two version enhance the images to correction to scatter for remove the de-haze factor. While analyzing the image quality of water images with the use of enhancement and restoration techniques, established the quality evaluation database. Mainly, the collection of real underwater images included the underwater environment of a constructed dataset; three classic underwater images are different colors like blue, green, and haze. Selecting images close range of brightness, dark, whole of bright. Using different methodologies of image enhancement, and restoration, deep learning and traditional methods including underwater dark channel prior, real enhancement dataset, cycle-GAN, UGAN(Unsupervised-Generative-Adversarial-Network). In EUVP contains over 7446 underwater images, preferred the three standard metrics, entropy information and undersea image quality measure [15] and also help of Large scale enhancement image of submarine image dataset with test and trail images shown in Fig. 11. Values lower of information entropy reflect a good performance and average gradient and underwater image quality measure are opposite.

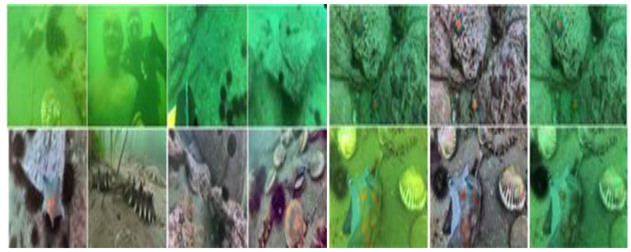

FIGURE 9. Sample on undersea degraded image in form [81].

FIGURE 10. Different level of undersea image in enhancement process [15].

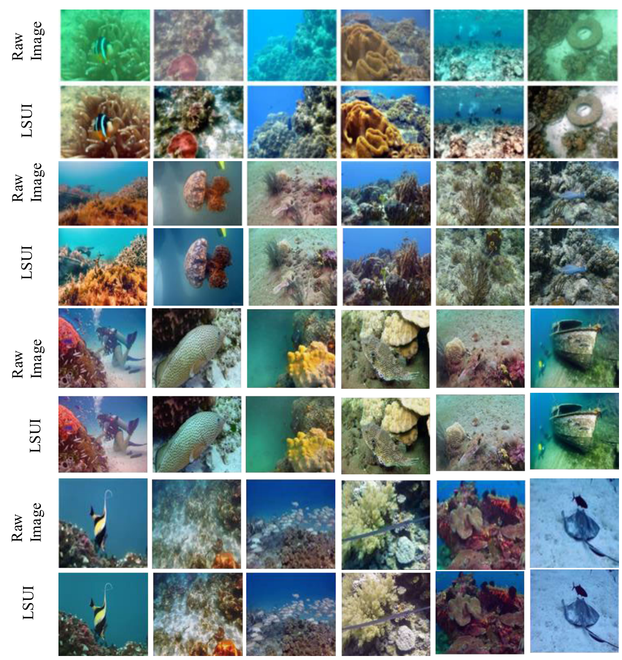

FIGURE 11. Comparison of raw image to large scale enhancement image make result from underwater [15].

VI. UNDERWATER QUALITY EVALUATION

The essential role played in modifying the design of optimization of the optical image system, transmission picture, and image improvement and renovation, intensity retrieval and allotment these are works under the image quality assessment (IQA) method. Some objective used in this method

TABLE 7. Undersea dataset and location.

Author	Fulfilled	Location
UOT32	Performance on tracking target in water environment	https://www.kaggle.com/datasets/landrykezebou/uot32-underwater-object-tracking-dataset
AUV	Equipped with a stereo rig which representative different scenarios	https://github.com/xinzhichao/Underwater_Datasets.git
Brackish	Located 9m below surface and single LED light.	https://www.kaggle.com/datasets/aalborguniversity/brackish-dataset
ONC	Scenes with sub-optimal light variety of real-world in enhancement method.	https://github.com/tunai/l2uwe/tree/master/data/OceanDark2_0
SQUID	Different spectral profile of different water types.	https://github.com/danaberman/underwater-hl
LSUI	Attenuation in different color channels and space areas for boosted enhancement	https://github.com/LintaoPeng/U-shape_Transformer_for_Underwater_Image_Enhancement

is to classify by the help of a reference image. Traditional objective evaluation methodology has to evaluate distortion of noise in Gaussian method of picture view by air, which is an authentic level of mixed degradation induced by water bodies; it fails to validate the quality of water model. Nil number of reference picture density metric to part perceptual image element. In the subjective quality evaluation on Underwater image quality evaluation datasets, stimulation results are displayed image-enhancing by various methods. Structural similarity metric that considers the image degradation a structural distortion [82]. UIQM (Underwater-image-quality-measurement) for Non-reference includes the sharpness, colorfulness, undersea images [83]. To propose the human perception methodology, the high dynamic range visual had various predictors two, which predicted both the appearance of the artifact and gave the overall quality of an underwater image [84]. The approach of UCIQE (undersea-image and quality-evaluation) used a even pairing of Chroma, intensity, shading of water image used in CIE-lab of color space [85]. Worn to evaluate the image quality and image sharpness [86]. To introduce the angular error to evaluate technique robustness and method to behavior to respect underwater noises [87]. To evaluate the structure and color of images while evaluating that results are similar [87]. To measure grayscale image underwater quality by use of global contrast [56]. Table 8 discussed about the evaluation metric of UWE are compare the Haze line, color correction, cycle-GAN, Global Histogram, Image light, Fusion based, Rayleigh Distribution, Singles image, Maximum intensity. Proposed weighted grayscale angle (WGSA) to measure the quality of restored image metric for scattering blur of the underwater image [88]. Measured grayscale histogram to exponential distributions that are defined robustness of index [89]. The deviation angular between the approximated momentum and existing one has measured by the true sequence of the video underwater. In the methodology of the robustness of image noise removal quantitatively [86]. Underwater quality duration methodology, that image colorfulness measurement, sharpness measurement, and contrast measurement were combined to evaluate image quality. The application choice depends on weighted coefficients. When evaluating the color deviation of the water image for example higher underwater image color metric has been assigned. Table 9 show the estimation formulas of Transmission Map (TM) and Brightness Light (BL) and framework of UWE with channel discuss of preliminary.

VII. DEHAZING IMAGES OF UNDERWATER

Underwater image dehazing process of crucial which counteract the effect of water absorption and scattering to retrieve a clearer image. The simplified equation representing the degradation in an underwater image, similar to atmospheric image degradation, is

$$I_{ww}(x, y) = J(x, y) \times T(x, y) + A(1 - T(x, y))$$

$I_{ww}(x, y)$ observed underwater image at pixel location(x,y). J(x,y) true (haze-free) image at pixel location (x,y). T(x,y) transmission map at pixel location (x,y) to measure the fraction of the light from the scene point that reaches the camera without being scattered [88]. The transmission is generally lower in turbid water and greater in clear water. The global atmospheric light A, which is a constant that represent the intensity of the ambient light underwater. In the context of underwater imaging, this can be thought of as the background light level due to scattering. For a typical outdoor image, this is the intensity of the haze itself. The primary objective of dehazing algorithms is to estimate J and T from the observed image I_{ww}. Once we can accurately estimate these two components, we can restore the haze-free image using the model [89]. There are various methods to estimate the transmission T and the ambient light A, ranging from classical image processing techniques to more modern deep learning-based methods. Once these are estimated, J can be obtained using the above equation by rearranging for J. $J(x, y) \times T(x, y)$ represents the attenuated object radiation It capture the decrease in direct visibility of the object due to water properties. A(1-T(x,y)) models the scattered ambient light which adds a veil or haze over the image. The dehazing the original scene J from the observed underwater image I, the challenge is to accurately estimate T and A. Once these are known, the object radiance J can be retrieved.

VIII. TECHNICAL CHALLENGES OF IMAGE ENHANCEMENT

Underwater optical imaging is confronted with unique challenges that can degrade the quality of captured images. While there are many techniques available for image enhancement and restoration, implementing them for underwater application poses several technical challenges. Fig. 12 here are some of those challenges:

TABLE 8. Quality evaluation metric of UWE dataset.

Assessment metrics	Compare the method for quality evaluation								
	Haze Line	Color correction methods	Cycle GAN	Global Histogram stretching Methods	Image Light Absorption	Fusion Based	Rayleigh Distribution	Singles image removal	Maximum intensity prior
Average Gradient(AG)	7.3022	4.9102	6.4738	7.5425	6.8722	7.5269	7.7487	6.3973	3.7631
Information Entropy(IE)	7.4034	7.3955	7.2785	4.2002	3.8512	2.7567	3.2654	0.1605	3.5161
Quality measure (QM)	4.0710	3.8220	4.8381	3.6472	3.5456	6.8470	3.5331	4.6140	2.2616

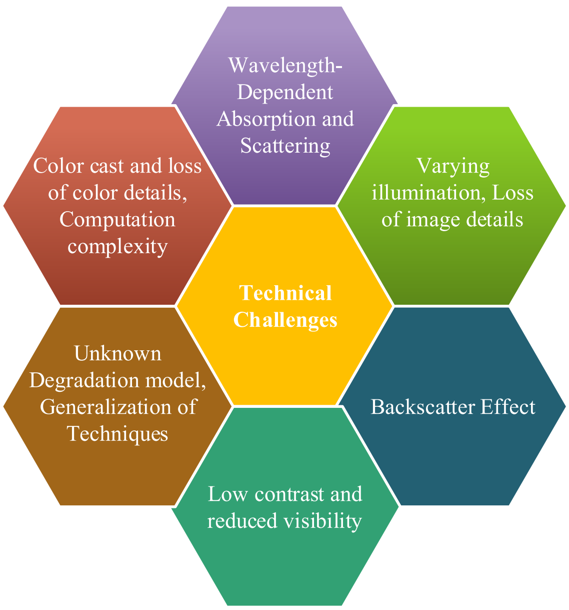

FIGURE 12. Technical challenges in underwater image enhancement.

A. WAVELENGTH-DEPENDENT ABSORPTION AND SCATTERING

Water absorbs different wavelengths of light unevenly. As a result, red and yellow wavelengths are absorbed more quickly than blue and green ones, leading to a predominant blue/green hue in underwater images [90]. Light scattering due to suspended particles and water molecules causes the blurring of images. Handling this non- uniform scattering is a challenge for restoration algorithms. Chlorophyll and phytoplankton in costal and oceanic water, the presence of chlorophyll and phytoplankton result in strong absorption in the blue, red parts of the spectrum due to photosynthesis. Wavelengths are shorter scattered more efficiently by small particles and molecules in the water. This phenomenon is known as Rayleigh scattering and contributes to the blue colors of water. Mie scattering are larger particles, such as suspended sediments and phytoplankton, tend to scatter light of longer wavelengths more effectively. In penetration of light the depth to which light can penetration in water is often measured using secchi disk. In clear oceanic water, light can penetrate to depths of sveral tens of meter, while in turbid coastal water, penetration may be limited to just a few meteres. Application applied related in underwater light crucial for various application including oceanography, photography and remote sensing from satellites or vehicles. Fisheries management relies on understanding the interaction of light with water to monitor phytoplankton blooms and assess the health of aquatic ecosystems.

B. VARYING ILLUMINATION

Due to absorption and scattering, the farther an object is from the camera, the darker it appears. This non- illumination poses challenges for global enhancement techniques [91], which may not work across the entire image. As descend deeper underwater the intensity of natural sunlight decreases significantly due to the absorption and scattering of light by water molecules and particles. This results in varying light levels with depth, making it progressively darker as you go deeper. Water clarity varies greatly in different underwater environments. Open ocean water relatively little suspended particulate matter, resulting in better visibility and more consistent illumination. In contrast, coastal or turbid water may contain a significant amount of suspended particles, leading to rapid fluctuation in illumination due to the scattering of light. Natural sunlight varies throughout the day, affecting the angle and intensity of illumination underwater. Cloud cover and weather condition can further influence the available light and its direction. Artificial light are different in undersea level, it have various properties and behaviors compared to natural sunlight, affecting how they interact with underwater subject and scenes.

C. BACKSCATTER EFFECT

When artificial light sources, like flashlights or camera flashes, are used underwater, light can bounce back from suspended particles before reaching the subject. This creates a "snowy" appearance known as the backscatter effect [92], which is challenging to remove without affecting image details. Backscatter is primarily caused by the scattering of light by suspended particles, Plankton, and other small debris in the water. When artificial light hits these particles, some of the light scatters in various direction, including back toward the camera lens. The appearance of backscatter typically appears as bright, white specks or spots in underwater images, resembling a snowstorm effect. The intensity and density of backscatter can vary depending on the water clarity, the amount of suspended particles, the angle and intensity of the artificial lighting. Backscatter tends to be more prominent at shallower depths, where more light is needed to properly illuminate the subject. As you go deeper, natural light levels decrease, and the backscatter effects become less pronounced.

D. LOW CONTRAST AND REDUCED VISIBILITY

Underwater images usually suffer from low contrast because of the limited range of light wavelengths reaching the camera [93]. Particulates in the water, like plankton or floating debris, can further scatter light reducing image clarity and increasing noise.

E. UNKNOWN DEGRADATION MODEL

Unlike some imaging environments where the degradation can be modeled with high accuracy(e.g., camera shake) [94], underwater imaging degradation is influence by many factors, making it hard to create an accurate model for restoration. Turbulence and water flow caused currents, tides and other fluid dynamics can introduce unpredictable fluctuation in the optical properties of the water. This turbulence can affect the scattering and absorption of light, leading to variation in signal quality. The suspended particles, such as sand, slit or plankton in the water can lead to scattering and absorption of optical signals. The density and distribution of theses particles can changes rapidly, making it challenging to predict their effects on signal degradation. Some marine organisms, such as certain types of plankton and jellyfish, produce bioluminescent light, which can introduce unexpected sources of interference in underwater optical systems. These bioluminescent events can be sporadic and difficult to predict. The quality of water in terms of clarity and color can vary significantly across different underwater location and over time. Factors such as pollution sedimentation and algae blooms can lead to rapid and unpredictable changes in water quality.

F. COLOR CAST AND LOSS OF COLOR DETAILS

The Prevailing blue/green hue in underwater images can mask other color [95]. Techniques to correct this color cast might also inadvertently alter other true color in the image. The color cast may manifest as blue or green tint in underwater images and videos. The extent of the color cast depends on the depth, water clarity and the presence of suspended particles. To correct color cast, underwater photographers often use color- correction filters or post processing software designed to restore natural color. These filters or adjustment help compensate for the selective absorption of light, bringing back accurate and vibrant colors.

G. TEMPORAL VARIATION

The underwater environment isn't static. Movement of water, changing lighting conditions, and varying amounts of suspended matter can mean that the degradation model changes over time [96], even within a short period. Tides are the periodic rising and falling of water level along coastlines, driven by the gravitational pull of the moon and the sun. They cause significant temporal variation in water depth and flow patterns in coastal and estuarine areas. Strong tidal currents can affect navigation and underwater habitats. Underwater ecosystems experience seasonal variation in temperature, light availability and flood resources. These changes can affect the behavior, migration patterns and reproductive cycles of marine species. Water temperature can fluctuate seasonally and diurnally. These temperature variations influence the distribution of marine life, the metabolic rates of organisms and the growth of phytoplankton and algae. Anthropogenic effects human activities, such as pollution, overfishing coastal development and shipping can introduce long term and short term temporal variation in underwater ecosystems. These effect can lead to habitat degradation, changes in species composition, and alteration in underwater landscapes.

H. COMPUTATION COMPLEXITY

High-quality restoration techniques often involve complex computations. Implementing these in real-time scenarios like live video feeds from underwater drones [97], can be technically challenging and resource-intensive.

I. LOSS OF IMAGE DETAILS

Enhancing contrast or removing haze can sometimes lead to a loss of fine details in the image. Striking a balance between enhancement and preserving details is challenge [98]. Color shift water selectively absorbs different wavelengths of light, leading to a color shift underwater scenes. Red and warm color are absorbed more quickly resulting in a blue or green color cast. Color distortion can make it challenging to capture the true colors of underwater subject and can contribute to the loss of color details. Color correction filter or post processing techniques can help restore accurate color. These filters are designed to compensate for the color shift caused by water absorption, allowing for more natural and vibrant color rendering. Clarity of presence suspended particles, such as plankton or sediment can reduce water clarity and contribute to a loss of image details. The suspended particles can create snowstorm effect in images reducing contrast and image clarity. Deeper underwater environment often has reduced visibility and may require more powerful lighting systems to capture fine details.

J. GENERALIZATION OF TECHNIQUES

Techniques optimized for one type of underwater (e.g., clear oceans waters may not work as well in another (e.g., turbid lake waters) creating universally applicable techniques is challenging. Color correction filters and post processing software can be used to generalize color correction techniques to restore accurate colors in underwater images and videos. Proper strobe placement and angle can be applied across different underwater scenes to minimize backscatter and enhance subject illumination. Remote sensing techniques, including satellite imagery and underwater drones equipped with sensors, can be applied to collect data and conduct research on marine life and ecosystem in diverse underwater settings.

IX. SOLUTION TO THE CHALLENGES

Addressing the technical challenges of image enhancement and restoration for underwater optical imaging requires a blend of traditional methods, innovative approaches and advancements in technology. Here are potential solution to the challenges previously outlined:

A. WAVELENGTH-DEPENDENT ABSORPTION AND SCATTERING

In spectral compensation Implement spectral compensation techniques to adjust the color balance based on the absorption rates of different wavelengths. Use polarized filters to reduce scattering, especially in sunny conditions.

B. VARYING ILLUMINATION

Adaptive Histogram Equalization method processes different section of the image separately, addressing the issue of non-uniform illumination. Local enhancement techniques algorithm enhance image quality based on local information can handle varying illumination better than global methods. The color of light can change with depth due to varying absorption of different wavelengths. This color temperature shift can affect the color balance in underwater image videos, requiring post processing correction.

C. LOW CONTRAST AND REDUCED VISIBILITY

The technique of CLAHE enhance contrast without overly amplifying noise. In gamma correction adjusting the brightness and contrast of images, gamma correction can enhance the visibility of underwater objects.

D. BACKSCATTER EFFECT

Originally designed for haze removal in terrestrial images, this method can be adapted for backscatter removal in underwater images. Blind Deconvolution techniques estimates the original images and the point spread function simultaneously without knowledge of the degradation function. Adjusting the angle and position of underwater strobes or light can help minimize backscatter. Positioning the strobes farther from the camera lens and slightly above the subject can reduce the chances of illuminating particles directly in the camera line of sight.

E. UNKNOWN DEGRADATION MODEL

Deep learning models of neural networks, especially convolutional neural networks (CNNs), can be trained to restore underwater images without a predefined degradation model. Multiple image fusion combine images taken under different conditions or setting to create a clearer composite image.

F. COLOR CAST AND LOSS OF COLOR DETAILS

White balancing algorithms correct the blue/green hue to restore natural colors in the underwater scene. Color transfer extract color properties from a reference image and apply them to the degraded image. The selective absorption of light underwater not only leads to color cast but also result in loss of color details and contrast. Colors may appear less vivid and distinct, making it challenging to capture the full spectrum of color present in a scene. Underwater image can appear washed out and lack the vibrant color that are visible to the naked eye. Fine color details and shades may be lost in the process.

G. TEMPORAL VARIATION

Adaptive algorithm to develop algorithms that can dynamically adjust their parameters based on the changing underwater environment. Real-time feedback loops use real time analytics to adjust imaging parameters on the fly.

H. COMPUTATIONAL COMPLEXITY

Hardware acceleration use dedicated hardware like GPUs to speed up complex computation for real-time processing. Optimized Algorithms streamline algorithms for specific tasks to reduce computational overhead.

I. LOSS OF IMAGE DETAILS

Multi-scale Processing enhance image at different scales and combine them to ensure both global enhancement and details preservation. Regularization techniques implement techniques like total variation regularization to preserve edges and details

J. GENERALIZATION OF TECHNIQUES

Transfer learning use pre-trained deep learning models and fine-tune them for specific underwater conditions. Hybrid approaches combine multiple enhancement techniques to create a more robust and adaptive solution.

X. APPLICATION IN UNDERWATER IMAGES

In recent years, underwater image application processing in various domains and systems, even the development of underwater image intelligence has increased it application show on Fig. 13. Few domains are protected by underwater archaeology, tracking underwater objects, water environment monitoring shown on Table 10.

TABLE 9. Formulas of TM and BL estimation.

Framework	TM Estimation	Preliminary	Brightness light (BL) Estimation
Difference of R G and B Channel	$t^c = MIP^c(x) + (1 - minMIP^c(x))$	Maximum intensity prior	$I^c(\arg\min MIP^c(x))$
Investigate the data driven to estimate the knowledge scene	$t^c = 1 - min_{y\in\cap(x),c}(I^c(y)B^c$	Dark channel prior	$I^c(\arg max\ P^c(x)$
95 use to eliminate the red channel	$t^c = 1 - min_{y\in\cap(x),c'}\left(\frac{I^{c'}(y)}{B^{c'}}\right)$	Underwater dark channel prior	$I^c(\arg max\ P^c(x))$
Depth estimate based on the rapid and effective scene	$t^c = Nrer_c^{d(x)}, d(x) = ULAP(x)$	Underwater light attenuation prior	$I^c\ (arg\ max_{x\epsilon p0.1\%} d(x))$
More background and scene depth are restored by the various scene	$[\theta_a d_D + (1-\theta_a)d_R] + (1-\theta_b)d_B$	Image blurring and light absorption	$\alpha B^k_{max} + (1-\alpha)B^k_{min}$

TABLE 10. Applications of underwater image processing.

Application	Description
Underwater Archaeology	Enhancing water images for archeological process
Marine biology	Analyzing marine organisms
Inspection of underwater	Visibility improvement for accessing the infrastructure
Robotics	Enhancing image quality for autonomous
Surveillance	Visibility enhance for undersea surveillance systems
Mapping undersea	Processing image for mapping and charting
Photography	Visual quality enhancing in underwater
Video Analytics	Monitoring and different analyzing for sea water

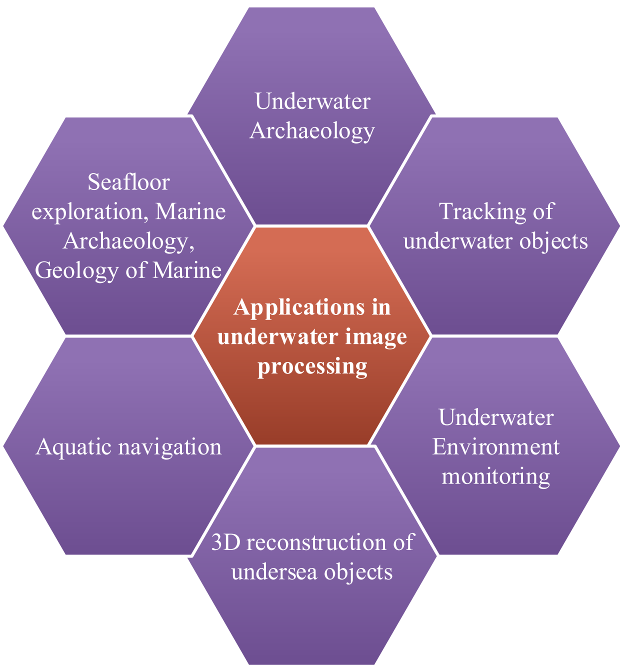

FIGURE 13. Applications of underwater image processing.

- Underwater Archaeology- The historical records are frequently used in underwater archaeology. The archaeological researcher studied changes in underwater minerals, trace the submerged sites.
- Tracking of underwater objects- several applications on underwater object detection. They have some influence of light and turbidity and visibility is very poor in a water environment because of the light optical camera.
- Underwater Environment monitoring- Appliance collect the information about the surrounding of submarine monitoring material show through the asteroid.
- 3D reconstruction of undersea objects-reconstructing 3D surface is a difficult task due to the degraded quality of images.
- Aquatic navigation- Using robots/automobile build upon the clearness of water images or video can rectify by construction map.
- Seafloor exploration- Collecting database about the venting of hydrothermal and geomorphology, and behavior of the deep sea. The main purpose of scientific research in natural, synthetic and organic enclosing the sea beds.
- Marine Archaeology- Human research with pond, sea, lake by the communication to finding the natural remains and seaboard-side.
- Geology of Marine- In structure of seaboard in details in sea floor is called marine geology. Paleontological includes investigating the ocean ground, it also joined with the coastal zone.

XI. CONCLUSION

In underwater image enhancement system for synthesis and estimation in depth map, it collects the various number of database in submarine picture in sea surrounding. The field of rehabilitation are color image to scatter the details of muddy particles recognized the undersea snow. Some issues happen in undersea of enhancement, restoration. In image processing has new area is underwater for research field to make more things up to now to explored. Regarding they submarine process of various problem to attempted which on sea engineering. So in that to discussed the restoration system mapping to increase of undersea images. The main reasons for underwater images are classification of enhancement methods and restoration methods of existing systems and also summarized the main objective and advantage. In addition to increase the condition of the water images and some issues with clearness of the water, absorption of light, attenuation process and contrast and removing crash instant of the collected images. The application of these techniques to degrade underwater images ignores the fact that the loss of contrast in a picture is corresponding to the length between the near to substance of the camera and images. In natural and artificial underwater images, brightness and high contrast is required for detecting objects in water resources. In methods require some additional process for the enhancement method handle the various kind of degraded part of images.

REFERENCES

[1] R. Srivastava, *Research Developments in Computer Vision and Image Processing: Methodologies and Applications*. Hershey, PA, USA: IGI Global, 2013.

[2] C. Ancuti, C. O. Ancuti, T. Haber, and P. Bekaert, ''Enhancing underwater images and videos by fusion,'' in *Proc. IEEE Conf. Comput. Vis. Pattern Recognit.*, Jun. 2012, pp. 81–88

[3] Q. Zhao, Z. Zheng, H. Zeng, Z. Yu, H. Zheng, and B. Zheng, ''The synthesis of unpaired underwater images for monocular underwater depth prediction,'' *Frontiers Mar. Sci.*, vol. 8, Sep. 2021, Art. no. 690962.

[4] A. S. A. Ghani and N. A. M. Isa, ''Enhancement of low quality underwater image through integrated global and local contrast correction,'' *Appl. Soft Comput.*, vol. 37, pp. 332–344, Dec. 2015.

[5] A. M. Reza, ''Realization of the contrast limited adaptive histogram equalization (CLAHE) for real-time image enhancement,'' *J. VLSI Signal Process.-Syst. Signal, Image, Video Technol.*, vol. 38, no. 1, pp. 35–44, Aug. 2004.

[6] R. Ferrari, J. X. Leon, A. J. Davies, J. H. R. Burns, S. A. Sandin, W. F. Figueira, and M. Gonzalez-Rivero, ''Advances in 3D habitat mapping of marine ecosystem ecology and conservation,'' *Frontiers Media Sci.*, vol. 8, Jan. 2022, Art. no. 827430.

[7] Y.-T. Peng, X. Zhao, and P. C. Cosman, ''Single underwater image enhancement using depth estimation based on blurriness,'' in *Proc. IEEE Int. Conf. Image Process. (ICIP)*, Sep. 2015, pp. 4952–4956.

[8] P. L. J. Drews, E. R. Nascimento, S. S. C. Botelho, and M. F. Montenegro Campos, ''Underwater depth estimation and image restoration based on single images,'' *IEEE Comput. Graph. Appl.*, vol. 36, no. 2, pp. 24–35, Mar. 2016.

[9] G. Hou, J. Li, G. Wang, H. Yang, B. Huang, and Z. Pan, ''A novel dark channel prior guided variational framework for underwater image restoration,'' *J. Vis. Commun. Image Represent.*, vol. 66, Jan. 2020, Art. no. 102732.

[10] Y.-T. Peng and P. C. Cosman, ''Underwater image restoration based on image blurriness and light absorption,'' *IEEE Trans. Image Process.*, vol. 26, no. 4, pp. 1579–1594, Apr. 2017.

[11] A. Galdran, D. Pardo, A. Picón, and A. Alvarez-Gila, ''Automatic red-channel underwater image restoration,'' *J. Vis. Commun. Image Represent.*, vol. 26, pp. 132–145, Jan. 2015.

[12] C. Li, C. Guo, W. Ren, R. Cong, J. Hou, S. Kwong, and D. Tao, ''An underwater image enhancement benchmark dataset and beyond,'' *IEEE Trans. Image Process.*, vol. 29, pp. 4376–4389, 2020.

[13] A. Duarte, F. Codevilla, J. D. O. Gaya, and S. S. C. Botelho, ''A dataset to evaluate underwater image restoration methods,'' in *Proc. OCEANS Shanghai*, Apr. 2016, pp. 1–6.

[14] W. Song, Y. Wang, D. Huang, A. Liotta, and C. Perra, ''Enhancement of underwater images with statistical model of background light and optimization of transmission map,'' *IEEE Trans. Broadcast.*, vol. 66, no. 1, pp. 153–169, Mar. 2020.

[15] M. J. Islam, Y. Xia, and J. Sattar, ''Fast underwater image enhancement for improved visual perception,'' *IEEE Robot. Autom. Lett.*, vol. 5, no. 2, pp. 3227–3234, Apr. 2020.

[16] R. Liu, X. Fan, M. Zhu, M. Hou, and Z. Luo, ''Real-world underwater enhancement: Challenges, benchmarks, and solutions under natural light,'' *IEEE Trans. Circuits Syst. Video Technol.*, vol. 30, no. 12, pp. 4861–4875, Dec. 2020.

[17] M. Jian, Q. Qi, J. Dong, Y. Yin, W. Zhang, and K.-M. Lam, ''The OUC-vision large-scale underwater image database,'' in *Proc. IEEE Int. Conf. Multimedia Expo (ICME)*, Jul. 2017, pp. 1297–1302.

[18] M. Yang, K. Hu, Y. Du, Z. Wei, Z. Sheng, and J. Hu, ''Underwater image enhancement based on conditional generative adversarial network,'' *Signal Process., Image Commun.*, vol. 81, Feb. 2020, Art. no. 115723.

[19] A. S. A. Ghani and N. A. M. Isa, ''Underwater image quality enhancement through Rayleigh-stretching and averaging image planes,'' *Int. J. Nav. Archit. Ocean Eng.*, vol. 6, no. 4, pp. 840–866, Dec. 2014.

[20] C.-Y. Cheng, C.-C. Sung, and H.-H. Chang, ''Underwater image restoration by red-dark channel prior and point spread function deconvolution,'' in *Proc. IEEE Int. Conf. Signal Image Process. Appl. (ICSIPA)*, Oct. 2015, pp. 110–115.

[21] X. Fu, P. Zhuang, Y. Huang, Y. Liao, X.-P. Zhang, and X. Ding, ''A retinex-based enhancing approach for single underwater image,'' in *Proc. IEEE Int. Conf. Image Process. (ICIP)*, Oct. 2014, pp. 4572–4576.

[22] S.-L. Wong, R. Paramesran, and A. Taguchi, ''Underwater image enhancement by adaptive gray world and differential gray-levels histogram equalization,'' *Adv. Electr. Comput. Eng.*, vol. 18, no. 2, pp. 109–116, 2018.

[23] P. R. Shinde and Dr. K. V. Kulhalli, ''A review on comparative analysis of different underwater image enhancement techniques,'' *Int. J. Res. Applied Sci. Eng. Technol.*, vol. 7, no. 1, pp. 853–855, Jan. 2019, doi: 10.22214/ijraset.2019.1136.

[24] C. Gao, L. Zha, S. Huang, Q. Li, J. Wu, and T. Zhang, ''An image contrast fusion enhancement algorithm based on retinex,'' in *Proc. 4th Int. Congr. Image Signal Process.*, Oct. 2011, pp. 660–664.

[25] S.-L. Lee and C.-C. Tseng, ''Low-illuminated image enhancement using power law transformation and image fusion,'' in *Proc. IEEE Int. Conf. Consum. Electron.-Taiwan (ICCE-TW)*, May 2018, pp. 1–2.

[26] X. Fu, D. Zeng, Y. Huang, Y. Liao, X. Ding, and J. Paisley, ''A fusion-based enhancing method for weakly illuminated images,'' *Signal Process.*, vol. 129, pp. 82–96, Dec. 2016.

[27] S. Park, B. Moon, S. Ko, S. Yu, and J. Paik, ''Low-light image enhancement using variational optimization-based retinex model,'' in *Proc. IEEE Int. Conf. Consum. Electron. (ICCE)*, Jan. 2017, pp. 70–71.

[28] A. Saleem, A. Beghdadi, and B. Boashash, ''Image fusion-based contrast enhancement,'' *EURASIP J. Image Video Process.*, vol. 2012, May 2012, Art. no. 10.

[29] O. K. Soni and J. S. Kumare, ''A survey on underwater images enhancement techniques,'' in *Proc. IEEE 9th Int. Conf. Commun. Syst. Netw. Technol. (CSNT)*, Apr. 2020, pp. 333–338.

[30] C. O. Ancuti, C. Ancuti, C. De Vleeschouwer, and P. Bekaert, ''Color balance and fusion for underwater image enhancement,'' *IEEE Trans. Image Process.*, vol. 27, no. 1, pp. 379–393, Jan. 2018.

[31] X. Liu, G. Zhong, C. Liu, and J. Dong, ''Underwater image colour constancy based on DSNMF,'' *IET Image Process.*, vol. 11, no. 1, pp. 38–43, Jan. 2017.

[32] D. Vijayalakshmi, M. K. Nath, and O. P. Acharya, ''A comprehensive survey on image contrast enhancement techniques in spatial domain,'' *Sens. Imag.*, vol. 21, no. 1, p. 40, Dec. 2020.

[33] L. A. Torres-Méndez and G. Dudek, ''Color correction of underwater images for aquatic robot inspection,'' in *Proc. Int. Workshop Energy Minimization Methods Comput. Vis. Pattern Recognit.*, in Lecture Notes in Computer Science, 2005, pp. 60–73.

[34] K. Iqbal, M. Odetayo, A. James, R. A. Salam, and A. Z. H. Talib, ''Enhancing the low quality images using unsupervised colour correction method,'' in *Proc. IEEE Int. Conf. Syst., Man Cybern.*, Oct. 2010, pp. 1703–1709.

[35] A. S. A. Ghani and N. A. M. Isa, ''Underwater image quality enhancement through integrated color model with Rayleigh distribution,'' *Appl. Soft Comput.*, vol. 27, pp. 219–230, Feb. 2015.

[36] A. S. A. Ghani and N. A. M. Isa, ''Automatic system for improving underwater image contrast and color through recursive adaptive histogram modification,'' *Comput. Electron. Agricult.*, vol. 141, pp. 181–195, Sep. 2017.

[37] D. Huang, Y. Wang, W. Song, J. Sequeira, and S. Mavromatis, ''Shallow-water image enhancement using relative global histogram stretching based on adaptive parameter acquisition,'' in *Proc. 24th Int. Conf. Multimedia Modeling (MMM)*, Bangkok, Thailand, Feb 2018.

[38] S. Vasamsetti, N. Mittal, B. C. Neelapu, and H. K. Sardana, ''Wavelet based perspective on variational enhancement technique for underwater imagery,'' *Ocean Eng.*, vol. 141, pp. 88–100, Sep. 2017.

[39] J. Ning, D. Wu, B. Han, and W. Ren, ''Image enhancement based on contourlet transform,'' *Proc. SPIE*, vol. 11052, Jan. 2019, Art. no. 1105217.

[40] S. S. Agaian, K. Panetta, and A. M. Grigoryan, "Transform-based image enhancement algorithms with performance measure," *IEEE Trans. Image Process.*, vol. 10, no. 3, pp. 367–382, Mar. 2001.
[41] K. Panetta, A. Samani, and S. Agaian, "A robust no-reference, no-parameter, transform domain image quality metric for evaluating the quality of color images," *IEEE Access*, vol. 6, pp. 10979–10985, 2018.
[42] Y. Wang, X. Ding, R. Wang, J. Zhang, and X. Fu, "Fusion-based underwater image enhancement by wavelet decomposition," in *Proc. IEEE Int. Conf. Ind. Technol. (ICIT)*, Mar. 2017, pp. 1013–1018.
[43] C. J. Prabhakar and P. U. Praveen Kumar, "Underwater image denoising using adaptive wavelet subband thresholding," in *Proc. Int. Conf. Signal Image Process.*, Dec. 2010, pp. 322–327.
[44] K. R. Joshi and R. S. Kamathe, "Quantification of retinex in enhancement of weather degraded images," in *Proc. Int. Conf. Audio, Lang. Image Process.*, Jul. 2008, pp. 1229–1233.
[45] S. Zhang, T. Wang, J. Dong, and H. Yu, "Underwater image enhancement via extended multi-scale retinex," *Neurocomputing*, vol. 245, pp. 1–9, Jul. 2017.
[46] Y.-X. Wang, M. Diao, and C. Hang, "Underwater image enhancement algorithm based on iterative histogram equalization with conventional light source," *Acta Photon. Sinica*, vol. 47, no. 11, pp. 1–11, 2018.
[47] W. Zhang, L. Dong, X. Pan, J. Zhou, L. Qin, and W. Xu, "Single image defogging based on multi-channel convolutional MSRCR," *IEEE Access*, vol. 7, pp. 72492–72504, 2019.
[48] C. Tang, U. F. von Lukas, M. Vahl, S. Wang, Y. Wang, and M. Tan, "Efficient underwater image and video enhancement based on retinex," *Signal, Image Video Process.*, vol. 13, no. 5, pp. 1011–1018, Jul. 2019.
[49] L. Wang, L. Xu, W. Tian, Y. Zhang, H. Feng, and Z. Chen, "Underwater image super-resolution and enhancement via progressive frequency-interleaved network," *J. Vis. Commun. Image Represent.*, vol. 86, Jul. 2022, Art. no. 103545.
[50] K. Liu and Y. Liang, "Enhancement of underwater optical images based on background light estimation and improved adaptive transmission fusion," *Opt. Exp.*, vol. 29, no. 18, p. 28307, 2021.
[51] E. Trucco and A. T. Olmos-Antillon, "Self-tuning underwater image restoration," *IEEE J. Ocean. Eng.*, vol. 31, no. 2, pp. 511–519, Apr. 2006.
[52] W. Hou, D. J. Gray, A. D. Weidemann, G. R. Fournier, and J. L. Forand, "Automated underwater image restoration and retrieval of related optical properties," in *Proc. IEEE Int. Geosci. Remote Sens. Symp.*, Jul. 2007, pp. 1889–1892.
[53] M. Boffety, F. Galland, and A.-G. Allais, "Color image simulation for underwater optics," *Appl. Opt.*, vol. 51, no. 23, p. 5633, 2012.
[54] H. Wen, Y. Tian, T. Huang, and W. Gao, "Single underwater image enhancement with a new optical model," in *Proc. IEEE Int. Symp. Circuits Syst. (ISCAS)*, May 2013, pp. 753–756.
[55] J. Ahn, S. Yasukawa, T. Sonoda, Y. Nishida, K. Ishii, and T. Ura, "An optical image transmission system for deep sea creature sampling missions using autonomous underwater vehicle," *IEEE J. Ocean. Eng.*, vol. 45, no. 2, pp. 350–361, Apr. 2020.
[56] Y. Y. Schechner and N. Karpel, "Recovery of underwater visibility and structure by polarization analysis," *IEEE J. Ocean. Eng.*, vol. 30, no. 3, pp. 570–587, Jul. 2005.
[57] T. Treibitz and Y. Y. Schechner, "Active polarization descattering," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 31, no. 3, pp. 385–399, Mar. 2009.
[58] T. Treibitz and Y. Y. Schechner, "Turbid scene enhancement using multi-directional illumination fusion," *IEEE Trans. Image Process.*, vol. 21, no. 11, pp. 4662–4667, Nov. 2012.
[59] H. Hu, L. Zhao, B. Huang, X. Li, H. Wang, and T. Liu, "Enhancing visibility of polarimetric underwater image by transmittance correction," *IEEE Photon. J.*, vol. 9, no. 3, pp. 1–10, Jun. 2017.
[60] H. Hu, L. Zhao, X. Li, H. Wang, and T. Liu, "Underwater image recovery under the nonuniform optical field based on polarimetric imaging," *IEEE Photon. J.*, vol. 10, no. 1, pp. 1–9, Feb. 2018.
[61] C. Sánchez-Ferreira, L. S. Coelho, H. V. H. Ayala, M. C. Q. Farias, and C. H. Llanos, "Bio-inspired optimization algorithms for real underwater image restoration," *Signal Process., Image Commun.*, vol. 77, pp. 49–65, Sep. 2019.
[62] L. Yang, J. Liang, W. Zhang, H. Ju, L. Ren, and X. Shao, "Underwater polarimetric imaging for visibility enhancement utilizing active unpolarized illumination," *Opt. Commun.*, vol. 438, pp. 96–101, May 2019.
[63] K. He, J. Sun, and X. Tang, "Single image haze removal using dark channel prior," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 33, no. 12, pp. 2341–2353, Dec. 2011.
[64] H.-Y. Yang, P.-Y. Chen, C.-C. Huang, Y.-Z. Zhuang, and Y.-H. Shiau, "Low complexity underwater image enhancement based on dark channel prior," in *Proc. 2nd Int. Conf. Innov. Bio-Inspired Comput. Appl.*, Dec. 2011, pp. 17–20.
[65] J. Y. Chiang and Y.-C. Chen, "Underwater image enhancement by wavelength compensation and dehazing," *IEEE Trans. Image Process.*, vol. 21, no. 4, pp. 1756–1769, Apr. 2012.
[66] S. Serikawa and H. Lu, "Underwater image dehazing using joint trilateral filter," *Comput. Electr. Eng.*, vol. 40, no. 1, pp. 41–50, Jan. 2014.
[67] X. Zhao, T. Jin, and S. Qu, "Deriving inherent optical properties from background color and underwater image enhancement," *Ocean Eng.*, vol. 94, pp. 163–172, Jan. 2015.
[68] L. Chao and M. Wang, "Removal of water scattering," in *Proc. 2nd Int. Conf. Comput. Eng. Technol.*, vol. 2, Apr. 2010, pp. V2-35–V2-39.
[69] I.-Z. Chen, J. Tavares, A. Iliyasu, and K.-L. Du, *2nd Int. Conf. Image Process. Capsule Netw. (ICIPCN)*, 2021, doi: 10.1007/978-3-030-84760-9.
[70] V. Tyagi, *Understanding Digital Image Processing*. Boca Raton, FL, USA: CRC Press, 2018.
[71] Y.-T. Peng, K. Cao, and P. C. Cosman, "Generalization of the dark channel prior for single image restoration," *IEEE Trans. Image Process.*, vol. 27, no. 6, pp. 2856–2868, Jun. 2018.
[72] J. Li, Z. Zhang, L. Qiao, and A. Herdean, "Neural computing and applications to marine data analytics," *Frontiers Mar. Sci.*, vol. 8, pp. 1–16, May 2021.
[73] H. Yu, J. Liu, L. Liu, Z. Ju, Y. Liu, and D. Zhou, "Intelligent robotics and applications," in *Proc. 12th Int. Conf. (ICIRA)*, Shenyang, China, Aug. 2019, doi: 10.1007/978-3-030-27526-6.
[74] D. Berman, D. Levy, S. Avidan, and T. Treibitz, "Underwater single image color restoration using haze-lines and a new quantitative dataset," *IEEE Trans. Pattern Anal. Mach. Intell.*, vol. 43, no. 8, pp. 2822–2837, Aug. 2021.
[75] F. Bai, C. Wang, C. Feng, W. Gong, L. Liu, K. Zeng, and C. Feng, "Underwater image restoration based on wavelet fusion and reweighted graph total variation prior," 2022, doi: 10.21203/rs.3.rs-1624223/v1.
[76] J. M. F. Vicente, J. R. Álvarez-Sánchez, F. D. L. P. López, J. T. Moreo, and H. Adeli, "Biomedical applications based on natural and artificial computing," in *Proc. Int. Work-Conf. Interplay Between Natural Artif. Comput. (IWINAC)*, Corunna, Spain, Jun. 2017, doi: 10.1007/978-3-319-59773-7.
[77] R. Liu, X. Fan, M. Hou, Z. Jiang, Z. Luo, and L. Zhang, "Learning aggregated transmission propagation networks for haze removal and beyond," *IEEE Trans. Neural Netw. Learn. Syst.*, vol. 30, no. 10, pp. 2973–2986, Oct. 2019.
[78] J. Brownlee, *Deep Learning for Computer Vision: Image Classification, Object Detection, and Face Recognition in Python*. Machine Learning Mastery, Apr. 2019, p. 563.
[79] J. Li, K. A. Skinner, R. M. Eustice, and M. Johnson-Roberson, "WaterGAN: Unsupervised generative network to enable real-time color correction of monocular underwater images," *IEEE Robot. Autom. Lett.*, vol. 3, no. 1, pp. 387–394, Jan. 2018.
[80] S. Anwar and C. Li, "Diving deeper into underwater image enhancement: A survey," *Signal Process., Image Commun.*, vol. 89, Nov. 2020, Art. no. 115978.
[81] A. S. A. Ghani, "Image contrast enhancement using an integration of recursive-overlapped contrast limited adaptive histogram specification and dual-image wavelet fusion for the high visibility of deep underwater image," *Ocean Eng.*, vol. 162, pp. 224–238, Aug. 2018.
[82] Z. Wang, A. C. Bovik, H. R. Sheikh, and E. P. Simoncelli, "Image quality assessment: From error visibility to structural similarity," *IEEE Trans. Image Process.*, vol. 13, no. 4, pp. 600–612, Apr. 2004.
[83] J. Guo, "Underwater image quality evaluation based on human visual system," in *Proc. Int. Conf. Big Data, Artif. Intell. Risk Manage. (ICBAR)*, Nov. 2021, pp. 115–119.
[84] H. Lu and S. Serikawa, "Underwater scene enhancement using weighted guided median filter," in *Proc. IEEE Int. Conf. Multimedia Expo (ICME)*, Jul. 2014, pp. 1–6.
[85] M. Yang and A. Sowmya, "An underwater color image quality evaluation metric," *IEEE Trans. Image Process.*, vol. 24, no. 12, pp. 6062–6071, Dec. 2015.
[86] W. Hou and A. D. Weidemann, "Objectively assessing underwater image quality for the purpose of automated restoration," *Proc. SPIE*, vol. 6575, Apr. 2007, Art. no. 65750Q.
[87] M. Arredondo and K. Lebart, "A methodology for the systematic assessment of underwater video processing algorithms," in *Proc. Eur. Oceans*, 2005, pp. 362–367.
[88] M. Žuži, J. Čejka, F. Bruno, D. Skarlatos, and F. Liarokapis, "Impact of dehazing on underwater marker detection for augmented reality," *Frontiers Robot. AI*, vol. 5, p. 92, Aug. 2018.

[89] S. Emberton, L. Chittka, and A. Cavallaro, "Underwater image and video dehazing with pure haze region segmentation," *Comput. Vis. Image Understand.*, vol. 168, pp. 145–156, Mar. 2018.
[90] S. S. Prabhakaran, S. K. Sahu, P. J. Dev, and P. Shanmugam, "Modelling the light absorption coefficients of oceanic waters: Implications for underwater optical applications," *J. Mar. Syst.*, vol. 181, pp. 14–24, May 2018.
[91] H. Lu, Y. Li, T. Uemura, H. Kim, and S. Serikawa, "Low illumination underwater light field images reconstruction using deep convolutional neural networks," *Future Gener. Comput. Syst.*, vol. 82, pp. 142–148, May 2018.
[92] Y. Shi, "Analysis and research on backscattering effect of underwater imaging," in *Proc. Int. Conf. Appl. Phys. Comput. (ICAPC)*, Sep. 2022, pp. 356–359.
[93] J.-K. Guo, C.-C. Sung, and H.-H. Chang, "Improving visibility and fidelity of underwater images using an adaptive restoration algorithm," in *Proc. OCEANS TAIPEI*, Apr. 2014, pp. 1–6.
[94] K. Wang, Y. Hu, J. Chen, X. Wu, X. Zhao, and Y. Li, "Underwater image restoration based on a parallel convolutional neural network," *Remote Sens.*, vol. 11, no. 13, p. 1591, Jul. 2019.
[95] X. Lei, H. Wang, J. Shen, and H. Liu, "Underwater image enhancement based on color correction and complementary dual image multi-scale fusion," *Appl. Opt.*, vol. 61, no. 17, pp. 5304–5314, 2022.
[96] J. Ren, J. Liang, B. Ren, X. Zheng, and C. Guo, "New patterns of temporal and spatial variation in water quality of a highly artificialized urban river-course—A case study in the Tongzhou section of the Beiyun River," *Water*, vol. 10, no. 10, p. 1446, Oct. 2018.
[97] C. Yuan, W. Chen, Y. Zhu, D. Li, and J. Tan, "A low computational complexity authentication scheme in underwater wireless sensor network," in *Proc. 11th Int. Conf. Mobile Ad-Hoc Sensor Netw. (MSN)*, Dec. 2015, pp. 116–123.
[98] C. Li, J. Guo, S. Chen, Y. Tang, Y. Pang, and J. Wang, "Underwater image restoration based on minimum information loss principle and optical properties of underwater imaging," in *Proc. IEEE Int. Conf. Image Process. (ICIP)*, Sep. 2016, pp. 1993–1997.
[99] M. Žuži and J. Čejka, "Robot vision and artificial perception," Tech. Rep., 2018.

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