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Trend Survey: Neural Network for Underwater Image Enhancement

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Abstract

Underwater environment brings unique challenges for imaging due to factors such as light attention, color distortion, and backscatter, which degrade image quality and obstruct visual perception. Traditional image enhancement techniques often find it difficult to handle these challenges effectively. Deep learning has a promising approach to tackle underwater image enhancement tasks by utilizing its ability to learn complex patterns and features directly from data. This review paper provides a comprehensive survey and analysis of deep learning techniques for underwater image enhancement. Highlighting the importance of clear and accurate visual data in various underwater image applications, including biology, oceanology, security etc., We will move to the limitations of existing methods and some approaches which have already overcome some of the limitations. Through an in-depth literature review, we evaluate the evolution of deep learning models specially trained for underwater images including convolution neural network (CNN), Generative Adversarial Networks (GANs) and autoencoders. We discuss the results of these models and highlight the recent developments such as state-of-art methods, transformation and transfer learning. Moreover, we identify key research directions and emerging trends in the field including development of accurate deep learning models for real time underwater image and its enhancement, integration of multimodal data sources for enhanced performance which will focus on future work on the underwater image enhancement. The paper focuses on the latest innovations and challenges in deep learning based underwater image enhancement. It will provide the foundation for many more models. As this path is continuously getting better, there is an opportunity to innovate multiple algorithmic approaches balancing hardware requirements.

Keywords: Deep Learning, under water images, CNN, Attention, GAN.

Introduction

Exploring the depths of the ocean feels like stepping into a fascinating world full of colorful creatures, beautiful coral reefs, and stunning underwater scenery. But beneath the surface beauty lies a mysterious realm that's hard to capture in photos. Underwater photography comes with its own set of challenges that make it tricky for both photographers and scientists. Even though underwater imaging holds a lot of promise for discovering new things, it's tough to make the images look their best using traditional methods.

The importance of underwater imaging goes beyond its aesthetic appeal, and encompasses a wide variety of scientific, industrial, and recreational applications. In marine biology, it is essential for the study of marine ecosystems, biodiversity, and environmental monitoring. Oceanographers use it to map the ocean floor topography, explore geological formations, track ocean currents, and gain valuable insight into Earth's ever-changing marine environments. Using underwater images, underwater search and rescue (S&R) teams can locate missing people, debris, or lost items in underwater bodies of water. High-resolution images enhance underwater visibility, making rescue operations more likely. In industries like offshore energy, underwater imaging is essential for underwater infrastructure inspection, environmental impact assessment, and the safety and effectiveness of underwater operations.

Yet underwater images mainly face issues in image acquisition and analysis. It is difficult to capture high-resolution images. The optical characteristics of water, such as light attenuation, color distortion, and backscatter, present significant challenges that impact the quality of images and impede visual perception. Light attenuation, which occurs due to the absorption and scattering of light as it moves through water, leads to a decrease in contrast and detail, especially at greater depths. Color distortion changes the way objects appear underwater by altering their colors and reducing color accuracy, making it difficult to faithfully represent the vivid colors of marine life and coral reefs. Backscatter, resulting from light reflecting off suspended particles and plankton in the water column, causes undesired speckles and haze in images, obscuring details and reducing overall clarity.

Traditionally, image enhancement techniques have relied on simple algorithms to adjust brightness, contrast, and color balance in an attempt to improve the visual quality of underwater images. However, these methods often fall short in effectively addressing the complex optical phenomena

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encountered in underwater environments. As a result, there is a growing recognition of the need for more advanced approaches that can adaptively enhance underwater imagery while preserving important visual information.

In the past few years, deep learning has emerged as a revolutionary technology with immense potential for advancing the domain of underwater image enhancement. Deep learning algorithms, which draw inspiration from the intricate structure and functioning of the human brain, possess the capability to learn intricate patterns and features directly from data. This enables them to accomplish complex tasks with unparalleled accuracy and efficiency. Among the various deep learning techniques, convolutional neural networks (CNNs) have attracted significant interest due to their exceptional ability to extract spatial features from images. Consequently, they are highly suitable for tasks like image classification and semantic segmentation.

Moreover, generative adversarial networks (GANs) have become a revolution in the field of image generation and manipulation by enabling the synthesis of realistic images that closely resemble real-world examples. Transfer learning, attention-guided networks, and transformer architectures represent further advancements in deep learning that offer novel solutions to the challenges of underwater image enhancement. By leveraging these cutting-edge techniques, researchers and practitioners are paving the way for a new era of underwater imaging that promises to reveal the hidden beauty and complexity of the ocean depths.

In this comprehensive review paper, we aim to delve deep into the realm of underwater image enhancement using deep learning techniques. By synthesizing the latest research and developments in the field, we seek to provide a comprehensive overview of the strengths and limitations of current approaches, as well as identify promising avenues for future research. Through an in-depth analysis of deep learning models such as CNNs, GANs, and transformer architectures, we aim to elucidate their potential to revolutionize underwater imaging and propel the field towards new frontiers of discovery and innovation. Join us on this exciting journey as we explore the fascinating world of underwater image enhancement and unlock the secrets of the deep blue sea.

Literature Review

1) Tingting Zhang (*et al*) in the year 2022 proposed paper "Underwater image enhancement using improved generative adversarial network"[1]

The paper proposes an enhanced method using Generative Adversarial Networks (GANs) to improve underwater image quality. It utilizes a convolutional encoder-decoder network similar to u-net, preserving spatial dependencies. Operations after convolution include batch normalization and leaky ReLU activation function for encoding, and ReLU for decoding. The approach integrates objective functions which combine the least square method, gradient punishment, L1 loss, and Gradient Difference Loss (GDL) to enhance color, sharpen images, and prevent weight explosion during training. Evaluation using Structural Similarity Index (SSIM) and Underwater Image Quality Measures (UIQM) evaluates color, sharpness, and contrast. Results indicate that the proposed method outperforms previous methods in terms of both SSIM and UIQM.

2) Qi Qi (*et al*) in the year 2022 proposed paper "SGUIE-Net: Semantic Attention Guided Underwater Image Enhancement with Multi-Scale Perception"[2]

The paper introduces SGUIE-Net, a novel method for enhancing underwater images by incorporating semantic guidance. The network architecture integrates multi-scale perception and semantic information as high-level constraints. SGUIE-Net outperforms existing methods on the UIEB dataset, displaying superior performance in full-reference metrics evaluations and effectively addressing color correction and backscatter challenges. The training process involves leveraging pre-trained models and is validated across various datasets for generalizability. Ablation studies highlight the efficacy of key components like cascaded attention-aware enhancement and dual-branch, multi-scale feature perception architecture.

3) Keming Cao (*et al*) in the year 2018 proposed paper "Underwater Image Restoration using Deep Networks to Estimate Background Light and Scene Depth"[3]

The paper presents an innovative approach to underwater image restoration by utilizing deep neural networks to estimate background light and scene depth. Through the proposed method, the restoration process effectively reverses the effects of light scattering and absorption outlined by the Image Formation Model (IFM), resulting in enhanced image clarity and detail. Evaluation on synthetic and real underwater images demonstrates the superiority of the approach over existing methods, as evidenced by improved image quality metrics and visually appealing results. This highlights the potential of deep learning techniques in addressing the challenges of underwater imaging and improving visual outcomes.

4) Qun Jiang (*et al*) in the year 2022 proposed paper "Two-step domain adaptation for underwater image enhancement"[4]

The proposed underwater image enhancement method combines a domain adaptation mechanism with an image enhancement network to improve visual quality. By training on a dataset of paired underwater and clear images, the model learns to enhance hazy underwater scenes effectively. Results demonstrate its superiority in image quality metrics and its applicability to both real-world and synthetic underwater images. Overall, it presents a promising solution for enhancing underwater imagery and facilitating various underwater tasks.

5) Ziyuan Xiao (*et al*) in the year 2022 proposed paper "USLN: A statistically guided lightweight network for underwater image enhancement via dual-statistic white balance and multi-color space stretch"[5]

The proposed method follows a statistic-based approach, modifying pixel values directly in the color space to enhance images. It introduces two trainable modules, focusing on white balance and contrast improvement, to achieve superior performance with fewer parameters. By incorporating visual priors and utilizing trainable modules, the method aims to effectively enhance underwater images. Overall, the proposed method provides a comprehensive approach to address the challenges of underwater image enhancement.

6) Alzayat Saleh (*et al*) in the year 2022 proposed paper "Adaptive Uncertainty Distribution in Deep Learning for Unsupervised Underwater Image Enhancement"[6]

The paper introduces the Uncertainty Distribution Network (UDnet) for underwater image enhancement, comprising two key modules: statistically guided multi-color space stretch and probabilistic adaptive instance normalization (PAdaIN). UDnet aims to learn meaningful enhancement distributions, addressing challenges like random distortion and low contrast without requiring ground truth data. The model outperforms ten popular enhancement methods across metrics in both paired and unpaired settings, offering a promising unsupervised approach to underwater image enhancement.

7) Zengxi Zhang (*et al*) in the year 2023 proposed paper "WaterFlow: Heuristic Normalizing Flow for Underwater Image Enhancement and Beyond" [7]

The proposed enhancement method's efficacy in underwater image detection tasks, emphasizing its semantic feature richness for subsequent detection. Results show higher detection confidence and increased detection of trepangs and urchins compared to other methods, as demonstrated on UCCS and Aquarium datasets. Quantitative analysis, particularly in UICM, indicates superior performance over representative methods. Limitations regarding local over enhancement and image artifacts when blocks are less than 3 are addressed, alongside discussions on the method's impact on underwater object detection and challenges posed by scene blur and light imbalance in detection tasks.

8) Meicheng Zheng and Weilin Luo in the year 2022 proposed paper " Underwater Image Enhancement Using Improved CNN Based Defogging"[8]

The CNN-based defogging method for underwater image enhancement utilizes a modified underwater imaging model, incorporating a comprehensive index to calculate ambient light and transmission maps for color balance. Deep separable convolution reduces parameter count, while a sub-network decreases main network depth. The CNN structure integrates a Basic Attention module and a pooling pyramid module to trace fog distribution and aggregate contextual information, respectively. This approach surpasses other methods in quantitative evaluation metrics like PSNR (Peak Signal to Noise Ratio) and SSIM (Structural SIMilarity), demonstrating its effectiveness in enhancing underwater image quality.

9) Hao-Hsiang Yang (*et al*) in the year 2021 proposed paper "LAFFNet: A Lightweight Adaptive Feature Fusion Network for Underwater Image Enhancement" [9]

This Paper proposed LAFFNet, a lightweight adaptive feature fusion network for underwater image enhancement, employs an encoder-decoder model with adaptive feature fusion (AAF) modules and channel attention. It significantly reduces parameters while surpassing state-of-the-art algorithms in underwater image enhancement. Evaluated on UFO-120 and EUVP datasets, LAFFNet outperforms existing solutions in both qualitative and objective metrics such as PSNR, SSIM, and UIQM, showcasing its effectiveness in enhancing underwater image quality and facilitating high-level vision tasks like salience object detection and single image depth estimation.

10) Xiaoteng Zhou (*et al*) in the year 2022 proposed paper "Learning Visual Representation of Underwater Acoustic Imagery Using Transformer-Based Style Transfer Method"[10]

The paper introduces a transformer-based style transfer model to generate pseudo-acoustic images for fish identification tasks in unknown waters, combining semantic information from optical images and stylized textures from acoustic images. With a focus on preserving global features and robust representation, it produces high-quality pseudo-acoustic images with complete structures. Evaluation metrics demonstrate its superiority over traditional methods, particularly in underwater target recognition tasks, highlighting its efficacy in enhancing underwater acoustic imagery for marine engineering applications.

11) Zhenghao Shi (*et al*) in the year 2022 proposed paper "Integrating deep learning and traditional image enhancement techniques for underwater image enhancement" [11]

The paper proposes a hybrid approach for underwater image enhancement, combining deep learning and traditional techniques to tackle issues of color distortion, blur, and low contrast. Through an attention-guided residual module, it corrects color distortion by compensating for red and green channel discrepancies. Traditional methods like CLAHE and Gamma correction, along with a multi-scale CNN, address blur and enhance contrast. The method significantly improves visual quality, outperforming existing techniques in both synthetic and real underwater image datasets, highlighting its efficacy in enhancing underwater imagery.

12) HuaYang (*et al*) in the year 2021 proposed paper " Underwater image enhancement with latent consistency learning-based color transfer"[12]

The proposed method for enhancing underwater images employs a color correction-based strategy, integrating template selection via a latent consistency learning network (LCL-Net) to improve enhancement by choosing clear underwater images for color transfer. It utilizes deep features of raw templates, resulting in significant time savings during image processing. Experimental results demonstrate its superiority over traditional and deep learning-based methods, exhibiting better performance in SSIM, PSNR, and MSE metrics, particularly in handling substantial color distortions. The approach is robust to different learning metrics, excelling in template ranking based on color-distribution consistency, and achieves superior performance when utilizing multiple templates, with the model trained using Kaiming initialization and smooth L1 loss.

13) Yang Wang (*et al*) in the year 2022 proposed paper "A deep CNN method for underwater image enhancement"[13]

The UIE-Net, a deep convolutional neural network, addresses color distortion and contrast enhancement in underwater images through its CC-Net and HR-Net subnetworks. Trained with dual-task learning, it simultaneously corrects color distortion and enhances contrast, leading to improved feature representation. Subjective evaluations against existing algorithms reveal UIE-Net's effectiveness in removing distortion, increasing contrast, and preserving details, while quantitative metrics like Entropy and PCQI confirm its competitive or superior performance, highlighting its efficacy in underwater image enhancement.

14) Yaofeng Xie (*et al*) in the year 2017 proposed paper "Lighting the darkness in the sea: A deep learning model for underwater image enhancement"[14]

The paper proposed method focuses on low-light underwater image restoration, outperforming existing methods such as KinD, Zero-DC, and LUW, as evidenced by qualitative and quantitative comparisons using UIQM, UCIQ, and PSNR metrics. The method exhibits superior image detail preservation, reduced blur, and higher overall image quality. Evaluation across different illumination conditions using LDS-Net further validates its effectiveness in enhancing underwater images, establishing it as a promising approach for low-light underwater image restoration.

15) Zeru Lan (*et al*) in the year 2022 proposed paper "An optimized GAN method based on the Que Attn and contrastive learning for underwater image enhancement" [15]

The research article introduces an enhanced GAN framework for underwater image enhancement, integrating Que-Attn and contrastive learning techniques. By employing PatchNCE loss and encouraging similar points in the feature space, the model enhances restoration quality and maximizes mutual information between input and output. Experimental results across multiple datasets, including EUVP, UIEB, and HICRD, demonstrate superior performance in terms of SSIM, PSNR, and UIQM metrics. The proposed method surpasses existing approaches, showcasing its robustness and generalization ability. Notably, it produces visually superior results with enhanced detail quality compared to traditional methods, highlighting its effectiveness in restoring degraded underwater images.

16) Lintao Peng (*et al*) in the year 2021 proposed paper "U-shape Transformer for Underwater Image Enhancement" [16]

The paper introduces a novel U-shape Transformer network designed for underwater image enhancement, addressing challenges like inconsistent attenuation across color channels and spatial regions. Incorporating modules such as CMSFFT and SGFMT, it effectively tackles these issues. Furthermore, it utilizes a multi-color space loss function to enhance contrast and saturation in the output images. Through extensive experiments and comparisons, the network demonstrates superior performance in removing color artifacts and casts, outperforming 10 state-of-the-art techniques in metrics like PSNR, SSIM, UCIQE, and UIQM. Overall, the U-shape Transformer network shows promise in significantly improving visual quality and addressing key challenges in underwater image processing.

17) Zhengyong Wang (*et al*) in the year 2021 proposed paper "Single Underwater Image Enhancement Using an Analysis-Synthesis Network" [17]

The paper presents ANA-SYN, a comprehensive framework for underwater image enhancement, comprising an analysis network and a synthesis network. The analysis network extracts and recalibrates underwater priors, while the synthesis network integrates priors and data features for enhancement. ANA-SYN outperforms methods relying on hand-crafted priors, showing superior results in PSNR, SSIM, UIQM, NIQE, and perceptual scores. By dynamically weighting and integrating priors, it achieves realistic color restoration, structure enhancement, and artifact reduction in challenging underwater images. The framework demonstrates robustness in real-world scenarios, surpassing state-of-the-art methods in overall evaluation metrics and user perception.

18) Wangzhen Peng (*et al*) in the year 2023 proposed paper "RAUNE-Net: A Residual and Attention-Driven Underwater Image Enhancement Method" [18]

RAUNE-Net, a novel underwater image enhancement method, integrates residual learning, channel attention, and spatial attention to effectively address color shifts, distortion, and low-light conditions. Its comprehensive architecture, including modules like wide-range perception and feature map smoothing, enables detailed feature extraction and noise reduction. Objective evaluations demonstrate RAUNE-Net's superior performance over eight existing methods, consistently achieving the highest PSNR and SSIM values across datasets. Subjective evaluations confirm its efficacy in correcting color biases and improving image clarity, highlighting its potential for practical applications in marine imaging.

19) Weiwen Chen (*et al*) in the year 2024 proposed paper "UWFormer: Underwater Image Enhancement via a Semi-Supervised Multi-Scale Transformer" [19]

The proposed method in the document is UWFormer, a novel semi-supervised Multi-scale Transformer designed for enhancing low-frequency features in underwater images. It consists of two key modules: the Nonlinear Frequency-aware Attention module and the Multi-scale Fusion Feed-forward network. These modules aim to improve color restoration and detail preservation in underwater images.

20) Ruhui Deng (*et al*) in the year 2023 proposed paper "Cformer: An underwater image enhancement hybrid network combining convolution and transformer" [20]

Cformer introduces a novel approach to underwater image enhancement by integrating global-local Transformer modules, including the Dual Self-Calibrated (DSC) block and Cascaded Self-Attention (CSEWin) Transformer block. Its unique network structure effectively captures both local and global features, enhancing image restoration quality. Utilizing a multi-objective loss function comprising MSE, VGG perceptual loss, and gradient loss further boosts its restoration capabilities. Through ablation studies, Cformer outperforms other methods in PSNR, SSIM, UIQM, UCIQE, and NIQE metrics, showcasing its prowess in underwater image enhancement. It excels in detail restoration, color correction, and texture preservation, positioning Cformer as a promising solution for underwater image processing.

21) Shijian Zheng (*et al*) in the year 2023 proposed paper " Underwater image enhancementusing Divide-and-Conquer network" [21]

The document introduces DC-net, a framework for underwater image enhancement comprising texture, color, and refinement networks. Texture enhancement is achieved through a multi-axis attention mechanism, while color correction employs a 3DLUT mechanism and gamma curve module. DC-net outperforms traditional and deep learning methods, achieving superior scores in qualitative and quantitative evaluations on underwater datasets. It significantly improves structural enhancement, segmentation, and depth map estimation, extending its application to weakly lit, de-hazy, and de-rain images, demonstrating versatility and effectiveness across various enhancement tasks.

22) Sheezan Fayaz (*et al*) in the year 2023 proposed paper " Intelligent Underwater Object Detection and Image Restoration for Autonomous Underwater Vehicles" [22]

A two-stage framework is proposed to enhance underwater image quality and address resource constraints in Unmanned Underwater Vehicles (UUVs). Stage one employs YOLOV8 and YOLOV4 for efficient Region of Interest (ROI) detection. Stage two utilizes a precise dehazing algorithm to restore ROI, aiding UUV navigation. The algorithm demonstrates superior performance in underwater object detection with high Mean Average Precision (mAP) and Recall rates, surpassing Faster RCNN and YOLOV3. It achieves rapid processing speeds and reduced resource consumption while enhancing image quality. The approach presents a promising solution for effective underwater imaging and UUV operations.

23) Yanling Qiu (*et al*) in the year 2023 proposed paper "A Correction-Based Dynamic Enhancement Framework towards Underwater Detection"[23]

The underwater image utility enhancement framework employs dynamic low-level corrections guided by a contribution dictionary based on detection priors. It preprocesses images through contrast, color, clarity, and brightness adjustments, enhancing image utility quality. Specific task-oriented detection models are then utilized for object detection. The method yields a significant enhancement in detection accuracy (15.86%/6.98%) compared to original images, operating at speeds of 105/126 FPS. It outperforms advanced enhancement techniques by improving image utility quality while maintaining low time complexity. The framework offers a dynamic and optimal enhancement path for various detection tasks in underwater scenarios.

24) Xiujuan Wang (*et al*) in the year 2022 proposed paper "Underwater fish image enhancement method based on color correction "[24]

The paper introduces a three-stage underwater image enhancement method, combining CIE-Lab spatial adaptive stretching, color equalization, and contrast stretching, resulting in enhanced brightness, contrast, and sharpness without color distortion. Evaluation using metrics like PSNR and SSIM demonstrates superior results compared to existing techniques, improving target recognition accuracy. Comprehensive evaluation indicates optimal outcomes with the proposed method, increasing overall image quality. Ablation experiment underscores the importance of a holistic approach, with combined stages yielding desired effects. Post-enhancement, target recognition significantly improves, enhancing accuracy, recall, and mAP percentages. The method effectively addresses underwater image quality deficiencies, yielding superior enhancement outcomes and target recognition capabilities.

25) Rong Wang (*et al*) in the year 2024 proposed paper "A Lightweight Multi-Branch Context Network for Unsupervised Underwater Image Restoration" [25]

The paper introduces a novel approach for unsupervised underwater image restoration, employing a lightweight multi-branch context network. It decomposes images into transmission maps, global background light, and scene radiance, using a comprehensive loss function for training. Outperforming state-of-the-art methods, it excels in color correction and contrast restoration with minimal parameters. The network architecture predicts scene radiance, estimates transmission maps, and computes global background light efficiently. Evaluation across underwater image datasets confirms the method's effectiveness, showcasing superior performance. Overall, it presents a promising solution for restoring degraded underwater images.

26) Pan Mu (*et al*) in the year 2023 proposed paper "Transmission and Color-guided Network for Underwater Image Enhancement "[26]

The paper discusses the challenges of underwater image enhancement due to factors like water absorption and scattering. It introduces the Adaptive Transmission and Dynamic Color-guided network (ATDCnet) to address color deviation and low contrast issues in underwater images. The network incorporates modules like Adaptive Transmission-directed Module (ATM) and Dynamic Color-guided Module (DCM) for color restoration. Additionally, an Encoder-Decoder-based Compensation structure is used for simultaneous color restoration and contrast enhancement. Through extensive experiments, the ATDCnet demonstrates superior performance on benchmark datasets.

27) Yang Li and Rong Chen in the year 2020 proposed paper "UDA-Net: Densely attention network for underwater image enhancement" [27]

The document presents a new underwater image enhancement model, UDA-Net, based on deep learning. The model includes a feature-level attention mechanism through a multi-scale grid convolutional neural network to improve single underwater images. This approach adapts to degraded image patches and conducts comprehensive experiments showing effectiveness. The paper discusses challenges in underwater imaging, existing image enhancement methods, and the shift towards deep learning models. The attentive network design aims to learn spatially variant degradation characteristics. Experimental results on synthetic and real-world underwater images demonstrate the model's superiority in terms of SSIM, PSNR, and processing speed.

28) Tie LiID (*et al*) in the year 2022 proposed paper "Multi-scale fusion framework via retinex and transmittance optimization for underwater image enhancement "[28]

The paper proposed method enhances underwater images through contrast enhancement via histogram quantization, color correction inspired by the Retinex model, and transmittance optimization. It utilizes a fusion framework to calculate weights for multi-algorithm fusion, resulting in improved image details. Experimental results demonstrate effective contrast improvement, color restoration, and turbidity reduction, with practical applications yielding clearer underwater images in real scenarios. Overall, the approach offers a comprehensive solution for enhancing underwater image quality through a combination of techniques targeting contrast, color, and detail enhancement.

29) Shiben Liu (*et al*) in the year 2022 proposed paper "Adaptive Learning Attention Network for Underwater Image Enhancement" [29]

The paper proposed LANet method for underwater image enhancement integrates five components: Multiscale Fusion, Parallel Attention, Adaptive Learning, Group Structure, and Multinomial Loss Functions. By employing these modules, LANet surpasses traditional methods in image quality metrics on various underwater datasets. It demonstrates adaptability, noise reduction, and fidelity to ground truth images while maintaining competitive speed at 18.42 frames per second, making it suitable for real-time applications in underwater robotics. LANet effectively removes color casts, enhances illumination, and restores detailed information in underwater images, offering a promising solution for enhancement tasks.

30) Shijian Zheng (*et al*) in the year 2024 proposed paper "Underwater image enhancement using Divide-and-Conquer network" [30]

The Divide-and-Conquer network (DC-net) improves underwater image quality via a dual-stream network for feature fusion, focusing on spatial domain enhancement. It outperforms conventional methods in handling underwater images, despite its computational intensity. Comparative evaluations with state-of-the-art methods confirm DC-net's superiority in image enhancement across various datasets. While effective, areas for improvement include computational intensity and consideration of frequency domain methods, underscoring its potential for further refinement in underwater image enhancement.

31) Jiajia Zhou (*et al*) in the year 2023 proposed paper "Area Contrast Distribution Loss for Underwater Image Enhancement" [31]

The Shallow-RepNet+BN+Lacd algorithm enhances underwater image quality by addressing color distortion and low contrast issues, surpassing baseline models like Shallow-UWnet. It achieves superior performance in SSIM and PSNR metrics, with faster processing speeds suitable for real-time applications. Additionally, its model compression results in fewer training parameters, enhancing efficiency without compromising performance. Overall, the algorithm presents a promising solution for marine imaging applications, effectively improving underwater image quality.

32) Hao Yang (*et al*) in the year 2024 proposed paper "Underwater Image Enhancement via Multi-Scale Feature Fusion Network Guided by Medium Transmission" [32]

The article introduces MFUNet, a multi-scale feature fusion network guided by medium transmission for enhancing underwater images, addressing color distortion and low clarity issues. By incorporating physical model-based and deep learning-based approaches, the method achieves superior performance with fewer parameters. Techniques such as medium transmission guidance, edge loss implementation, enhanced network hierarchy, multi-color space encoder, channel attention module, residual enhancement module, and loss function contribute to the effectiveness of MFUNet. Extensive experiments demonstrate its superiority over existing methods in visual quality and quantitative metrics, making it a significant advancement in underwater image enhancement.

33) Meicheng Zheng and Weilin Luo (*et al*) in the year 2022 proposed paper "Underwater Image Enhancement Using Improved CNN Based Defogging" [33]

The article focuses on enhancing underwater images using a fusion algorithm composed of a color restoration module, an end-to-end defogging module, and a brightness equalization module. The color restoration module balances color based on the CIE Lab color model. The end-to-end defogging module employs a CNN network with depth separable convolutions and basic attention modules. The brightness equalization module uses contrast limited adaptive histogram equalization. The article highlights the importance of underwater image processing in various applications and discusses the limitations of traditional techniques. By combining different enhancement methods, the proposed fusion algorithm improves color correction and detail enhancement in underwater images.

34) Zefeng Zhao (*et al*) in the year 2023 proposed paper "Single underwater image enhancement based on adaptive correction of channel differential and fusion" [34]

The study introduces the Adaptive Correction of Channel Differential and Fusion (ACCDF) method for enhancing single underwater images, focusing on deblurring and color correction based on color attenuation levels. By limiting histogram distribution and employing bilinear interpolation at image boundaries, ACCDF improves image clarity and color accuracy. Additionally, transmission map estimation prevents over- and underexposure, enhancing overall image quality. Evaluation results show promising outcomes, with ACCDF images exhibiting superior visual quality despite a larger MSE compared to some methods like CLAHE. High SSIM and UCIQE values indicate ACCDF's effectiveness in color saturation and textural clarity, providing images closer to the ground truth with enhanced details. Overall, ACCDF demonstrates effective deblurring and color correction capabilities, offering an improved visual experience for underwater imagery.

35) Surya Kavitha Tirugatla (*et al*) in the year (2023) proposed paper "Underwater Image Enhancement using Fusion of CLAHE and Total Generalized Variation" [35]

The CLAHE-TGV method outperforms existing techniques like Retinex, DCP, and CLAHE in enhancing underwater images. It achieves significantly higher values in metrics such as PSNR, SSIM, AG, Sobel count, and entropy, showing improvements ranging from 20.97% to 80.48% over existing methods. Moreover, it demonstrates superior performance in qualitative and quantitative evaluations, including UCIQE, UIQM, PCQI, and MSE, with enhancements ranging from 11.56% to 58.65% across different images. Overall, CLAHE-TGV proves to be highly effective in enhancing underwater image quality compared to established methods.

36) Jingchun Zhou, (*et al*) in the year (2024) proposed paper "A Pixel Distribution Remapping and Multi-prior Retinex Variational Model for Underwater Image Enhancement" [36]

The document discusses a novel underwater image enhancement method combining pixel distribution remapping (PDR) with a multi-priority Retinex variational model to address challenges like color bias and brightness loss in underwater images. By introducing pre-compensation, channel stretching, and pixel distribution remapping, color artifacts are prevented, image contrast is enhanced, and image quality is improved. Additionally, luminance components are decoupled using Retinex theory, noise interference is reduced, and gamma correction adjusts luminance to compensate for losses. The effectiveness of the proposed method surpasses current state-of-the-art techniques in correcting color bias and compensating for luminance losses. Experimental validations demonstrate the method's efficacy in underwater image enhancement.

37) Nan Wang (*et al*) in the year 2023 proposed paper "UWGAN: Underwater GAN for Real-world Underwater Color Restoration and Dehazing "[37]

The method employs an Unsupervised Generative Adversarial Network (GAN) to generate realistic underwater images with color distortion and haze effects, followed by a U-Net model trained on synthetic datasets for color restoration and dehazing, aiming for clear image reconstruction while maintaining structural similarity. Experimental results highlight its effectiveness across various underwater vision tasks, supported by an ablation study exploring different loss functions. Outperforming existing methods both qualitatively and quantitatively, it shows promise on real-world datasets and achieves rapid processing speed

38) Xiaowen Shi and Yuan-Gen Wang (*et al*) in the year 2024 proposed paper "CPDM:Content-Preserving Diffusion Model for Underwater Image Enhancement "[38]

The Content-Preserving Diffusion Model (CPDM) for underwater image enhancement introduces a diffusion-based approach to preserve essential content while enhancing image quality. CPDM integrates a conditional input module and content compensation module to guide high-quality result generation, outperforming leading methods in PSNR, SSIM, and MSE metrics across diverse datasets. Its success lies in iteratively refining images and preserving critical content information like edges and textures. Ablation studies validate each module's effectiveness, with the full CPDM model achieving optimal results through step-by-step module addition.

39) Dazhao Du (*et al*) in the year 2024 proposed paper "UIEDP: Underwater Image Enhancement with Diffusion Prior " [39]

UIEDP enhances underwater images by combining a diffusion model with existing UIE algorithms, leveraging natural image priors for high-quality results without supervised training. Addressing real-time enhancement challenges, UIEDP employs acceleration techniques from diffusion models and DDIM for efficient generation. Experimental results demonstrate UIEDP's superiority over traditional methods like Fusion and USUIR in both quantitative metrics and visual comparisons, showcasing its effectiveness in correcting color distortions and enhancing image details.

40) Zhenwei Zhang (*et al*) in the year 2021 proposed paper "MetaUE: Model-based Meta-learning for Underwater Image Enhancement" [40]

The paper introduces MetaUE, a model-based deep learning approach for restoring clean images in diverse underwater scenarios. It utilizes a multi-variable convolutional neural network to estimate clean images, background light, and transmission maps, with meta-learning for pre-training on synthetic datasets and fine-tuning on real underwater data. MetaUE demonstrates superior interpretability and generalization, surpassing state-of-the-art methods in underwater image restoration. Additionally, its applicability extends to other degraded images like low-light conditions and haze, showcasing its robustness and potential for broader image restoration tasks. Despite its improved generalization, further research aims to enhance performance consistency across diverse underwater datasets.

41) Muhammad Hamzaa (*et al*) in the year 2023 proposed paper "MetaUE: Model-based Meta-learning for Underwater Image Enhancement" [41]

The FA-Net is introduced as an end-to-end solution for underwater image enhancement, leveraging deep learning and feature attention mechanisms. It incorporates Residual Feature Attention Blocks (RFAB) for channel and pixel attention, facilitating the learning of high-frequency information while filtering out low-frequency details. The model outperforms previous methods both quantitatively and qualitatively, demonstrating its superiority in accuracy. Additionally, FA-Net shows promise for addressing low-level vision tasks like single-image depth estimation and salient object detection.

42) Jingchun Zhou (*et al*) in the year 2024 proposed paper "DGNet: Dynamic Gradient-Guided Network for Water-Related Optics Image Enhancement [42]

Our method addresses the challenges of underwater image enhancement by dynamically updating pseudo-labels using predicted images, enhancing adaptability and avoiding local optima. It incorporates Feature Restoration and Reconstruction modules for noise reduction, achieving PSNR of 25.6dB and SSIM of 0.93 on the UIEB dataset. Our lightweight approach outperforms state-of-the-art methods, including Semi-UIR, with a 3.3% PSNR improvement, 88.3% fewer parameters, and 61.7% increased computational efficiency. This novel strategy enhances visual quality and generalizability, providing a significant advancement in underwater exploration.

43) Xuyan Hao (*et al*) in the year 2023 proposed paper "DGC-UWnet: Underwater image enhancement based on computation-efficient convolution and channel shuffle" [43]

DGC-UWnet is a novel underwater image enhancement model designed for both efficiency and effectiveness. It employs depthwise convolution, group convolution, and channel shuffle to reduce model parameters and computational complexity while improving generalizability. Through skip connections and feature fusion techniques, it produces visually pleasing results with fast processing speed. Comparative experiments demonstrate its superiority over state-of-the-art algorithms in subjective perception and quantitative metrics. Additionally, it enhances object detection performance, particularly evident in its compatibility with YOLOv5l on the UC3 dataset, showcasing its practical utility in underwater applications.

44) Xu Liu1 (*et al*) in the year 2023 proposed paper "Learning multiscale pipeline gated fusion for underwater image enhancement" [44]

The Multiscale Gated Fusion conditional GAN (MGF-cGAN) is introduced for underwater image enhancement, featuring a generator comprising Multiscale Feature Extract Module (Ms-FEM) and Gated Fusion Module (GFM). Ms-FEM utilizes three parallel subnets for richer feature extraction, while GFM adaptively fuses these outputs for improved chromaticity and contrast. Incorporating Multiscale Structural Similarity Index Measure (MS-SSIM) loss enhances human-like perception during training. Experimental validation across benchmark datasets demonstrates superior visual perception compared to classical and State-of-The-Art (SOTA) methods, achieving notable PSNR and RMSE scores. MGF-cGAN also excels in underwater saliency detection and SURF key matching, showcasing its suitability for underwater multimedia preprocessing.

45) WENYI GE (*et al*) 2022 proposed paper "Multi-prior underwater image restoration method via adaptive transmission" [45]

The MUAT method presents a sophisticated multi-priors approach for accurately estimating transmission maps in underwater image restoration. By integrating atmospheric light differences and channel variances, it dynamically computes transmission ratios, effectively mitigating color distortion and detail blur caused by varying imaging distances. Furthermore, the introduction of a global white balance method contributes to alleviating color distortions, enhancing overall visual fidelity. Comprehensive experimentation across diverse underwater scenarios underscores the method's robustness and efficacy, demonstrating significant improvements in detail enhancement and color fidelity compared to state-of-the-art techniques.

Conclusion

Underwater image enhancement is incredibly challenging due to the complex light absorption, color distortion, and scattering properties of the aquatic environment. Traditional enhancement techniques have often failed to reach the necessary level of accuracy and lacked the ability to address all these challenges simultaneously. This review has presented a thorough survey of recent advancements in deep learning, particularly convolutional neural networks (CNNs), generative adversarial networks (GANs), and transformer-based architectures, which have shown huge significance in improving underwater image clarity, color preciseness, and overall visual quality.

Analyzing state-of-the-art models, we discover the evolution from basic CNNs to hybrid and attention-based architectures, and from supervised to semi-supervised and unsupervised learning strategies. These methods not only enhance visual features but also support related tasks such as object detection and marine biodiversity assessment.

Despite the progress, key challenges such as real-time processing, model generalization across all underwater conditions, and computational efficiency remain key areas of research. Future directions should focus on lightweight models for deployment on edge devices and improved transfer learning strategies to further enhance performance and adaptability. This ongoing innovation provides a vital ground for developing robust underwater imaging solutions, which leads to deeper insights into marine environments and expanding the scope of underwater exploration and research

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