Problem A

Research on Underwater Image Enhancement in Complex Scenarios

For ocean exploration, clear and high-quality underwater images are crucial for deep-sea topography surveying and seabed resource investigation. **However, in complex underwater environments, the image quality deteriorates due to phenomena such as absorption and scattering of light during its propagation in water, resulting in blurriness, low contrast, color distortion, etc. These conditions are referred to as underwater image degradation. The main causes of underwater image degradation include light propagation loss in water, forward scattering and backward scattering effects, as well as the scattering effect of suspended particles on light [5].**

These factors collectively result in the loss of details and clarity during the transmission process of underwater images, affecting visual recognition and analysis.

(a) (b)

(c) (d)

Figure 1. Schematic diagram of underwater image degradation, (a) shows green color cast, (b) shows blue color cast, (c) shows imaging blur, (d) shows insufficient light.

The schematic diagram of the underwater imaging process is shown in Figure 2. According to the Jaffe-McGlamery underwater imaging model, **the underwater image captured by the camera can be represented as a linear combination of three components: direct component, forward scattering component, and backward scattering component [1].** Among them, the forward scattering component refers to the light that enters the imaging system after being scattered by suspended particles in water from target surface reflection or radiation. This component will cause blurring in the obtained image. The backward scattering component refers to the light that enters the imaging system after natural light entering water is scattered by suspended particles, resulting in low contrast in the obtained image. In general cases, due to close distance between objects and cameras, a simplified imaging model is used:

$$I(x) = J(x)t(x) + B(t(x)),$$

where $I(x)$ represents the degraded underwater image, $J(x)$ represents the clear image, B is the ambient light in the underwater environment, and $t(x)$ is the light transmission function of the underwater scene. The light transmission rate varies under different conditions. At the same time, the underwater ambient light also changes with factors such as depth and the turbidity of the water, all of which can lead to increased degradation of underwater images.

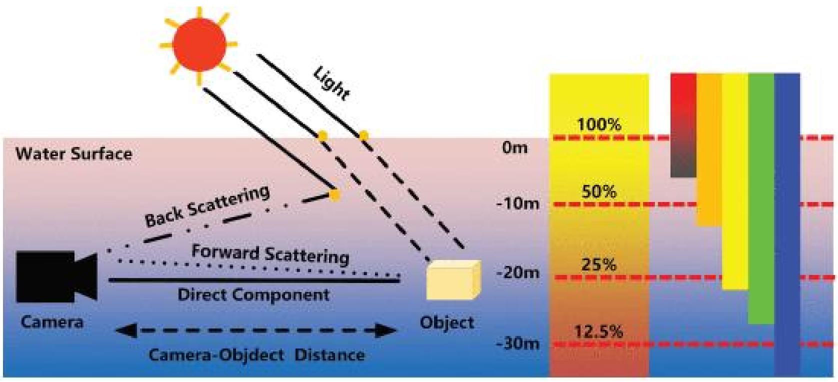

Figure 2. Conceptual diagram of underwater image degradation principle [6]

Before performing enhancement and other processing operations on underwater images, it is necessary to conduct statistical analysis on the image to be processed, as shown in Figure 3. Image analysis generally utilizes mathematical models combined with image processing techniques to analyze underlying features and higher-level structures, thereby extracting intelligent information. For example, using a histogram can statistically analyze the distribution of colors in different channels of the image, while applying edge operators can provide clarity information about object contours in the image. These pieces of information help us classify images into different categories and propose targeted solutions for image enhancement.

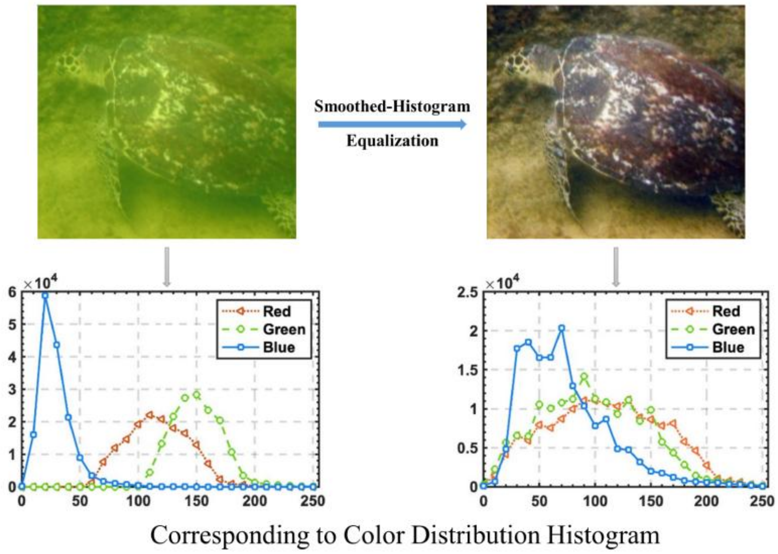

Figure 3. Color distribution curves of underwater images before and after using enhancement techniques, with each channel's distribution curve being more balanced and closer to each other, thus improving the visual effect [7].

Underwater image enhancement technology is a technique that improves the quality of images captured in underwater environments by applying signal processing, image processing, and machine learning theories. **It aims to reduce problems such as image blur, color distortion, and decreased contrast caused by the absorption and scattering of light in water, thereby improving the visibility and clarity of underwater images.**

Underwater image enhancement and restoration methods can be divided into **traditional methods and deep learning methods**. Traditional methods can be further categorized into **non-physical models and physics-based** models. Non-physical model methods improve visual quality by **directly adjusting the pixel values of images**, including **applying existing image enhancement methods and specially designed algorithms**. Physics-based model methods **model and estimate parameters to invert the degradation process of underwater images.** These methods can invert based on assumptions or prior knowledge, or they can use the optical properties of underwater imaging to improve the restored images. However, due to the complexity of underwater scenes, most existing methods cannot handle all scenarios. Therefore, an underwater scene enhancement algorithm tailored for complex scenarios is very important for subsequent tasks in underwater vision.

To estimate the degree of underwater image degradation in different scenarios and provide targeted enhancement methods, please answer the following questions:

Question 1: Please use image statistical analysis techniques similar to those mentioned in the above text to perform multi-angle analysis on the underwater image provided in Attachment 1. Classify the image provided in Attachment 1 into **three** categories: **color cast, low light,** and **blur**, and fill in the filenames in the three positions in the "Answer.xls" attachment. Also, explain the reasons for such classification.

Question 2: Based on the types of degradation proposed in Question 1, using the underwater imaging model provided in the problem, construct an underwater scene image degradation model with the images attached. Analyze the degradation reasons of underwater images captured from different scenes [1] (including but not limited to color cast, low light, etc.). Analyze the similarities or differences of these degradation models (for example, categorize from perspectives such as color, lighting, clarity, etc.).

Question 3: Based on the underwater scene image degradation model established in Question 2, propose an underwater image enhancement method tailored for a single scene (such as color cast, blur, low light), and validate the proposed enhancement method using the image data provided in the attachment. **Include the enhanced results of the test images from Attachment 2 and their corresponding evaluation metrics in the paper, calculate and present the PSNR, UCIQE, UIQM, and other evaluation metrics for the output images**, and **fill them in the table Attachment 1 results provided in "Answer.xls".**

Question 4: The modeling adaptability of existing underwater image enhancement models varies across different scenarios. Please, in conjunction with the above question and the images provided in the attachment, propose an underwater image enhancement model tailored for complex scenarios **(e.g., a non-physical model, references [2]-[5] may be consulted).** This model should be capable of enhancing underwater image degradation issues across a variety of complex scenes. **Include the enhanced results of the test images from attachment 2 and their corresponding evaluation metrics in the paper for display**, calculate and output the PSNR, UCIQE, UIQM, and other evaluation metrics of the output image, and **fill them in the table Attachment 2 results provided in "Answer.xls".**

Question 5: Compare various enhancement techniques for specific scenarios with a single enhancement technique for complex scenarios, and propose feasibility suggestions for underwater visual enhancement in practical applications.

Attachment:

Attachment: https://pan.baidu.com/s/1tXeoiDvxsGbIQ42obLf5xw?pwd=2024 code: 2024

Appendix:

Underwater image evaluation metrics:

PSNR (Peak Signal-to-Noise Ratio), UCIQE (Underwater Color Image Quality Evaluation), and UIQM (Underwater Image Quality Measure) are crucial indicators used to assess image quality. Below is a comprehensive description of the calculation methods for these three metrics.

PSNR (Peak signal-to-noise ratio) :

PSNR is an objective standard for measuring image quality, which calculates the mean square error (MSE) between the original image and the processed image, and converts it into decibel units to measure image quality.

UCIQE (Underwater Color Image Quality Evaluation) :

UCIQE [9] is a linear combination of color density, saturation, and contrast, used to quantitatively evaluate the non-uniform color cast, blurriness, and low contrast in underwater images. It is an image quality assessment metric that does not require a reference (ground truth) image. The specific definition is as follows:

$$UCIQE = c_1 \times \sigma_c + c_2 \times con_l + c_3 \times \mu_s$$

Among them, σ_c represents the chromaticity standard deviation, con_l represents brightness contrast, and μ_s represents average saturation. c_1, c_2, and c_3 are weighting coefficients. As mentioned above, there is a good correlation between chromatic variance and human perception for underwater color images of interest. Using chromatic differences to describe color bias also has other reasons.

UIQM (Underwater Image Quality Measure) :

UIQM [8] is an evaluation index that comprehensively considers attributes such as colorfulness, sharpness, and contrast of underwater images. The calculation formula is:

$$UIQM = c_1 \times UICM + c_2 \times UISM + c_3 \times UIConM,$$

where UICM, UISM, and UIConM represent the measurements of colorfulness, sharpness, and contrast of underwater images respectively. c_1, c_2, and c_3 are the weighting coefficients.

References:

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