A Survey of Image Enhancement Techniques: From Traditional to Deep Learning Approaches

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Abstract - Image enhancement is a critical component of many image processing tasks, as it aims to improve the visual quality and clarity of images. In this paper, we present a thorough review of various image enhancement techniques, including traditional methods like histogram equalization and contrast stretching, as well as newer techniques based on deep learning.
This literature survey compares the different approaches to image enhancement, highlighting their respective strengths and limitations. It also discusses the potential applications and future directions of image enhancement research. By providing a comprehensive overview of the state-of-the-art in image enhancement, this survey serves as a valuable resource for researchers and practitioners in this field.
Overall, our review shows that image enhancement is a rapidly evolving area of research, with new techniques and technologies emerging all the time. From traditional methods to deep learning-based approaches, each technique has its own advantages and limitations, and their effectiveness can vary depending on the specific task and dataset.
As such, future research in image enhancement will likely focus on developing more advanced and versatile techniques that can adapt to different imaging scenarios and datasets. This includes exploring novel deep learning architectures, incorporating other imaging modalities like hyperspectral and polarimetric data, and integrating image enhancement with other image processing tasks such as segmentation and object detection.

I. INTRODUCTION

Image enhancement is a key step in many image processing tasks, with the goal of improving the visual quality and clarity of an image. It can be applied to a wide range of images, including photographs, medical images, and satellite images, to name a few. Image enhancement techniques can be classified into two broad categories: traditional methods and modern approaches based on deep learning.
Traditional methods include techniques such as histogram equalization, which aims to stretch the intensity range of an image to cover the full range of possible pixel values, and contrast stretching, which adjusts the contrast of an image by stretching the intensity range of the pixels to cover the full range of possible values. These techniques are simple and easy to implement, but they may not always produce satisfactory results, especially for images with complex structures or non-uniform illumination.
More recently, deep learning approaches have been proposed for image enhancement, which are based on convolutional neural networks (CNNs). These approaches can learn complex image features and patterns from large datasets, and can produce more realistic and natural-looking enhancement results. However, they require a large amount of training data and computational resources, and may not always generalize well to new types of images.
In this paper, we present a literature survey of various image enhancement techniques, including both traditional methods and deep learning approaches. The different techniques in image enhancement are compared and contrasted, highlighting their strengths and limitations, and discussing the potential applications and future directions of image enhancement research. This survey aims to provide a comprehensive overview of the state-of-the-art in image enhancement and to serve as a valuable resource for researchers and practitioners working in this field.

II. LITERATURE SURVEY

A. *3C Operator.*

This article [1] presents a novel solution for improving color appearance in image enhancement under challenging conditions, such as hazy night-time scenes, underwater environments, or under non-uniform artificial lighting. The proposed approach, called Color Channel Compensation (3C), addresses the problem of severely non-uniform color spectrum distributions encountered in these scenarios, which can result in artifacts and loss of color information.
Traditional image enhancing techniques can be subject to noise and color shifting when at least one color channel is close to completely lost. To address this, the 3C method proposes a pre-processing technique that reconstructs the lost channel using information from the opponent color channel. The algorithm subtracts a local mean from each opponent color pixel, which helps recover some of the lost color from the two colors involved in the opponent color channel (either red-green or blue-yellow).
Despite its simplicity, the 3C operator consistently improves the performance of conventional restoration methods. The authors demonstrate the utility of their approach by conducting an extensive qualitative and quantitative evaluation for white balancing, image dehazing, and underwater enhancement applications.
The experimental results demonstrate that the 3C method effectively addresses the loss of color information in challenging imaging scenarios, leading to improved image quality and appearance. The authors provide a detailed analysis of the benefits of their approach, including comparisons with state-of-the-art image enhancing techniques. Overall, the 3C method shows promise for improving the quality and usefulness of images captured in challenging conditions, and could find applications in a variety of fields such as surveillance, underwater exploration, and remote sensing.

B. *Locally Adaptive Color Correction*

Underwater images often suffer from strong color degradation due to a combination of wavelength-dependent light attenuation and scattering. This results in complex color casts that are influenced by the scene depth map and the light spectrum. Color transfer, a popular technique for correcting color casts, assumes that the casts are stationary and can be defined by global parameters. However, this approach is not directly applicable to the locally variable color casts commonly encountered in underwater scenarios.

To address this challenge, this paper [4] proposes a novel fusion-based strategy that combines color transfer with local color correction, based on the estimated light attenuation level from the red channel. The approach leverages the Dark Channel Prior (DCP) to restore the color-compensated image, by inverting the simplified Koschmieder light transmission model, similar to outdoor dehazing techniques. The resulting method effectively enhances image contrast and also supports accurate transmission map estimation.

The authors demonstrate the effectiveness of their approach through extensive experiments, which show that the proposed color correction significantly improves the effectiveness of local keypoint matching. The fusion-based strategy also provides more accurate color correction compared to traditional global methods, leading to improved image quality and appearance.

The authors provide a detailed analysis of the benefits of their approach, including comparisons with state-of-the-art techniques for underwater image enhancement. The results demonstrate that the proposed method outperforms existing approaches in terms of both subjective and objective image quality metrics. The proposed method could find applications in various fields such as marine biology, oceanography, and underwater surveillance, where accurate color representation is essential for data analysis and interpretation.

In summary, this paper presents a novel fusion-based strategy for color correction in underwater images, which combines color transfer with local color correction based on light attenuation estimates. The method effectively enhances image contrast and supports accurate transmission map estimation, improving the quality and usefulness of underwater images.

C. *Contrast Limited Histogram Equalization (CLAHE)*

The paper [2] presents a new approach to enhance underwater images in real-time applications. The proposed method can enhance underwater images in real-time applications, where the time for processing the image is a critical factor. The approach is based on the combination of two algorithms, namely the Multi-scale Retinex algorithm and the Contrast Limited Adaptive Histogram Equalization (CLAHE) algorithm. The multi-scale Retinex algorithm is used to enhance the color and brightness of the image, while CLAHE is used to improve the contrast of the image.

The multi-scale Retinex algorithm is applied to the input image to enhance the color and brightness. The multi-scale Retinex algorithm uses a set of filters with different sizes to enhance the image at different scales. The enhanced image is then passed through the CLAHE algorithm to improve the contrast. The CLAHE algorithm divides the image into smaller blocks and applies histogram equalization to each block separately. This helps to avoid the over-enhancement of bright regions, which is a common problem in histogram equalization.

The proposed approach has been tested on a dataset of underwater images, and the results have been compared with existing state-of-the-art methods. The experimental results show that the proposed approach outperforms the existing methods in terms of image quality and processing time. The proposed approach is also capable of running in real-time, making it suitable for real-time applications such as underwater surveillance, underwater robotics, and underwater exploration.

The authors have also evaluated the performance of the proposed approach on different quality metrics such as Peak Signal to Noise Ratio (PSNR), Structural Similarity Index (SSIM), and Visual Information Fidelity (VIF). The experimental results show that the proposed approach achieves higher values for these quality metrics compared to existing methods.

In conclusion, the paper presents a novel approach to enhance underwater images in real-time applications. The proposed approach combines the multi-scale Retinex algorithm and CLAHE algorithm to improve the color, brightness, and contrast of the underwater images. The experimental results show that the proposed approach outperforms existing state-of-the-art methods in terms of image quality and processing time. The proposed approach is suitable for real-time applications such as underwater surveillance, underwater robotics, and underwater exploration.

D. *Joint Luminance and Chrominance Learning Network (JLCL-Net)*

The paper [5] addresses the problem of underwater image enhancement, which is a challenging task due to the inherent properties of the underwater environment such as color attenuation, backscatter, and low visibility. Traditional image enhancement methods, such as histogram equalization, may not be effective in such scenarios. To address this issue, the authors propose a novel approach that jointly learns the luminance and chrominance information of the underwater image to enhance its quality.

The proposed method consists of two main stages. In the first stage, a deep learning model is trained on a dataset of underwater images to learn the mapping between the degraded and enhanced images. Specifically, the authors propose a novel network architecture that combines a residual block with a U-Net structure to jointly learn the luminance and chrominance information of the input image. The residual block helps the network learn the residual information between the degraded and enhanced images, while the U-Net structure enables the network to capture both global and local information of the image.

In the second stage, the trained model is used to enhance the quality of the input underwater image. The degraded image is first pre-processed to remove the color cast caused by the underwater environment. Then, the luminance and chrominance components of the pre-processed image are separated and fed into the trained model to obtain the enhanced image. Finally, the enhanced luminance and chrominance components are combined to obtain the final output image.

The proposed method is evaluated on several benchmark datasets, and the results show that it outperforms state-of-the-art methods in terms of various image quality metrics such as peak signal-to-noise ratio (PSNR), structural similarity index (SSIM), and underwater image quality index (UIQM). The authors also conduct an ablation study to show the effectiveness of different components of their proposed method.

In conclusion, the proposed method in this paper provides a promising solution for enhancing the quality of underwater images by jointly learning the luminance and chrominance information of the input image. The proposed method has shown superior performance over state-of-the-art methods and has the potential to be used in various underwater imaging applications such as underwater robotics, marine biology, and underwater exploration.

E. *Illuminance Domain Analysis*

The poor image quality obtained by traditional underwater vision systems is a significant issue that hampers the performance of underwater robots. The scattering and absorption of light by the water result in poor visibility, low contrast, and color distortion, which limits the effectiveness of these systems. Therefore, enhancing the quality of the images captured by the underwater vision system is critical for improving the performance of underwater robots.

The proposed algorithm in this paper [6] utilizes an innovative approach that combines illuminance domain analysis with improved versions of the DCP and Retinex algorithms. By estimating the background illumination of the water body in the imported image, the algorithm selects the appropriate enhancement algorithm based on a critical illumination value. This approach enables the algorithm to provide optimal enhancement results in different water environments.

The improved DCP algorithm used in the proposed algorithm addresses the limitation of the traditional DCP algorithm by enhancing the depth of field effect in the dark channel image and accurately estimating the environmental color of the water body. Furthermore, the improved Retinex algorithm enhances the quality of images by reducing noise and color distortion, which makes the algorithm more robust.

The UCIQE method used to evaluate the quality of the enhanced images provides more accurate and objective experimental results. This method measures the degree of distortion, naturalness, and quality of the enhanced image, which provides a comprehensive evaluation of the algorithm's performance.

The proposed algorithm has significant potential for various applications in underwater robotics, including underwater fishing, dike inspection, nuclear facility inspection, treasure hunting, archaeology, fish assessment, ship management, and customs inspection. The enhanced image quality will improve the accuracy and efficiency of these operations, making them more reliable and effective.

Overall, the proposed algorithm is a significant step forward in underwater image enhancement, providing a solution to the challenges of poor image quality and enhancing the performance of underwater robots in challenging and complex underwater environments.

F. *Fusion Algorithm*

Underwater images often suffer from a range of issues such as color distortion, low contrast, and low brightness, which can make it difficult to extract relevant information from them. To address these challenges, the authors of this study proposed a fusion algorithm [7] that involves several techniques.

One of the main issues with underwater images is color distortion caused by the absorption and scattering of light in water. To address this problem, the authors updated the scalar values of the R, G, and B channels to make the histograms of these channels similar. This technique helps to equalize the colors and produce a more visually balanced image.

Another issue with underwater images is low contrast, which can make it difficult to distinguish between objects in the image. The authors employed an optimized contrast algorithm to determine the optimal transmittance, which helps to enhance the contrast of the image. This approach is different from the traditional method of refining transmittance in the dark channel prior-based restoration and provides a better result.

To improve the brightness and contrast of underwater images further, the authors employed a histogram stretching algorithm based on the red channel. This approach increases the dynamic range of the image, making it more visually appealing and easier to extract relevant information.

The effectiveness of the proposed fusion algorithm was demonstrated through experiments conducted on underwater images, showing significant improvements in both subjective and objective evaluations of image quality. The authors compared their underwater image processing strategy with other popular techniques, demonstrating that their approach has an advantage over others.

Overall, the proposed fusion algorithm is a promising approach for the restoration and enhancement of underwater images. By employing several techniques, the algorithm addresses the challenges associated with underwater images and improves their quality, making it easier to extract relevant information from them.

G. *Minimal color loss principle and locally adaptive contrast enhancement*

The MLLE method proposed in this paper [8] is a promising technique for addressing the common challenges faced in underwater imaging, including color deviations and low visibility due to light absorption and scattering. By employing a locally adaptive color correction and contrast enhancement approach, the MLLE method is able to enhance the visual quality of underwater images while preserving important details.

The first stage of the MLLE method focuses on correcting color deviations in the image by using a minimum color loss principle to obtain a color transfer image from the input image. Additionally, a maximum attenuation map-guided fusion strategy is introduced to locally adjust the color and details of the input image. This stage ensures that the resulting image has vivid colors and improved contrast.

In the second stage, the MLLE method adaptively adjusts the contrast of the input image using integral and squared integral maps to compute the mean and variance of local image blocks. The color balance strategy is also applied to balance the color differences between channel a and channel b in the CIELAB color space. This stage further enhances the visual quality of the image by improving its contrast and detail.

The experimental results presented in the paper demonstrate that the MLLE method outperforms state-of-the-art methods in three underwater image enhancement datasets. Furthermore, the MLLE method is computationally efficient, with a processing speed of only 1 second on a single CPU for an image of size $1024 \times 1024 \times 3$. The experiments also show that the MLLE method can effectively improve the performance of underwater image segmentation, keypoint detection, and saliency detection, making it a promising technique for a variety of underwater imaging applications such as underwater inspection and underwater robotics.

Overall, the MLLE method proposed in this paper offers a promising solution for enhancing the visual quality of underwater images while preserving important details, and its potential applications in underwater imaging make it a valuable contribution to the field.

H. *Unsupervised Adaptation Network*

Underwater vision presents numerous challenges compared to open-air environments due to factors such as degraded visibility, scattering, and geometrical distortion. These issues make it difficult to develop efficient and accurate machine vision and robotic perception systems for underwater applications. Thus, researchers have been exploring innovative methods to address this problem, and the proposed deep learning architecture [9] is one such promising solution.

The suggested architecture employs an original approach of style-level and feature-level adaptation to handle the challenge of joint underwater depth estimation and color correction. The style adaptation network (SAN) is designed to learn a style-level transformation that adjusts in-air images to the style of the underwater domain. This is crucial because the appearance of images changes significantly when captured underwater, and this adaptation helps compensate for this difference.

The task network (TN) jointly estimates scene depth and corrects color from a single underwater image by learning domain-invariant representations. The network leverages the SAN's adaptation to estimate depth and correct color efficiently. The entire framework can be trained end-to-end using an adversarial learning approach, where the network learns to generate realistic underwater images to aid underwater-related machine vision and robotic perception.

Extensive experiments were conducted to evaluate the proposed architecture's effectiveness. The experiments were performed under air-to-water domain adaptation settings, where the network was trained on in-air images and tested on underwater images. The results showed that the proposed method outperformed existing state-of-the-art methods in both depth estimation and color correction tasks.

The proposed architecture offers a promising solution to the challenges of underwater vision and can enable advancements in underwater-related machine vision and robotic perception. The ability of the architecture to adapt to the underwater domain using style-level and feature-level adaptation makes it a unique approach that can enhance the accuracy and efficiency of underwater vision systems.

I. *An Effectual Underwater Image Enhancement using Deep Learning Algorithm*

Underwater image processing is a challenging task due to the inherent characteristics of the underwater environment. The light waves that propagate through water undergo several physical phenomena that lead to image degradation, such as attenuation, scattering, and absorption. This makes it difficult to obtain clear and high-quality images for further analysis and applications, particularly in real-time systems.

Image restoration techniques have been widely used to remove haze from source images. However, these techniques require multiple images of the same scene, captured from different viewpoints, to estimate the depth and haze parameters. This makes them unsuitable for underwater image processing since it is difficult to capture multiple images of the same scene underwater.

To overcome this issue, a deep learning approach has been proposed to de-haze individual underwater images without requiring multiple images. The proposed approach [10] involves training a convolution neural network (CNN) model to remove the haze from underwater images and improve their quality. The CNN model takes a single input image and outputs a de-hazed image with improved quality.

The proposed approach has several advantages over existing methods. It can produce high-quality images without requiring multiple images, making it suitable for real-time systems. Moreover, the CNN model can generalize well to different images and features obtained from separate areas, making it suitable for different underwater environments and applications.

Autonomous underwater robots are becoming increasingly important for various applications, such as underwater exploration, monitoring, and disaster response. However, these robots must be able to interpret and analyze underwater images to make intelligent decisions and take appropriate actions. The proposed deep learning approach can significantly contribute to developing such robots by improving the quality of underwater images for better interpretation and analysis.

In conclusion, the deep learning approach can overcome the challenges of underwater image processing and significantly contribute to developing autonomous underwater robots capable of managing various underwater situations.

III. COMPARISON

Method	UCIQUE
3C[1]	0.485
Fusion Algorithm [7]	0.5197
CLAHE [2]	0.6471
JLCL-Net [5]	0.6361
Minimal Color Loss [8]	0.782
Illuminance Domain Analysis [6]	0.5688
Locally Adaptive Color Correction [4]	0.5691
Unsupervised Adaptation Networks [9]	0.44
Deep Learning Algorithm [10]	0.537

TABLE 1

COMPARISON USING UCIQUE

The advantage of the 3C [1] method is that they consistently improves the outcome of conventional restoration processes. They are also more suitable at the preprocessing stage and can be used for real-time and online applications. The methods achieves the best performance in terms of both visual effects and numerical scores, is beneficial for several underwater vision tasks and has good generalization capability for foggy and sandstorm images. CBM3D denoising algorithm was introduced to make the image smoother and rounder whereas locally adaptive color correction [4] can effectively estimate transmission map and remove the haze effect for various underwater scenes. Unsupervised adaptation networks [9] works well for both depth estimation and color correction tasks.

One key advantage of Illuminance domain analysis is that it is able to effectively capture and exploit the statistical properties of an image in the illuminance domain, which can lead to more accurate and consistent results. Stated methods also have some disadvantages such as, they are less beneficial as a post-processing operator and the real-time performance cannot be guaranteed, especially for large numbers of images. Some of the methods might also give unsatisfactory results if the image contains multiple colour and they cannot handle the underwater images acquired in low light conditions well. Due to factors such as different water environment and brightness, using the same method to enhance the image will have limitations. For locally adaptive color correction [4], the current processing frame rate (about 12 fps) cannot meet the requirements of the current processing frame rate (about 12 fps) cannot meet the requirements of underwater depth estimation and real-time color correction.

IV. CONCLUSIONS

This paper presented a comprehensive survey of different underwater image enhancement techniques aimed at improving the visual quality of underwater images. Through our review, we explored various approaches including image restoration, color enhancement, and inpainting, and discussed their respective strengths and limitations.

We also highlighted the challenges and opportunities presented by underwater imaging, such as low visibility, color distortion, and noise, and discussed the potential applications of these techniques in various fields such as oceanography, biology, and environmental monitoring. Our survey revealed that there is still a need for more effective and efficient image enhancement techniques that can address the unique challenges of underwater imaging.

Further research is needed to develop and evaluate new approaches that can overcome these challenges and provide enhanced visual quality for a variety of applications. Additionally, there is a need for more comprehensive evaluation methods that can accurately assess the performance of different enhancement techniques in different scenarios.

In summary, this paper provides a valuable overview of the state-of-the-art in underwater image enhancement and offers insights into the future direction of this rapidly evolving field. By highlighting the challenges and opportunities in underwater imaging and suggesting potential research directions, we hope to inspire researchers and practitioners to continue pushing the boundaries of this important area of image processing.

V. REFERENCES

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