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Presentation of an Optimal Method to Increase the Quality of Underwater Imaging

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Abstract

Most underwater intelligent vehicles and marine remote-control vehicles are equipped with optical cameras for underwater imaging. However, due to the properties of water and its impurity, the quality of the images taken by these imaging devices is not good enough, because the water weakens the light, and the deeper the water, the more the intensity of the light will decrease. Since different wavelengths show different behaviour in the collision with the water column, processing and study of these wavelengths is very important to obtain the desired image. The spectral signature can be used for underwater applications. In this research, to increase the quality of underwater images, a new method has been introduced to improve image contrast. In this method, first, with structured lighting, different wavelengths are irradiated to the underwater target in a laboratory environment, then underwater images are processed by the proposed algorithm, and finally, a multispectral image is achieved by stacking images with different wavelengths. The results showed the relative superiority of the proposed method over other methods. The research results show that the proposed algorithm works faster than other methods with a speed of 0.9 seconds. Also, the amount of PSNR and MSE are 16.20 and 15.56 respectively has performed better than other methods.

***Keywords**:* Underwater Imaging, Spectral, Underwater Target, Algorithm

1. Introduction

Underwater imaging is a useful tool for scientific research (Vodopivec et al., 2018). When processing underwater images, the basic physics of light propagation in water must be considered, as water is a much more complex environment than air (Monks, 2022). The effect of light absorption and scattering by the inherent optical properties of seawater and its components are very important (Torahi Hasani Moghaddam, 2019). These parameters' effects depend on the wavelength of light, microscopic aquatic organisms active in the water, all colored particles suspended in water, and all minerals

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dissolved in water (Lee et al., 2014; Masoumi et al., 2014). However, the latest generation of underwater imaging systems has benefited from advances in light generation, imaging sensors, and data processing. These advances led to underwater images that were once dreamed of. Observations on light attenuation in ocean waters show that not only the intensity of sunlight decreases with increasing depth, but also the wavelengths in the sun's spectrum also decrease at the same rate (Bostater et al., 2019). Short wavelengths (ultraviolet) and longer wavelengths (infrared) are absorbed quickly, but blue and green wavelengths penetrate deeper. In the clearest ocean waters, only about 1 percent of surface radiation penetrates 150 meters (about 500 feet) deep. The sunlight never penetrates to a depth of 1000 meters (about 3300 feet) (Doron et al., 2007). Therefore, we need external light sources when performing imaging. Similar to sonar systems that can detect and map underwater objects using sound signals, underwater optical imaging systems are divided into passive and active sensing (VanMiddlesworth et al., 2014). In underwater imaging, passive systems use natural light illuminated by a source other than the imaging system. Active systems use a source that produces light. These systems have significant advantages for underwater imaging, typically allowing imaging in wide ranges with higher contrast than passive systems that use sunlight. In addition, it is possible to image even in areas with a moderate amount of light by using short laser pulses or a monochromatic laser, and take image even in areas with a normal amount of light.

(Shen et al., 2021), have presented research on underwater optical imaging as a review of key technologies and applications. In this work, they reviewed the six most common methods based on signal light enhancement. They present the individual working mechanisms, latest representative advances, and suitable application conditions. Moreover, they also present a detailed comparison of these techniques. In each technique, they present their applicable environments and conditions according to the following indicators: operating distance (from 2 attenuation lengths (AL) to 13.5 AL), resolution (from centimeter to millimeter), and field of view (FOV). By summarizing and analyzing the existing problems that restrict the underwater optical imaging techniques, the future development trends are prospected in this research.

(Liu et al., 2021), have presented underwater hyperspectral imaging system with liquid lenses. In this paper, they developed a novel integrated underwater hyperspectral imaging system for deep sea surveys and proposed an autofocus strategy based on liquid lens focusing transfer. The calibration tests provided a clear focus result for hyperspectral transects and a global spectral resolution of less than 7 nm in spectral range from 400 to 800 nm. The prototype was used to obtain spectrum and image information of manganese nodules and four other rocks in a laboratory environment. The classification of the five kinds of minerals was successfully realized by using a support vector machine. They tested the UHI prototype in the deep sea and observed a Psychropo tidae specimen on the sediment from the in situ hyperspectral images. The results showed that the prototype developed here can accurately and stably obtain hyperspectral data and has potential applications for in situ deep-sea exploration.

(Moghimi and Mohanna, 2021), have worked on real-time underwater image enhancement method. This paper discusses the eff ect of the software and hardware parts for the underwater image, surveys the state-of-art diff erent strategies and algorithms in underwater image enhancement, and measures the algorithm performance from various aspects. They also consider the important conducted studies on the field of quality enhancement in underwater images. They have analyzed the methods from five perspectives: (a) hardware and software tools, (b) a variety of underwater imaging techniques, (c) improving real-time image quality, (d) identifying specific objectives in underwater imaging, and (e) assessments. Finally, the advantages and disadvantages of the presented real/non-real-time image processing techniques are addressed to improve the quality of the underwater images. This systematic review provides an overview of the major underwater image algorithms and real/non-real-time processing.

Based on the reviews in the background section, most of the similar researches have used predetermined sensors and algorithms and have focused on the implementation of algorithms. Unlike most similar researches, in this research, the whole imaging process up to the implementation of the innovative algorithm was done by the researchers and has the ability to be developed. The aim of this study is underwater imaging with an optimal method so that high-quality information can be obtained from these sources. One of the innovations of this research is the use of a native and innovative setup that can perform imaging operations without problems in the water. In this research, different electromagnetic spectrums have been investigated for underwater imaging capabilities, and the results can be used for future research in this field.

2. Material and Method

The block diagram of the research is shown in Figure (1).

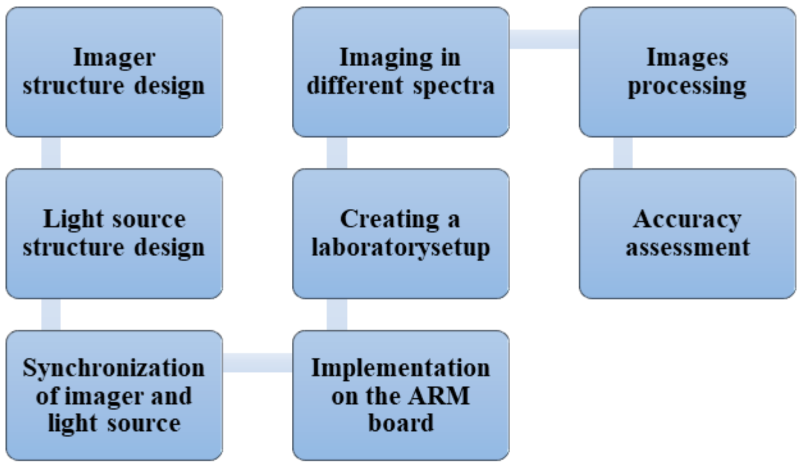


Figure1. Block diagram of research

2.1. Methods and Algorithm for Improving Underwater Images

In general, there are several methods for underwater image processing to achieve the desired result, these methods can be classified into two general approaches, hardware and software base methods (Ma et al., 2018; HasaniMoghaddam et al., 2021; Ghane Ezabadi et al., 2021). Each of these methods has unique uses based on advantages and disadvantages. Light has the properties of intensity, wavelength, and polarization. Natural light is not polarized, while light reaching an imaging sensor often has some form of polarization. Preliminary studies show that scattering can be reduced by using a polarizer. There are two old methods for underwater polarization imaging, one is to use a polarizing filter attached to the front of the camera to capture images, and the other is to use a polarized light source to capture images in the same scene (Amer et al., 2019). The polarization method is designed to simplify the recording of images and also to significantly reduce the amount of noise.

2.2. Range Gated Imaging

In recent years, several advanced long-range gating imaging systems have been proposed to improve underwater visibility (Yin et al., 2020). The application of the long-range system in advanced imaging is mostly due to its ability to prevent or minimize the backscatter of radiation in unfavorable environments, such as muddy sea water (Chen et al., 2015). The gating-long-range process starts when the laser sends a pulse on the target or object. As light travels, it is absorbed and scattered, at which point the camera gate is closed. Figure (2), shows the obtained results in the conditions of gated and non-gated systems for three levels of turbidity. The target range is about three meters, generally the gated image is of higher quality at all values of turbidity and distance, while the image of the non-gated system shows the lowest value at high turbidity levels. Gated images are basically tuned to achieve the highest image quality, it is believed that the potential of the gated system will be increased if fine tuning of the gating timing is considered.

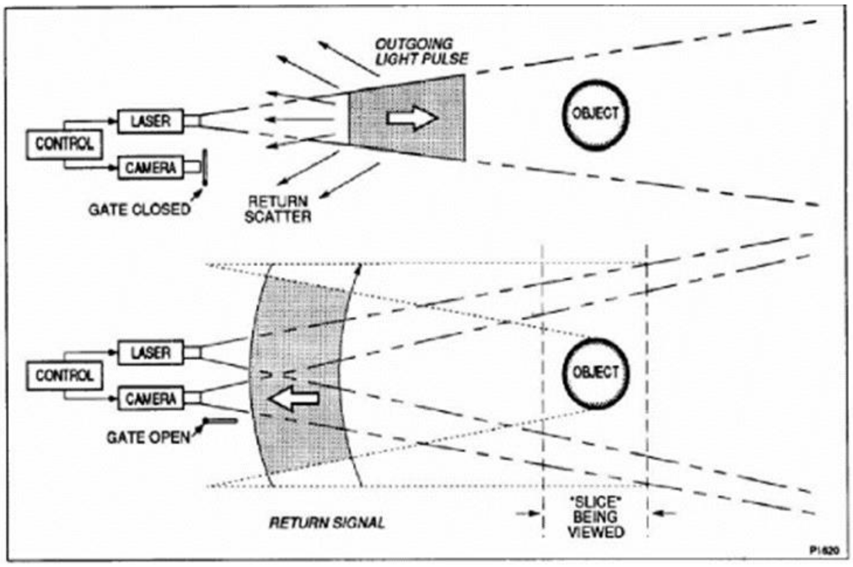


Figure 2. Range gated imaging (Grasso et al., 2005)

3. Results and Discussion

3.1. Providing a Suitable Configuration for Multispectral Imaging

In this study, we designed an LED-based underwater multispectral imaging system that uses three cameras to capture images in six different spectra (RGB cameras provide only three channels, red, green, and blue). This spectral reflectance achieves a more accurate resolution than the RGB method and has a simpler structure as well as lower cost than existing underwater multispectral imaging techniques. As shown in the figure (3), our system consists of a 12-megapixel a4tech webcam, two light sources separately, including the main wavelength of LEDs 405 nm, 450 nm, 500 nm, 530 nm, 565 nm, 590 nm, 615 nm, 660 nm, which are tested at a working current of 750 mA, a voltage of 3.7 V and a temperature of about 25 °C.

Figure 3. Light source structure and LEDs in different spectrums

3.2. Synchronization and Software

A raspberry pi microprocessor based on Linux operating system is programmed to synchronize light sources and acquire camera images. Also, a software based on python programming language is considered for fast switching between LEDs in different spectrums, setting parameters and imaging at a certain time simultaneously. It was designed and built separately for each set of LEDs to run power LEDs in different ranges of the electronic circuit, which was considered one of the requirements of this project due to the different and very sensitive current and voltage of this sample of LEDs. To separate the electronic parts from the Raspberry processor, a circuit consisting of a number of optical connectors has been designed. The output power of each of the LEDs is ideally 3 watts and the nominal current is about 750 mA.

3.3. Laboratory Structure

In the experiments, an example of the USAF 1951 reference pattern is used as the imaging target, which is shown in Figure (4). The reference image shows the resolution of the captured images in relation to the distance, the dimensions of the lines in the image are designed from one to ten millimetres wide, and the manufacturing process is implemented based on laser cutting. Also, a water tank measuring 150*40*60 cm has been used to simulate the water environment. The walls of the tank are completely opaque and designed without any light reflection to prevent the light from artificial sources from returning into the water. To simulate deep water, all the images were received in a completely dark environment and the only light source is the light produced by artificial light sources. Also, the light sources and imaging camera are placed by a waterproof chamber inside the tank to simulate an environment exactly similar to the deep-water environment.

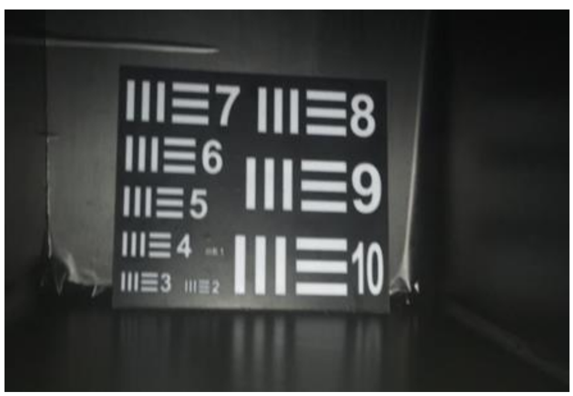


Figure 4. USAF pattern

In this research, as an optimal structure for underwater imaging, a simple method has been used to enhance the visibility of scenes photographed under artificial light in an environment with different water turbidity values. In contrast to various methods that rely on scanning and specialized hardware, satisfactory results have been obtained in this method using two structured light sources. In addition to underwater environments, this method can be used to remove fog effects. Here, by using two light sources with different angles, we will try to increase the contrast and reduce the scattering effect. Also, due to the use of specific wavelengths separately, wavelength improvement methods and image processing algorithms can be used to improve imaging conditions.

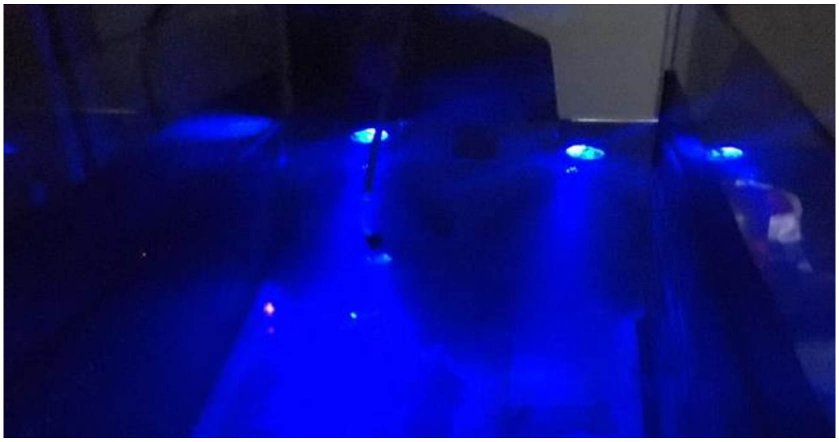


Figure 5. An example of structured lighting implemented in a laboratory environment

4. Result of Test and Implementation

The results obtained in the laboratory and under similar conditions of the underwater environment show a significant improvement of the images extracted by the proposed method. In laboratory investigations, the improvement of images using two light sources separated from each other and with a specific angle next to the imaging camera showed acceptable results in the field of removing scattering effects. In the experiments, the same impurity concentration and light sources with different angles and distances have been used. The best angle for a distance of 110 cm from the camera to the target and taking into account the optimal size of the imaging system is about 80 degrees, which is described in Figure (6).

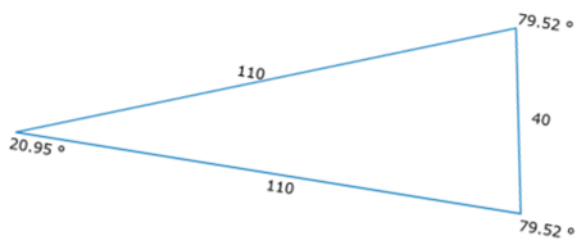
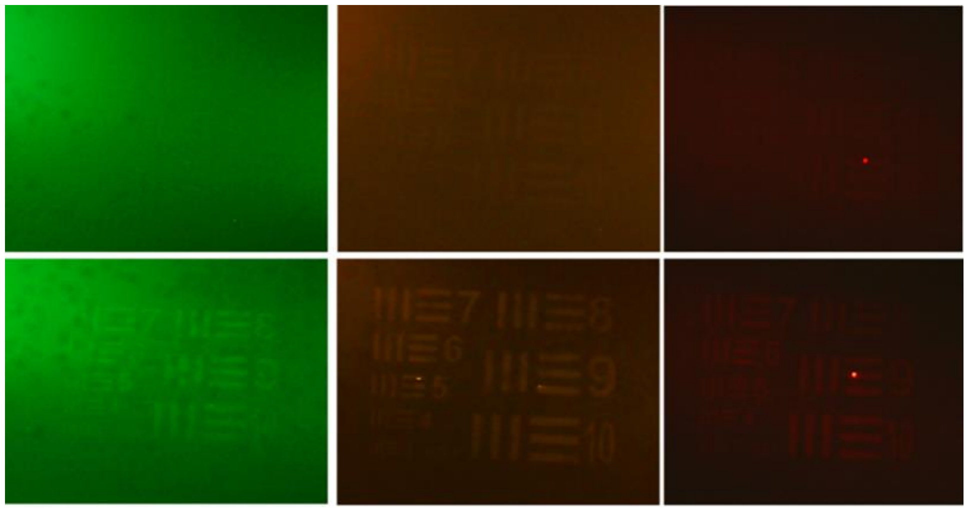


Figure 6. Angle of the light sources relative to the camera, taking into account the criteria of the imaging system

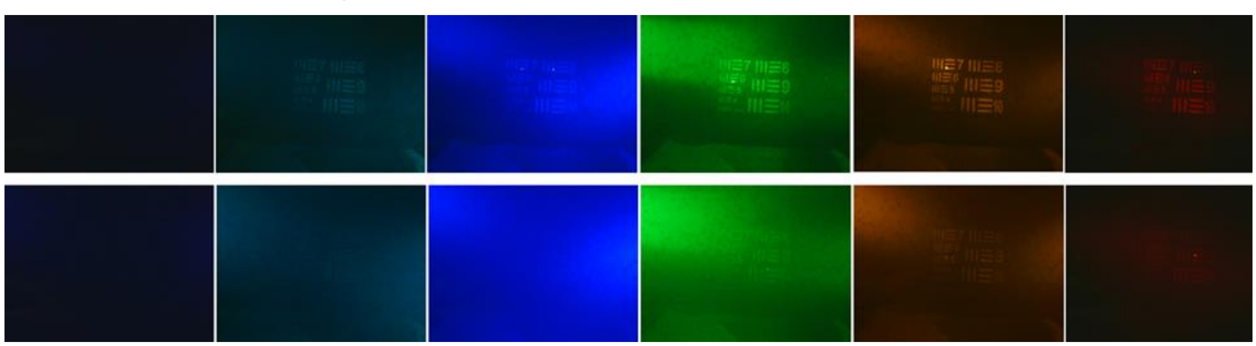
The images received by the structured lighting method and the usual method are shown in Figure (7).



520 nm 570 nm 640 nm

Figure 7. The top images of the light source in the vicinity of the imaging camera and an angle of 90 degrees, the bottom image using two distant sources with a distance of 20 cm from the camera lens with an angle of 80 degrees to the line of the camera and the light source.

In the images received by the camera and the light source in the vicinity of the camera, a very large amount of scattering can be seen. In the 520 nm spectrum, due to the intensity and penetrating power of the green spectrum, the amount of scattering is so high that we will not be able to see the target, also other light spectrums with larger wavelengths are scattered to a relatively lesser extent, the reason for this is the light intensity in these wavelengths that it is relatively less than the wavelength of 520 nm. The more the amount of light irradiated on the object, the more scattering is returned to the camera. Scattering reduces visibility. Scattering reduces visibility, but in images captured using a structured light source, as can be seen visually, the amount of scattering caused by the water column is significantly reduced, which an effective step in underwater image is processing. In the next step, the images with different concentrations and fixed distance received by the structured light source are shown. These images were received in six different wavelengths within the range of human vision. The reason for this is to check the amount of absorption and scattering in different wavelengths alone and finally to superimpose the images. The imaging results in similar conditions of the underwater environment are shown in Figure (8).



340 nm 390 nm 460 nm 520 nm 570 nm 640 nm

Figure 8. The first line of images corresponds to a concentration of about 1 milliliter per liter and the second line corresponds to a concentration of about 2.5 milliliters per liter. The amount of impurities has a direct effect on the amount of absorption and dispersion.

After imaging using structured lighting, it is time to apply the proposed algorithm on the received images. At this stage, using the codes implemented on the Raspberry Pi microprocessor, we can apply the proposed image improvement algorithm. The results of these implementations are shown in the Figure (9).

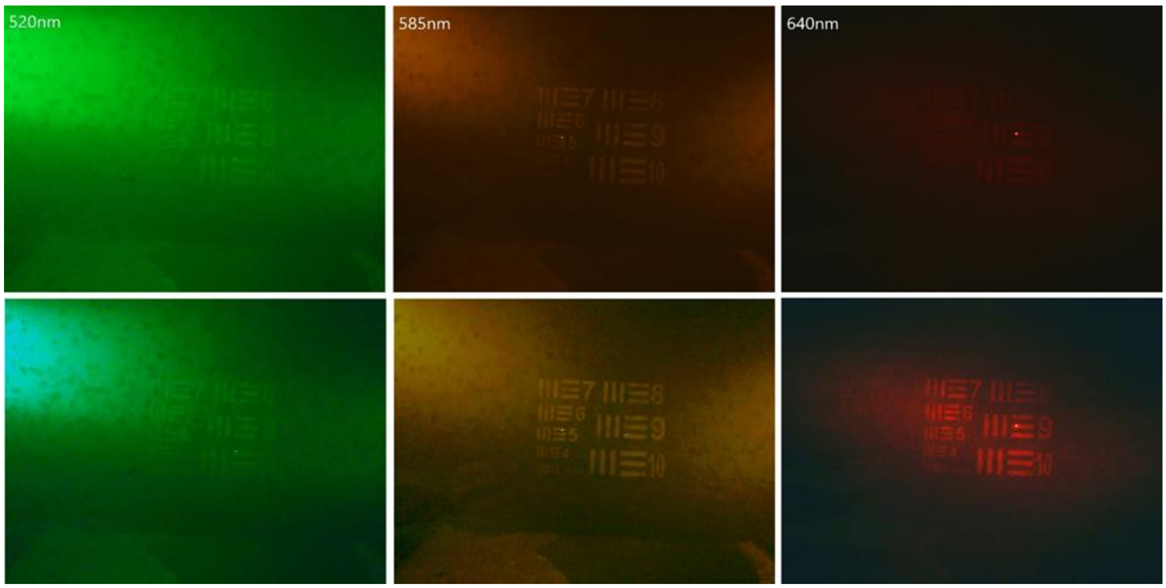


Figure 9. Top row of the original captured images with a structured light source at opposite wavelengths and the bottom row of images processed by the improved fog removal algorithm.

As it can be seen that the recycled images have relatively better visual quality. The improvement of visual quality is due to the hardware and software processing steps, which include the removal of a significant amount of scattering by the structured light source and, in the next step, the processing algorithm applied to the images with specific spectra.

5. Evaluation of the Quality of Underwater Images

Algorithms for measuring the quality of underwater images are used to compare the proposed method with the known methods in the world. These algorithms are designed to compare important parameters in underwater images. In this research, our proposed method measures the average squared difference between the actual and ideal pixel values by using the mean square error parameters MSE. The next measured quantity is the PSNR signal-to-noise ratio, which is derived from the mean squared error and represents the ratio of the maximum pixel intensity to the distortion power. DDIM structural similarity index is another quality measure of reconstructed images. This quantity combines image structure, luminance and contrast together. Since the human visual system is good at understanding structure, the quality measure of SSIM is more closely related to the degree of visual quality. The results of the comparison between the measurement criteria show the relative equality of the algorithm proposed in this article with the algorithms proposed in the world. Also, in the performed calculations, the processing time in the proposed algorithm has been halved due to the use of the directed filter, this causes a significant reduction in the amount of processing. This feature is considered an advantage for applying these algorithms in portable integrated systems. Table (1), shows a set of data related to this issue.

Table 1. Accuracy assessment

Algorithm	MSE	SSIM	PSNR	TIME (sec)
Proposed method	**15.56**	0.718	**16.20**	**0.9**
CLHAE	17.79	0.684	15.58	15
ICM	18.30	0.697	15.50	23
DCP	18.78	0.748	15.39	15
UDCP	17.79	0.728	15.58	18

The overall results show that the proposed algorithm has performed poorly in a number of spectra and very strong in a number of spectra, although the changes caused by the processing are clearly visible visually. The results obtained in this research are consistent with (Lin., 2018), (Liu et al., 2018), findings. One of the most important innovations of this research compared to similar articles is the use of a completely native and innovative setup. Contrary to similar results in other articles, this setup is able to produce light in different electromagnetic spectrums, which makes it possible to take underwater images in different spectral.

6. Conclusion

Due to the small amount of information about underwater scenes, underwater fog image recovery is a difficult task in computer vision. But humans can quickly recognize the depth of an underwater image without any auxiliary information. When we estimate the background light, the farthest point of the depth map corresponding to the original image is often considered as the candidate for the background light. By reducing the amount of natural light underwater, the maximum intensity difference between stronger and weaker channels is used to estimate the background light. This rule motivates us to conduct experiments on different underwater images to discover an effective primer for underwater image restoration. After examining a large number of images taken underwater, we have come to the conclusion that the background light is found in the pixels that have the greatest difference between the intensity levels in different light channels. Therefore, the background light can be separated from the main light and the components in the scene. In general, when the scene moves to a very distant region, the intensity values in the shorter wavelength channels increase and the intensity values decrease in the longer wavelength channels, leading to a correlation between the depth of the scene and the difference between the intensities of the channels with length. The wave gets smaller and the channel gets bigger with the wavelength.

References

Amer, K. O., Elbouz, M., Alfalou, A., Brosseau, C., & Hajjami, J. (2019). Enhancing underwater optical imaging by using a low-pass polarization filter. *Optics Express, 27*(2), 621. https://doi.org/10.1364/oe.27.000621

Bostater Jr, C. R., & Aziz, S. (2019). Water wave glint corrections, water depth, light attenuation, and WorldView-3 remote sensing algorithms for Indian River lagoon. In *Remote Sensing of the Ocean, Sea Ice, Coastal Waters, and Large Water Regions 2019* (Vol. 11150, pp. 70-80. SPIE. https://doi.org/10.1117/12.2534093

Chen, Z., Yu, J., Zhang, A., & Song, S. (2015). Control system for long-range survey hybrid-driven underwater glider. In *OCEANS 2015-Genova* (pp. 1-16). IEEE. https://doi.org/10.1109/oceans-genova.2015.7271706

Doron, M., Babin, M., Mangin, A., & Hembise, O. (2007). Estimation of light penetration, and horizontal and vertical visibility in oceanic and coastal waters from surface reflectance. *Journal of Geophysical Research, 112*(C6). https://doi.org/10.1029/2006jc004007

Ghane Ezabadi, N., Azhdar, S., & Jamali, A. A. (2021). Analysis of dust changes using satellite images in Giovanni NASA and Sentinel in Google Earth Engine in western Iran. *Journal of Nature and Spatial Sciences (JONASS)*, *1*(1), 17-26.

Grasso, R. J., Odhner, J. E., Wikman, J. C., Skaluba, F. W., Dippel, G. F., McDaniel, R. V., ... & Seibel, W. (2005, October). A novel low-cost targeting system (LCTS) based upon a high-resolution 2D imaging laser radar. In *Electro-Optical Remote Sensing* (Vol. 5988, pp. 183-188). SPIE.

HasaniMoghaddam, H., Torahi, A. A., & Zeaiean, P. (2021). Fusion of Hyperspectral and High resolution imagery based on different level of HAAR DWT. *Application of Geography information system and remote sensing in planning*, *11*(4), 7-17.

Lin, X. (2018). Adaptive Underwater Optical Wireless Sensor Network Using LED-Based Visible Light Communications. The *Second International Conference on Materials Chemistry and Environmental Protection*. https://doi.org/10.5220/0008187902220227.

Liu, J., Guan, W., Wang, X., & Liu, J. (2018). Optical imaging study of underwater acousto-optical fusion imaging systems. In *Proceedings of the 13th International Conference on Underwater Networks & Systems* (pp. 1-5). https://doi.org/10.1145/3291940.3291982.

Liu, B., Men, S., Ding, Z., Li, D., Zhao, Z., He, J., Ju, H., Shen, M., Yu, Q., & Liu, Z. (2023). Underwater Hyperspectral Imaging System with Liquid Lenses. *Remote Sensing*, *15*(3), 544. https://doi.org/10.3390/rs15030544.

Lee, K. E., Barber, L. B., & Schoenfuss, H. L. (2014). Spatial and Temporal Patterns of Endocrine Active Chemicals in Small Streams Indicate Differential Exposure to Aquatic Organisms. *JAWRA Journal of the American Water Resources Association*, *50*(2), 401–419. Portico. https://doi.org/10.1111/jawr.12162.

Ma, Y., Feng, X., Chao, L., Huang, D., Xia, Z., & Jiang, X. (2018). A New Database for Evaluating Underwater Image Processing Methods. In *2018 Eighth International Conference on Image Processing Theory, Tools and Applications (IPTA)* (pp. 1-6). https://doi.org/10.1109/ipta.2018.8608131.

Masoumi, H., Jamali, A. A., & Khabazi, M. (2014). Investigation of role of slope, aspect and geological formations of landslide occurrence using statistical methods and GIS in some watersheds in Chahar Mahal and Bakhtiari Province. *J. Appl. Environ. Biol. Sci*, *4*(9), 121-129.

Moghimi, M. K., & Mohanna, F. (2021). Real-time underwater image enhancement: a systematic review. *Journal of Real-Time Image Processing*, *18*(5), 1509–1525. https://doi.org/10.1007/s11554-020-01052-0.

Monks, J. N. (2022). The Physical Principles of Light Propagation and Light–Matter Interactions. In *Principles of Light Microscopy: From Basic to Advanced* (pp. 1–16). https://doi.org/10.1007/978-3-031-04477-91.

Shen, Y., Zhao, C., Liu, Y., Wang, S., & Huang, F. (2021). Underwater Optical Imaging: Key Technologies and Applications Review. *IEEE Access*, *9*, 85500–85514. https://doi.org/10.1109/access.2021.3086820.

Torahi, A. A., & Hasani Moghaddam, H. (2019). Determination of Flood extent using OLI data (case study: Dezful 2016 flooding). *Environment and Water Engineering*, *5*(1), 24-35. https://doi.org/10.22034/jewe.2019.154927.1289.

Vodopivec, M., Mandeljc, R., Makovec, T., Malej, A., & Kristan, M. (2018). Towards automated scyphistoma census in underwater imagery: A useful research and monitoring tool. *Journal of Sea Research*, *142*, 147–156. https://doi.org/10.1016/j.seares.2018.09.014.

VanMiddlesworth, M. M. A. (2014*). Toward autonomous underwater mapping in partially structured 3D environments* (Doctoral dissertation, Massachusetts Institute of Technology). https://doi.org/10.1575/1912/7136.

Yin, X., Cheng, H., Yang, K., & Xia, M. (2020). Bayesian reconstruction method for underwater 3D range-gated imaging enhancement. *Applied Optics*, *59*(2), 370-379.