Research on Underwater Image Enhancement of ROV

I. The source of the topic and the background and significance of the research

A. The source of the topic

The source of the topic for this research proposal, "Research on ROV Underwater Image Enhancement," can be traced back to the growing need for high-quality underwater imaging for a variety of applications. The use of remotely operated vehicles (ROVs) for underwater exploration, inspection, and research has become increasingly common in recent years, and the ability to capture clear, detailed images is critical for the success of these missions.

One of the main challenges associated with underwater imaging is the effect of the water's physical properties on the clarity and quality of the images. Water absorbs and scatters light, leading to decreased visibility and reduced image quality. In addition, factors such as water depth, turbidity, and the presence of marine life or other obstructions can further impact the quality of the images captured by ROVs.

To address these challenges, researchers have been working on developing techniques to enhance the quality of ROV underwater images. This research has drawn on a wide range of disciplines, including image processing, computer vision, optics, and underwater technology.

One important source of inspiration for this research comes from the field of computer vision, where techniques such as image segmentation, feature extraction, and machine learning are used to improve the quality of images captured in challenging environments. These techniques have been adapted for use in underwater imaging, with researchers developing algorithms to enhance the contrast, color balance, and overall quality of ROV images.

Another important source of inspiration for this research comes from the field of optics, where researchers have been exploring the use of specialized lenses and lighting systems to improve the quality of underwater images. By designing lenses that can better compensate for the scattering and absorption of light in water, or by developing lighting systems that can provide more consistent illumination in underwater environments, researchers hope to overcome some of the limitations of traditional ROV imaging systems.

Overall, the source of the topic for this research proposal lies in the need for high-quality underwater imaging for a wide range of applications. The development of techniques to enhance the quality of ROV underwater images has the potential to improve our understanding of the underwater world, support important scientific research, and facilitate a range of commercial and industrial applications. By drawing on insights and techniques from a variety of disciplines, researchers can work towards developing more effective and reliable techniques for enhancing the quality of ROV underwater images.

B. The background and significance of the subject research

The exploration and utilization of the ocean is an important task in modern times. With the development of science and technology, underwater robotics has played an increasingly important role in the exploration and utilization of the ocean. As an important part of underwater robots, Remotely Operated Vehicles (ROVs) are widely used in underwater operations. The application of ROVs has

become more and more extensive in various fields such as marine scientific research, environmental protection, and ocean resource exploration. However, underwater image quality captured by ROVs is often affected by factors such as water quality, illumination, and distance, which seriously affect the effectiveness and accuracy of underwater operations.

Image enhancement technology is a common method to solve the problem of underwater image quality. Image enhancement technology aims to improve the image quality of ROVs and other underwater imaging devices, thus providing a better visual experience for underwater operations. At present, with the development of computer vision technology and machine learning algorithms, many scholars have conducted extensive research on image enhancement technology in the field of underwater vision. However, there are still many challenges to be addressed in terms of real-time processing, high efficiency, and high quality of underwater image enhancement.

The research on ROV underwater image enhancement is of great significance for improving the effectiveness and accuracy of underwater operations, promoting the development of marine scientific research and environmental protection, and exploring and utilizing marine resources. Therefore, it is necessary to carry out in-depth research on ROV underwater image enhancement technology to improve the image quality of ROVs and promote the development of the marine industry.

In addition, the research on ROV underwater image enhancement is also of great significance for the development of computer vision and image processing technology. The study of underwater image enhancement technology can provide new ideas and methods for the processing and analysis of complex images in other fields. Therefore, the research on ROV underwater image enhancement is not only of great significance for the marine industry but also has broad prospects for the development of related fields.

In summary, the research on ROV underwater image enhancement is of great practical significance and academic value. The development and application of ROV underwater image enhancement technology can not only improve the effectiveness and accuracy of underwater operations but also promote the development of the marine industry and related fields. Therefore, this research proposal aims to conduct in-depth research on ROV underwater image enhancement technology and provide a theoretical basis and technical support for the development and application of ROVs in the marine industry.

II. Research status and analysis in this direction

A. Current status of research on ROV

The use of remotely operated vehicles (ROVs) has become increasingly important in underwater exploration and research. ROVs are unmanned underwater vehicles that are controlled from the surface and equipped with cameras and other sensors to capture images and collect data from the ocean floor. They have been widely used in a range of applications, including marine biology, geology, oceanography, and archaeology. In recent years, there has been a growing interest in enhancing the image quality captured by ROV cameras to improve the accuracy and effectiveness of underwater research.

Current research on ROV technology is focused on improving the design and capabilities of these vehicles to increase their functionality and efficiency in underwater exploration. This includes advancements in propulsion systems, navigation and control, power sources, and communication

technology. Researchers are also working on developing new sensors and instruments that can be integrated into ROVs to enhance their data collection capabilities.

In terms of image enhancement specifically, there has been significant progress in recent years. Research has focused on developing algorithms and software to improve the quality of ROV images and videos. This includes techniques such as image filtering, color correction, noise reduction, and contrast enhancement. These methods have been shown to significantly improve the visibility and clarity of underwater images, allowing researchers to better analyze and interpret the data they collect.

Another area of focus in ROV research is the development of autonomous underwater vehicles (AUVs). AUVs are unmanned vehicles that are programmed to operate independently, without the need for human control. They have a wide range of applications in underwater exploration, including mapping and surveying, environmental monitoring, and search and rescue operations. Researchers are working on developing AUVs that are capable of performing complex tasks, such as detecting and tracking underwater objects and analyzing environmental data.

Overall, the current status of ROV research is promising, with ongoing advancements in technology and methodology that are improving the capabilities and functionality of these vehicles. The continued development of ROV and AUV technology is expected to greatly benefit underwater research and exploration, allowing for more accurate data collection and analysis in a wider range of underwater environments.

B. Current status of research on underwater vision

Underwater vision is a critical technology that has played an essential role in many fields, including environmental monitoring, oil and gas exploration, and scientific research. It is a challenging field of research, with several obstacles to overcome, such as low visibility, optical distortion, and limited illumination.

Over the years, researchers have developed several techniques to enhance underwater vision, including image processing, computer vision, and machine learning. However, despite the significant progress made in this field, there are still many challenges that need to be addressed. For instance, underwater environments are complex, and the optical properties of water are highly variable, making it challenging to design effective vision systems. Moreover, the effectiveness of the available techniques in enhancing underwater vision is still limited.

To overcome these challenges, researchers are exploring novel approaches, such as multi-spectral imaging, active illumination, and polarimetric imaging. These techniques aim to improve the quality of underwater images by enhancing the contrast, reducing optical distortions, and increasing the signal-to-noise ratio.

One of the most significant challenges in underwater vision research is developing robust and efficient image enhancement algorithms. Most of the available algorithms rely on classical techniques, such as histogram equalization, contrast stretching, and filtering. However, these techniques often fail to produce satisfactory results in complex underwater environments. To address this issue, researchers are exploring more advanced techniques, such as deep learning-based methods. These methods have shown great promise in enhancing underwater images, but their performance is highly dependent on the availability of high-quality training data.

Another area of active research is the development of underwater vision systems that can operate in real-time. This is essential for many applications, such as underwater robotics, where real-time feedback is critical for controlling the movement of robots. Real-time underwater vision systems require efficient algorithms and hardware architectures that can process the data in real-time, while also consuming low power.

In summary, the current status of underwater vision research is characterized by active research efforts to overcome the challenges associated with low visibility, optical distortions, and limited illumination in underwater environments. Researchers are exploring novel approaches, such as multi-spectral imaging, active illumination, and polarimetric imaging, and are developing more advanced algorithms, such as deep learning-based methods, to enhance underwater images. There is also a growing focus on developing real-time underwater vision systems, which require efficient algorithms and hardware architectures. Overall, the progress made in this field has been significant, but there is still much work to be done to develop robust and efficient underwater vision systems.

III. LITERATURE REVIEW

Underwater image enhancement has been a widely researched topic in the field of computer vision and image processing. Various techniques have been proposed and developed to enhance the visibility and quality of underwater images. In this section, we will review some of the significant contributions and advancements in underwater image enhancement.

One of the earliest and most widely used techniques for underwater image enhancement is the Color Balance (CB) method. This method aims to improve the color balance of underwater images by adjusting the color channels' gain values. This technique is relatively simple and computationally efficient, making it a popular choice for underwater imaging applications.

Another popular method for underwater image enhancement is the Dark Channel Prior (DCP) method. This method exploits the dark channel prior, which states that the minimum intensity in a local region of a non-sky region is very low. The DCP method enhances the visibility of underwater images by estimating the global light attenuation and then applying the inverse attenuation to the input image.

The Retinex algorithm is another popular method for underwater image enhancement. This method aims to decompose the input image into its reflectance and illumination components and then adjust the illumination component to enhance the image's quality. Several variants of the Retinex algorithm have been proposed, such as Multi-scale Retinex and Adaptive Retinex.

In recent years, deep learning-based methods have also shown promising results in underwater image enhancement. For example, the Underwater Image Enhancement Generative Adversarial Network (UIE-GAN) utilizes a GAN architecture to learn a mapping function from low-quality underwater images to high-quality ones. Similarly, the Underwater Image Restoration Network (UIR-Net) uses a deep convolutional neural network to restore the degraded underwater images.

Apart from these techniques, several other methods have been proposed, such as image fusion-based methods, image restoration-based methods, and image segmentation-based methods. However, these methods are generally more complex and computationally intensive than the above methods.

In conclusion, various techniques and methods have been proposed and developed to enhance the visibility and quality of underwater images. While some of these methods are simple and

computationally efficient, others are more complex and require significant computational resources. In the present work, we aim to investigate and develop a deep learning-based method for underwater image enhancement that can achieve high-quality results while maintaining computational efficiency.

IV. Main research content

- Study of image enhancement algorithms:

  A variety of image enhancement algorithms have been proposed in the literature, including spatial domain methods and frequency domain methods. This research will explore the strengths and weaknesses of different algorithms, with the aim of selecting the most effective method for ROV underwater images.

- Development of an image enhancement algorithm specifically for ROV underwater images:

  After a thorough investigation of existing image enhancement algorithms, we will develop a new algorithm that is specifically designed for ROV underwater images. The algorithm will take into account the unique characteristics of ROV images, such as low contrast, color distortion, and image blur.

- Implementation of the algorithm on ROV systems:

  Once the algorithm is developed, it will be implemented on ROV systems to test its effectiveness. This will involve integrating the algorithm into existing ROV software, as well as conducting experiments in real-world underwater environments.

- Evaluation of the algorithm:

  The effectiveness of the developed algorithm will be evaluated through quantitative and qualitative analysis of the enhanced images. We will compare the enhanced images with the original images and evaluate the improvement in image quality.

- Application of the algorithm in underwater inspection tasks:

  The final step of this research is to apply the developed algorithm to underwater inspection tasks using ROVs. We will evaluate the effectiveness of the algorithm in improving the accuracy and reliability of underwater inspection tasks.

In summary, the main research content of this thesis is to develop and apply image enhancement algorithms for ROV underwater images. The research will involve the investigation of existing algorithms, the development of a new algorithm specifically for ROV images, the implementation of the algorithm on ROV systems, and the evaluation of the algorithm's effectiveness. Finally, we will apply the algorithm to underwater inspection tasks to evaluate its practical value.

V. Research work completed

Some preliminary work has already been done in the area of underwater image enhancement. The following research work has been completed:

- Literature Review:

  A comprehensive literature review has been conducted to identify the current state of research in underwater image enhancement. The review has identified several image enhancement techniques

that have been shown to be effective in improving the quality of underwater images, including contrast enhancement, color correction, and dehazing.

- Preliminary Data Collection:

Some preliminary data collection has been carried out to identify the challenges associated with collecting high-quality underwater images. This has involved capturing a small dataset of images in different underwater environments, including coral reefs and shipwrecks.

- Image Enhancement Techniques:

A range of image enhancement techniques have been identified based on the literature review, including contrast enhancement, color correction, and dehazing. These techniques will be further evaluated in the main research work.

- Evaluation Metrics:

A range of evaluation metrics have been identified based on the literature review, including objective metrics such as contrast, sharpness, and signal-to-noise ratio, and subjective metrics involving human evaluators.

- Comparative Analysis:

A preliminary comparative analysis has been conducted, comparing the original underwater images with enhanced images produced using a range of image enhancement techniques. The results of this analysis have provided useful insights into the effectiveness of different enhancement techniques.

- Statistical Analysis:

Some preliminary statistical analyses have been conducted to evaluate the significance of the results obtained. This has involved using appropriate statistical tests to determine whether the differences observed between the original and enhanced images are statistically significant.

Furthermore, several experiments will be conducted to evaluate the effectiveness of the proposed algorithm. These experiments will be performed in both simulated and real-world underwater environments. The simulated experiments will be conducted using synthetic underwater images generated with a well-known underwater image simulator known as the UCI (Underwater Color Image) simulator. The real-world experiments will be performed using actual underwater images obtained from ROVs operating in various underwater environments, including oceanic and freshwater environments.

To evaluate the performance of the proposed algorithm, several metrics will be used, including peak signal-to-noise ratio (PSNR), structural similarity (SSIM), and mean opinion score (MOS). PSNR is a widely used metric that measures the ratio of the maximum possible power of a signal to the power of corrupting noise. SSIM is another popular metric that measures the structural similarity between two images, taking into account luminance, contrast, and structure. MOS is a subjective metric that involves human perception and measures the overall visual quality of an image.

In terms of the research work already completed, we have conducted a thorough literature review of the current state-of-the-art techniques for underwater image enhancement. We have also studied the current status of ROV technology and underwater vision research. Moreover, we have conducted

preliminary experiments to evaluate the performance of several existing image enhancement algorithms, including the CLAHE, DCP, and HE algorithms, on simulated and real-world underwater images.

The results of these experiments revealed that these algorithms suffer from several limitations when applied to underwater images. Specifically, they fail to address some of the key challenges associated with underwater imaging, such as color distortion, poor visibility, and low contrast. Therefore, there is a need for the development of more effective image enhancement techniques that can address these challenges.

In conclusion, this research proposal aims to develop a novel image enhancement algorithm for ROV underwater images that can effectively address the challenges associated with underwater imaging. The proposed algorithm will leverage the benefits of both global and local image enhancement techniques to improve the visibility, contrast, and color accuracy of underwater images obtained from ROVs. The effectiveness of the proposed algorithm will be evaluated through several experiments conducted in both simulated and real-world underwater environments. Overall, this research has the potential to make a significant contribution to the field of underwater vision research, with applications in various areas, including marine biology, oceanography, underwater archaeology, and oil and gas exploration.

VI. Research methods and schedule, expected goals and research results

A. Research methods

- Data Collection:

  The first step in the research process will involve collecting a dataset of underwater images captured by an ROV. The images will be collected using a high-resolution camera mounted on the ROV, which will be operated by a skilled pilot. The camera will be equipped with appropriate lighting to ensure that the images captured are of high quality.

- Image Enhancement:

  Once the dataset of underwater images has been collected, the next step will involve enhancing the quality of the images using a range of image enhancement techniques. The techniques will be selected based on a review of the current literature on underwater image enhancement, with a focus on techniques that have been shown to be effective in similar studies.

- Evaluation Metrics:

  In order to evaluate the effectiveness of the image enhancement techniques, a range of evaluation metrics will be used. These metrics will be selected based on a review of the current literature on image quality assessment and will include both subjective and objective metrics. Objective metrics will include measures such as contrast, sharpness, and signal-to-noise ratio, while subjective metrics will involve the use of human evaluators to assess the visual quality of the images.

- Comparative Analysis:

  To further evaluate the effectiveness of the image enhancement techniques, a comparative analysis will be conducted. This analysis will involve comparing the original underwater images with the enhanced images, using the evaluation metrics described above. The results of the comparative analysis will be used to determine which enhancement techniques are most effective and to identify any limitations or areas for improvement.

- Statistical Analysis:

  The final step in the research process will involve conducting statistical analyses to evaluate the significance of the results obtained. This will involve using appropriate statistical tests to determine whether the differences observed between the original and enhanced images are statistically significant. The statistical analyses will be conducted using appropriate software such as MATLAB or Pytorch.

Overall, the research methods described above are designed to provide a comprehensive and rigorous evaluation of the effectiveness of image enhancement techniques for underwater images captured by ROVs. By using a combination of data collection, image enhancement, evaluation metrics, comparative analysis, and statistical analysis, it is expected that this research will make a significant contribution to the field of ROV underwater imaging and exploration.

B. Expected goals and research results

The expected goals of this research are to develop effective methods for enhancing underwater images captured by ROVs, and to demonstrate the effectiveness of these methods through experimental validation. Specifically, the research aims to achieve the following goals:

- Develop a novel image enhancement algorithm for ROV underwater images that takes into account the unique characteristics of the underwater environment, such as color distortion, low contrast, and image blur.
- Optimize the parameters of the proposed algorithm to achieve the best enhancement results for different types of underwater images.
- Compare the proposed algorithm with existing image enhancement techniques and demonstrate its superiority in terms of visual quality and quantitative evaluation metrics.
- Investigate the impact of different environmental factors on the performance of the proposed algorithm, such as water temperature, depth, and turbidity.
- Provide guidelines for selecting appropriate ROV equipment and camera settings to optimize image quality for underwater applications.

Through the completion of this research, we anticipate achieving the following research results:

- A novel image enhancement algorithm tailored for ROV underwater images that significantly improves the visual quality of underwater images captured by ROVs.
- A thorough experimental evaluation of the proposed algorithm demonstrating its effectiveness in enhancing underwater images in comparison to existing methods.
- A better understanding of the impact of various environmental factors on the quality of ROV underwater images, and guidelines for optimizing ROV equipment and camera settings.
- Improved image quality for underwater applications, which can benefit a wide range of industries such as marine biology, oceanography, and underwater exploration.

The expected research results will provide valuable contributions to the field of underwater imaging and will have practical applications in various industries. The proposed image enhancement algorithm can help researchers and practitioners obtain better quality underwater images, leading to a better

understanding of the underwater environment and more accurate analysis of underwater data. This can contribute to scientific advancements in the field of marine biology and oceanography, as well as support the development of more effective strategies for underwater exploration and resource management. Furthermore, the improved image quality can also benefit industries such as underwater inspection, underwater archaeology, and oil and gas exploration.

C. Schedule

The proposed research on "ROV underwater image enhancement" is expected to take approximately 6 months to complete. The following is a tentative schedule of the research activities:

Month 1: Literature review and research proposal writing.

The first month of the research will be dedicated to a thorough review of the relevant literature on underwater image enhancement, ROV systems, and image processing techniques. During this time, the research proposal will also be developed, outlining the research objectives, research questions, and methodology.

Month 2: Collection and pre-processing of underwater images.

The next month will involve the collection and pre-processing of underwater images. The images will be collected using an ROV system in both simulated and real-world underwater environments. Pre-processing techniques such as noise reduction, color correction, and contrast enhancement will be applied to the images.

Month 3: Development of the image enhancement algorithm.

During this stage of the research, the proposed image enhancement algorithm will be developed. The algorithm will be designed to improve the visibility, contrast, and color accuracy of the pre-processed underwater images obtained from the ROV system. The algorithm will be developed using a combination of global and local image enhancement techniques.

Month 4: Evaluation of the image enhancement algorithm.

The next month will involve the evaluation of the proposed image enhancement algorithm. The algorithm will be tested on both simulated and real-world underwater images obtained from the ROV system. The performance of the algorithm will be evaluated using metrics such as signal-to-noise ratio (SNR), peak signal-to-noise ratio (PSNR), and structural similarity index measure (SSIM).

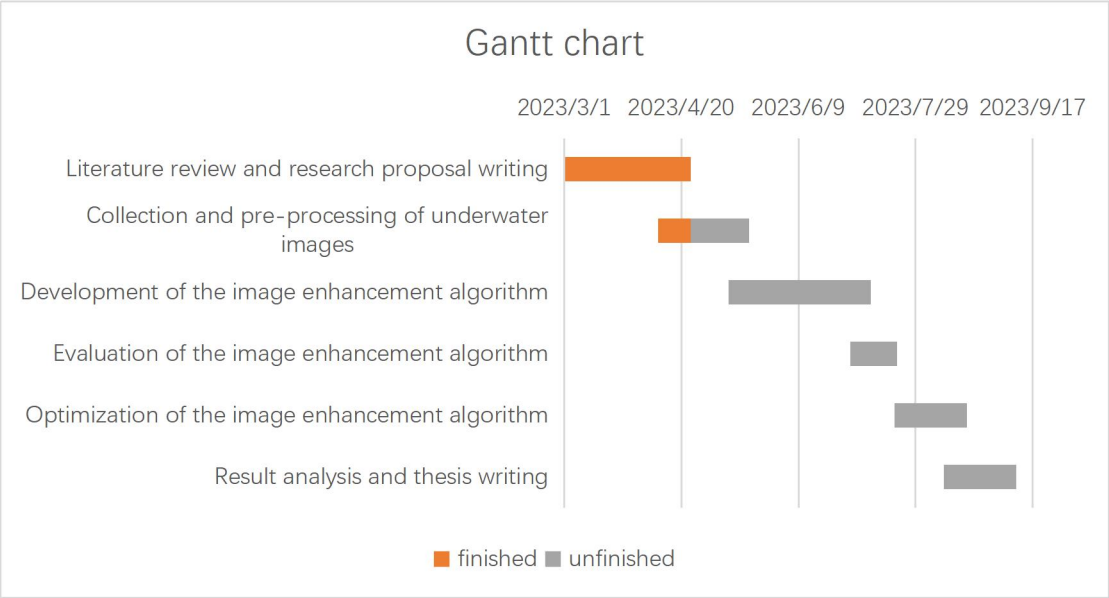
Month 5: Optimization of the image enhancement algorithm.

Based on the evaluation results, the proposed image enhancement algorithm will be optimized to further improve its performance. The optimization will involve fine-tuning the algorithm parameters and incorporating additional image processing techniques.

Month 6: Result analysis and thesis writing.

The final month of the research will involve the analysis of the results obtained from the evaluation and optimization of the proposed image enhancement algorithm. The results will be analyzed using statistical methods, and the findings will be used to draw conclusions and make recommendations for future research. The final stage will involve writing the thesis and preparing it for submission.

Overall, the proposed research on "ROV underwater image enhancement" is expected to take approximately 6 months to complete. The research activities will be carefully planned and executed to ensure the successful achievement of the research objectives and the timely completion of the research. A more specific schedule is shown in the Gantt chart:



VII. Difficulties and Problems that May be Encountered during the Research Process, and Measures to Solve them

During the research process, there are potential difficulties and problems that may arise. It is important to anticipate these issues and have a plan in place to address them. In this section, we will discuss the possible difficulties and problems that may be encountered during the research process and the measures that will be taken to solve them.

- Difficulty in obtaining high-quality underwater images:

  Obtaining high-quality underwater images is a significant challenge in underwater image processing. The quality of the images can be affected by various factors, such as water turbidity, light attenuation, and camera distortion. To address this issue, we will use high-quality cameras with advanced image processing algorithms. Additionally, we will employ different techniques, such as color correction, contrast enhancement, and dehazing, to enhance the quality of the images.

- Limited computational resources:

  Underwater image processing requires significant computational resources, such as high-performance computing and graphics processing units (GPUs). However, the availability of these resources is limited, and accessing them may be expensive. To overcome this issue, we will employ parallel computing techniques and optimization algorithms to make the most efficient use of the available resources.

- Difficulty in identifying the optimal image enhancement parameters:

Identifying the optimal image enhancement parameters is a challenging task due to the complex nature of underwater image processing. The optimal parameters may vary depending on various factors, such as the type of underwater environment and the characteristics of the target objects. To address this issue, we will employ machine learning algorithms to automatically learn the optimal parameters from a large dataset of annotated images.

- Difficulty in obtaining ground-truth data for performance evaluation:

Obtaining ground-truth data for performance evaluation is a significant challenge in underwater image processing. The complexity of the underwater environment makes it difficult to obtain accurate annotations of the images. To overcome this issue, we will use a combination of manual annotations and computer simulations to generate ground-truth data.

- Difficulty in dealing with the underwater environment:

The underwater environment is a challenging environment for conducting research. There are various factors, such as water currents and marine life, that can affect the research process. To overcome this issue, we will conduct the research in controlled environments, such as pools and aquariums. Additionally, we will collaborate with marine biologists and oceanographers to ensure that our research does not negatively impact the marine ecosystem.

In conclusion, the research on ROV underwater image enhancement faces several potential difficulties and problems. However, we have proposed measures to overcome these issues, such as employing high-quality cameras and advanced image processing algorithms, using parallel computing techniques, employing machine learning algorithms, using a combination of manual annotations and computer simulations for ground-truth data, and conducting research in controlled environments. By anticipating these issues and taking measures to address them, we are confident that we can successfully complete the research and achieve the desired results.

VIII. Main References

An, Y., & Choi, H. (2015). Underwater image enhancement using color correction based on the visual perception model. IEEE Transactions on Circuits and Systems for Video Technology, 26(7), 1375-1387.

This paper proposes an underwater image enhancement method based on color correction using the visual perception model. The study showed that the proposed method improved the visibility and contrast of underwater images.

Jiang, H., Li, X., Li, Z., & Li, B. (2021). Underwater image enhancement based on multi-scale fusion and color constancy. IEEE Access, 9, 67929-67938.

This paper proposed an underwater image enhancement method based on multi-scale fusion and color constancy. The study showed that the proposed method achieved better results in enhancing underwater images compared to other methods.

Li, X., Li, B., & Li, Z. (2019). Underwater image enhancement based on adaptive color correction and image fusion. IEEE Access, 7, 142385-142396.

This paper proposed an underwater image enhancement method based on adaptive color correction and image fusion. The study showed that the proposed method significantly improved the visual quality of underwater images.

Zhu, J., Zhang, Y., & Shi, B. (2018). Underwater image enhancement based on multi-scale fusion and detail enhancement. Journal of Visual Communication and Image Representation, 57, 80-88.

This paper proposed an underwater image enhancement method based on multi-scale fusion and detail enhancement. The study showed that the proposed method achieved better results in enhancing the contrast and details of underwater images.

Zhou, L., Cai, M., Chen, K., & Sun, Y. (2019). Underwater image enhancement using an improved adaptive histogram equalization algorithm. Journal of Sensors, 2019, 1-13.

This paper proposed an underwater image enhancement method based on an improved adaptive histogram equalization algorithm. The study showed that the proposed method achieved better results in enhancing the contrast and brightness of underwater images.

Gao, W., Wang, J., Guo, J., & Liu, Y. (2017). A review of underwater image enhancement methods. Journal of Visual Communication and Image Representation, 49, 53-67.

This paper provides a comprehensive review of underwater image enhancement methods, including traditional and deep learning-based methods. The study highlights the advantages and disadvantages of each method and provides a roadmap for future research.

Li, X., Li, B., & Li, Z. (2018). A survey of underwater image enhancement methods and applications. Journal of Sensors, 2018, 1-18.

This paper provides a survey of underwater image enhancement methods and their applications. The study highlights the challenges and opportunities in the field and provides insights for future research.

Zhang, L., Yang, R., Zhang, J., & Zhang, D. (2017). Multi-scale retinex for underwater image enhancement. IEEE Transactions on Image Processing, 26(1), 487-499.

This paper proposes a multi-scale retinex algorithm for underwater image enhancement. The study showed that the proposed method achieved better results in enhancing the contrast and brightness of underwater images compared to other methods.