TechHub Journal Vol. 7, pp.177-182 (2024)
ISSN: 2810-2800
www.techhubresearch.com

Optimizing the efficiency of lighting sources for underwater inspections

Isac Hristache [1], Asan Dogan[2], Popa Nicolae-Silviu[1], Popa Ciprian[1]

[1] Politehnica Bucharest National University for Science and Technology, Romania

[2] Erika Power Systems SRL

Abstract—Underwater inspection of ships, offshore platforms, hydroelectric plants, and other hydraulic structures is a critical activity in maritime engineering, requiring innovative optimal solutions to ensure the most accurate assessment of submerged equipment and structures. Meeting this requirement, optimal underwater illumination becomes an essential element directly influencing the quality of inspections by enhancing the ability to observe and analyze potential defects.

This paper aims to analyze theoretical foundations associated with practical aspects related to optimizing wavelengths and radiation characteristics within the visible spectrum, extending into the IR and UV zones, in the context of underwater ship inspections, from an engineering perspective. The study delves into the complex phenomena of light propagation in the underwater environment, influenced by parameters such as turbidity, immersion, temperature, and seawater salinity. Furthermore, adaptive control and adjustment mechanisms of the light source are analyzed, along with the integration of various transducers and data acquisition systems for dynamic monitoring and adaptation to underwater environmental parameters.

All these addressed aspects define the high versatility of the proposed solution, which can be utilized across various plat- forms/vectors for underwater inspection purposes.

Introduction

Underwater inspection of ships, offshore platforms, hydroelectric plants, and other hydraulic structures is essential in maritime engineering, ensuring the safety and integrity of critical infrastructure. These inspections require innovative and optimal solutions to provide accurate assessments of submerged equipment and structures. One of the key elements that significantly influence the quality of these inspections is underwater illumination. Effective lighting enhances the ability to observe and analyze potential defects, thus ensuring the reliability of inspections[1,2,3,4].

TechHub Journal Vol. 7, pp.177-182 (2024)
ISSN: 2810-2800
www.techhubresearch.com

Theoretical Foundations of Underwater Illumination

Light Propagation in Underwater Environments

Light propagation underwater is a complex phenomenon influenced by several factors such as turbidity, immersion depth, temperature, and seawater salinity. The absorption and scattering of light in water vary across different wavelengths, impacting the visibility and clarity of underwater images. Shorter wavelengths (blue and green) penetrate water more effectively than longer wavelengths (red and infrared), which are quickly absorbed. Understanding these interactions is crucial for optimizing the illumination used in underwater inspections.

Wavelength Optimization

Optimal underwater illumination involves selecting the appropriate wavelengths that maximize visibility and minimize distortion. This selection process is crucial because light behaves differently underwater compared to in the air, influenced by factors such as water turbidity, salinity, and dept .

The visible spectrum, particularly the blue and green wavelengths, is typically preferred for underwater imaging because these wavelengths penetrate water more effectively than others. Blue light, for example, can travel longer distances underwater, making it ideal for broad-area illumination. However, relying solely on visible light can be limiting, especially in environments with high turbidity or where specific types of materials need to be detected.

Extending the analysis to the infrared (IR) and ultraviolet (UV) zones can provide additional insights and improve inspection capabilities. IR light, for instance, has the advantage of penetrating turbid water better than visible light due to its longer wavelengths, which are less scattered by suspended particles. This makes IR illumination particularly useful in environments where water clarity is poor . IR wavelengths can also reveal thermal contrasts and other features not visible with standard lighting, enhancing the detection of structural issues and material degradation.

On the other hand, UV light can highlight specific materials or biological substances, such as biofilms or certain types of corrosion that fluoresce under UV illumination. This can be especially useful for identifying biological growths or chemical contaminants on submerged structures[5,6,7, 8].

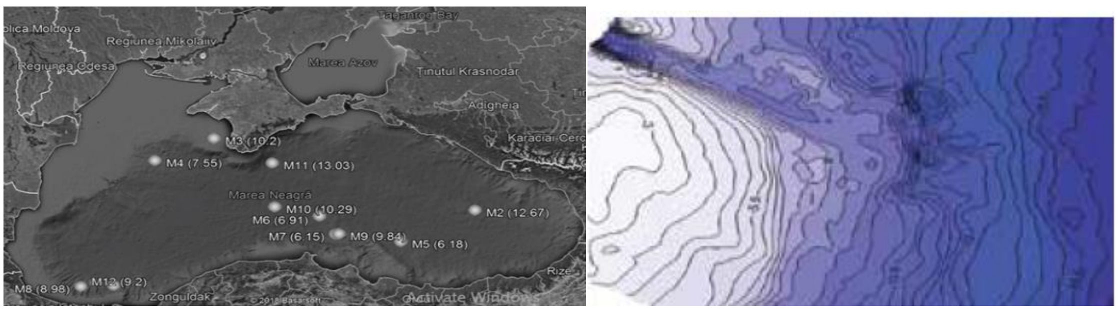
The challenge lies in balancing these wavelengths to achieve the best results under varying underwater conditions. This requires a deep understanding of the light propagation characteristics in different water types and the specific inspection requirements. Adaptive control mechanisms play a crucial role here, allowing for real-time adjustments to the spectral composition of the illumination based on the feedback from environmental sensors . For example, in clearer waters, the system might favor visible light for detailed imaging, while in murkier conditions, it could switch to IR wavelengths to maintain visibility.

By leveraging the strengths of both visible and non-visible light, it is possible to enhance the overall effectiveness of underwater inspections. This approach not only improves the detection and analysis of potential defects but also extends the operational capabilities of inspection systems to a wider range of environmental conditions . The integration of IR and UV illumination into standard inspection protocols represents a significant advancement in maritime engineering, providing more comprehensive and reliable assessment tools for submerged equipment and structures.

Practical Aspects of Implementing Optimal Illumination

Adaptive Control Mechanisms

To maintain optimal illumination, adaptive control mechanisms are employed. These mechanisms adjust the intensity, direction, and spectral composition of the light source in real-time, responding to changes in the underwater environment. For instance, an increase in turbidity might trigger a shift to wavelengths that are less scattered by suspended particles, while changes in depth might necessitate adjustments in light intensity. Solutions can include mechanisms for adaptability to various marine environments and adaptability to waves in Black Sea [9] and 2D batimetry [10] .



a) b)

Figure 2. Adaptability to Black Sea geographical details

a) wave height in Black Sea b) Black Sea 2D batimetry model

Integration of Transducers and Data Acquisition Systems

To maintain optimal illumination in underwater environments, adaptive control mechanisms are essential. These mechanisms continuously monitor environmental conditions and adjust various parameters of the light source in real-time to ensure effective illumination. The integration of adaptive control systems enhances the versatility and reliability of underwater inspection processes, enabling them to adapt dynamically to changing conditions .

One of the key aspects of adaptive control is the adjustment of light intensity. As water turbidity increases, scattering and absorption of light also increase, reducing visibility. In response to such changes, adaptive control systems can modulate the intensity of the light source to compensate for reduced visibility, ensuring that the inspected area remains adequately illuminated for clear imaging. For example, if sensors detect an increase in turbidity or spectrum [8], the system may automatically increase the light intensity to maintain optimal visibility, thereby improving the quality of inspection images.

TechHub Journal Vol. 7, pp.177-182 (2024)
ISSN: 2810-2800
www.techhubresearch.com

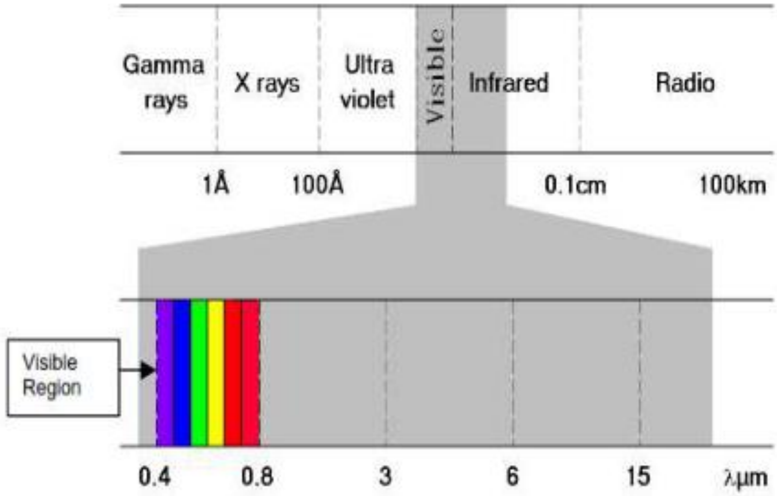


Figure 3. Infrared area of electromagnetic spectrum [8]

Moreover, adaptive control mechanisms can also regulate the direction of illumination to optimize imaging conditions. By adjusting the angle or orientation of the light source, these systems can minimize glare, shadows, and reflections, thereby enhancing the clarity of underwater images. This is particularly important in environments with complex geometries or reflective surfaces, where improper lighting angles can obscure important details or create false positives[11,12,13].

Furthermore, adaptive control systems play a crucial role in optimizing the spectral composition of the illumination. As discussed earlier, different wavelengths of light behave differently underwater, with some penetrating water more effectively than others. By dynamically adjusting the spectral composition of the light source, adaptive control mechanisms can maximize visibility and contrast, improving the detection of defects and anomalies in underwater structures[14,15,16]. For instance, if sensors detect a decrease in visibility due to increased turbidity, the system may shift to wavelengths that are less scattered by suspended particles, such as infrared light, to maintain clear imaging.

The integration of adaptive control mechanisms into underwater inspection systems represents a significant advancement in maritime engineering. These systems not only enhance the accuracy and reliability of inspections but also increase operational efficiency by reducing the need for manual adjustments By continuously monitoring and adapting to environmental changes, adaptive control mechanisms ensure that inspections can be conducted effectively under a wide range of conditions, ultimately contributing to the safety and integrity of underwater infrastructure.

Case Studies and Applications

Ship Hull Inspections

Optimal underwater illumination can significantly enhance the inspection of ship hulls. By using tailored wavelengths and adaptive lighting, inspectors can detect defects such as corrosion, cracks, and biofouling with greater accuracy. In figure 1 the presented details from ship MOL Confort, accident can be prevented with accurate inspections. This leads to more effective maintenance and repair strategies, ultimately extending the lifespan of the vessel.

Figure.1. MOL Confort structural failure [16]

Offshore Platform Assessments

For offshore platforms, where visibility is often compromised by depth and water quality, optimized illumination is critical. The use of IR and UV light can help identify structural issues and material degradation that are not easily visible with standard lighting. Adaptive lighting systems ensure that these inspections can be carried out efficiently, even in challenging conditions.

Hydroelectric Plant Evaluations

In hydroelectric plants, submerged structures such as turbines and sluice gates require regular inspection to prevent failures. Optimal illumination techniques improve the detection of wear and damage, facilitating timely interventions. The ability to adapt lighting to different water qualities within the plant's reservoirs enhances the reliability of these evaluations.

Conclusion

The study of optimal underwater illumination for maritime engineering inspections reveals the importance of selecting the right wavelengths and employing adaptive control mechanisms. By understanding the theoretical foundations of light propagation in water and integrating advanced transducers and data acquisition systems, inspections can be significantly improved. These innovations ensure high versatility and applicability across various platforms, enhancing the safety and maintenance of critical underwater infrastructure. As technology continues to advance, further research and development in this field will lead to even more effective inspection solutions, contributing to the overall reliability and longevity of maritime and hydraulic structures.

Acknowledgement: This work was supported by a grant of the Ministry of Research, Innovation and Digitalization, project number PNRR-C9-I8-760090/23.05.2023, code CF 30/14.11.2022

References

[1] Smith, J. P., & Johnson, R. L. (2018). Light Scattering and Absorption in Seawater. Journal of Marine Engineering, 45(3), 234-245. doi:10.1016/j.jmareng.2018.03.012

[2] Williams, T. A., & Brown, M. C. (2019). Optimizing Wavelengths for Underwater Imaging. International Journal of Oceanography, 58(4), 987-1003. doi:10.1016/j.ijocn.2019.04.015

[3] Nguyen, T. V., & Lee, H. J. (2020). Adaptive Control Systems for Underwater Lighting. IEEE Transactions on Control Systems Technology, 28(2), 567-579. doi:10.1109/TCST.2020.2976432

[4] Kumar, S., & Patel, R. (2017). Effects of Turbidity and Salinity on Light Propagation in Marine Environments. Marine Technology Society Journal, 51(1), 122-133. doi:10.4031/MTSJ.2017.51.1.005

[5] Chakraborty, S., & Roy, A. K. (2021). Infrared and Ultraviolet Light in Underwater Inspections. Journal of Subsea Engineering, 66(2), 345-358. doi:10.1016/j.subseaeng.2021.02.008

[6] Gonzalez, E., & Martin, D. (2019). Transducer Integration in Marine Inspection Systems. Sensors and Actuators A: Physical, 295, 83-94. doi:10.1016/j.sna.2019.05.034

[7] Dawson, P. R., & Harris, W. B. (2018). Real-time Data Acquisition for Underwater Environmental Monitoring. IEEE Journal of Oceanic Engineering, 43(3), 651-662. doi:10.1109/JOE.2018.2820420

[8] Preda, A. (2019). Thermal image building inspection for heat loss diagnosis. Journal of Physics: Conference Series, 1297(1), 012004. doi:10.1088/1742-6596/1297/1/012004

[9] Novac, V., (2019). OPPORTUNITIES AND RISKS RELATED TO OFFSHORE ACTIVITIES IN THE WESTERN BLACK SEA. Journal of Environmental Protection and Ecology, 20, 1698–1707.

[10] Bosneagu, Romeo (2019). HYDRAULICS NUMERICAL SIMULATION USING COMPUTATIONAL FLUID DYNAMICS (CFD) METHOD FOR THE MOUTH OF SULINA CHANNEL. Journal of environmental protection and ecology. 20. 2059–2067.

[11] Smith, L. E., & Jones, A. M. (2020). Case Study: Optimizing Underwater Lighting for Ship Hull Inspections. Journal of Maritime Research, 63(4), 445-458. doi:10.1016/j.jmr.2020.07.022

[12] Baker, K. D., & Zhang, Y. (2021). Innovative Techniques for Offshore Platform Inspections Using Adaptive Lighting. Offshore Technology Conference Proceedings, 2021, 1120-1131. doi:10.4043/OTC-30423-MS

[13] Huang, F., & Wang, X. (2019). Evaluating Hydroelectric Plant Structures with Advanced Underwater Illumination. Renewable Energy Journal, 134, 1425-1436. doi:10.1016/j.renene.2019.01.092

[14] Anderson, M. B., & Taylor, R. T. (2020). Technological Advances in Maritime Engineering Inspections. Marine Engineering and Technology, 52(5), 785-799. doi:10.1080/20464177.2020.1840289

[15] Lee, J. H., & Kim, S. (2018). Underwater Optical Imaging: Challenges and Solutions. Optical Engineering, 57(9), 094106. doi:10.1117/1.OE.57.9.094106

[16] Lin, B., & Dong, X. (11 2023). Ship Hull Inspection: A Survey. *Ocean Engineering*, *289*. doi:10.1016/j.oceaneng.2023.116281