Sea-floor Image Restoration with Variable Absorbance Coefficient

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Abstract

Light scattering from suspended particles and attenuation over the water column are constant phenomena that reduce underwater image quality due to low contrast and color distortion. Common image restoration techniques such as the image formation model, assumes a constant attenuation coefficient across color channels. This results in a restoration solution with limited application. We propose a method of image restoration that considers the wavelength-dependent attenuation of underwater images by providing concurrent measurements of the coefficient of attenuation for each color channel. In this paper, a description of the design of a turbidity meter is made. It used to extract absorbance of light in the RGB channel. We conduct experiments to validate the operation of the turbidity meter based on Beer-Lamberts law.

Keywords: Underwater image quality, image restoration, Turbidity meter, Coefficient of attenuation

1. Introduction

Underwater imaging is a critical aspect of perception for marine robotic platforms and by extension it influences many underwater scientific missions like Sea life monitoring, population census, exploration, or inspection tasks. Unlike terrestrial imaging, acquiring clear images underwater is a challenge that negatively affects the performance of robotic systems [1].

Images captured underwater suffer from contrast degradation and color distortion mainly because of interaction of light travel in water. When a ray of light travels from the source to the scene, it is affected in 2 ways. First, some of the rays are "absorbed" by the medium thereby reducing its intensity. Secondly, the direction of propagation may be changed when it collides with suspended particles in a phenomenon called scattering. This results in deflections and backscattering that deteriorates the image contrast while the color is distorted due to the wavelength dependent attenuation of light as it travels the water column [2], [3].

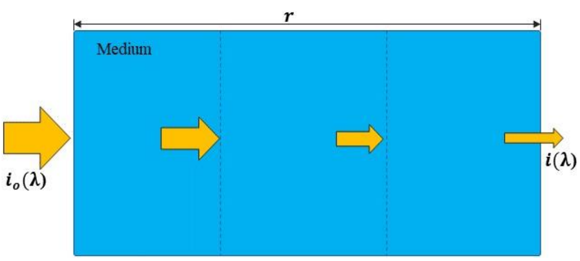

Fig. 1 Attenuation of light in Water medium.

Over the years several methods have been used to correct and enhance distorted underwater images. These methods are generally sensitive to the location of application and often require tuning for different imaging conditions or only provide reliable performance for short range images. The image formation model is also a common method for restoring hazy images. However, its application to underwater images assumes a constant coefficient of attenuation for the image RGB channels. This makes its performance inadequate because attenuation parameters vary with season, climate and geography [4]. In this paper, we describe the design of a simple turbidity meter for real-time measurement of turbidity as a means of applying wavelength-dependent attenuation coefficient to restore degraded images. The paper is organized into the following sections. In Section 2, the design principle and structure of the turbidity meter is described. Section 3 presents the hardware structure and Section 4 describes the experimental setup and result discussion. The conclusion and future task to be conducted are presented in Section 5.

2. Design Principle

2.1. *Underwater Image formation model*

Based on the image formation model, for each color channel $\lambda \in \{\boldsymbol{R}, \boldsymbol{G}, \boldsymbol{B}\}$, the image intensity at each pixel comprises of 2 components, the attenuated signal and background light as shown in Eq. (1):

$$I_\lambda(x) = J_\lambda(x) \cdot t_\lambda(x) + (1 - t_\lambda(x)) \cdot A_\lambda(x) \quad (1)$$

where $\boldsymbol{I}_\lambda$ is distorted image captured by the optical sensor, $\boldsymbol{x}$ is the pixel coordinate, $\boldsymbol{J}_\lambda$ is the object radiance to be restored, $\boldsymbol{t}_c$ is the transmission in the color channel and $\boldsymbol{A}_\lambda$ is the global background light.

The transmission Eq. (2) depends on the distance of objects $\boldsymbol{z}(\boldsymbol{x})$ in the scene and attenuation coefficient $\boldsymbol{\beta}_\lambda$ for each color channel:

$$t_\lambda = exp^{(-\beta_\lambda z(x))}. \quad (2)$$

As opposed to the common assumption of a fixed attenuation coefficient for color channels, we propose to influence the attenuation coefficient $\boldsymbol{\beta}_\lambda$ by varying it with respect to the color channel from measurements of water turbidity. The total attenuation coefficient $\boldsymbol{\beta}_\lambda$ describes how much light of a particular wavelength is attenuated as it travels through a medium as postulated by the Beer-Lambert law which states that "the intensity of light decreases exponentially with distance. The formulation is as expressed below:

$$\boldsymbol{A} = -\log\left(\frac{\boldsymbol{i}}{\boldsymbol{i_0}}\right) \quad (3)$$

$$\boldsymbol{\beta} = -\frac{\boldsymbol{1}}{\boldsymbol{r}}\log\left(\frac{\boldsymbol{i}}{\boldsymbol{i_0}}\right) \quad (4)$$

From Eq. (3), $\boldsymbol{A}$ is the absorbance of light traveling a certain distance from the source $\boldsymbol{i}$ to the scene $\boldsymbol{i_0}$. The equation is rearranged to Eq. (4) where the distance of light travel by $\boldsymbol{r}$ to calculate the attenuation coefficient $\boldsymbol{\beta}$. This is as described in Figure 1.

2.2. *Turbidity meter design principle*

Turbidity is the measure of the degree of suspended particles (turbidity) in water. To achieve this, we design a simple turbidity meter to continually determines the attenuation coefficient of light based on the density of suspended particles in the water. The design solution is based on transmitted light as stipulated by JIS K0101 "Testing Methods for Industrial Water" described in Figure 2 [5]. Basically, the light transmitted from the light source positioned at one side of the water medium is measured at the opposite side by a light sensor.

For our application in the restoration of underwater images, the turbidity meter is designed to satisfy the following requirements.

i. A modular configuration for ease to mount on an underwater vehicle.
ii. Measure turbidity in the 3 color channels (RGB).
iii. Inhibit ambient illumination.
iv. Continuous data acquisition and transfer.
v. Permit water flow to capture variation in turbidity.

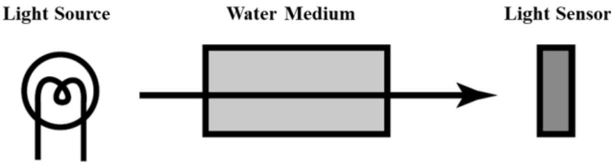

Fig. 2 Turbidity Measurement based on Transmitted Light

3. Hardware structure of turbidity meter

The turbidity meter structure has 3 main parts: LED hull, ambient light inhibitor and sensor hull as shown in Figure 3.

It has a cylindrical structure with dimension of 480x130[mm] and 3 LEDs for Red, Green, and Blue light sources as well as 3 light sensors, for each light source. The ambient light inhibitor is a 3D printed polylactic acid (PLA) model. It has several functions including blocking out external light, restricting each light source to its light sensor, provide a path for water flow, ensuring a constant distance of transmitted light, and provide mounting for the LED hull and Sensor hull. The LED and sensor hulls are 3-inch acrylic hulls facing each other at 100mm. This is the optical path length as recommended by JIS K0101.

The turbidity meter communication is achieved via I^2C between the sensors and Arduino-nano while an Xport module transfers the data to PC via an ethernet interface. Table 1 shows the specification of the turbidity meter and Figure 4 shows its cross-sectional view and Figure 5 is an overview of the electrical and communication system of the turbidity meter.

Table 1: Turbidity Meter Component Specification

Category	Specification
Weight in air	2.7kg
Illuminance Sensor	TSL2561 (0.1 – 40,000 lux)
Power LED	RGBLED-OSTCWBTHC1S
Power Supply	5V
Current	18mA
Communication	I^2C Arduino Nano XPort

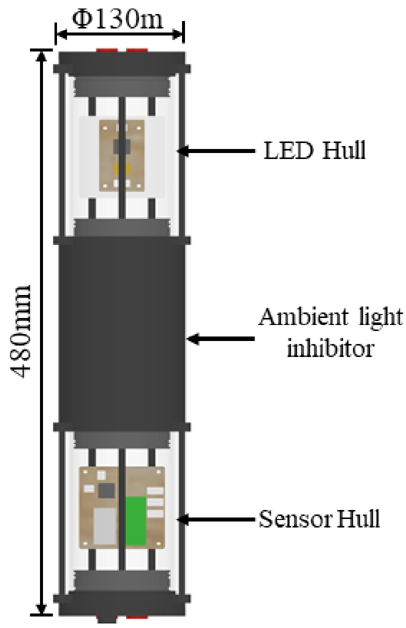

Fig. 3 Turbidity Meter

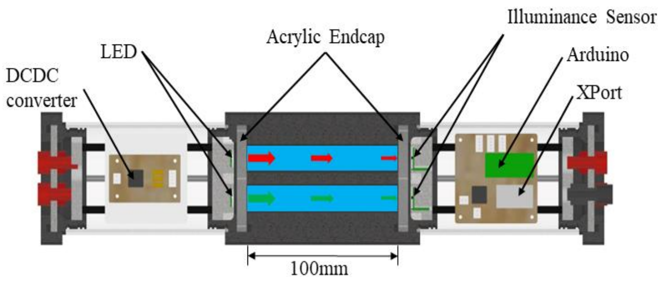

Fig. 4 Cross-sectional view of Turbidity meter

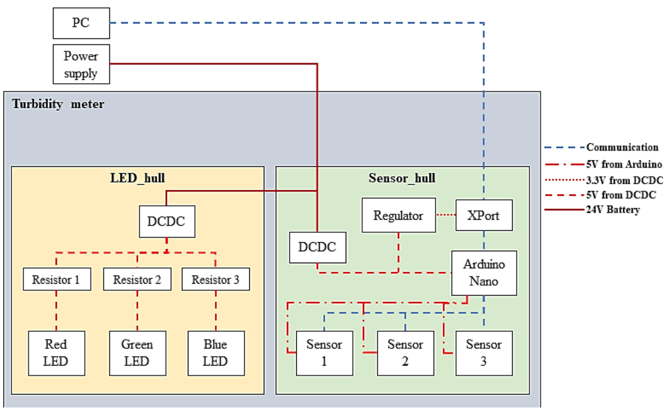

Fig. 5 Overview of system diagram

4. Experiments and Results

The formazin standard and kaolin standard are the standard solutions used for evaluation of any turbidity measurement device. In this work, the kaolin standard solution is used because it is used in the JIS standard. It is a type of clay that is low-cost, can be obtained easily, and is harmless.

4.1. *Experimental procedure*

We construct an apparatus (Figure 6) to assess how the light is absorbed in turbid water (kaolin solution). The set up consists of a 3-inch cylindrical PVC pipe that prevents ambient light from penetration. The Sensor hull is mounted at the lower part of the pipe using a jig to make the attachment rigid and watertight while the LED hull is mounted at the top side. Using the formulation in Eqn. 5, we calculated volume of water needed to vary the water level to simulate different water depth of 5, 10, 20, 30, 40, 50 and 60 [cm] and measure effects of attenuation.

$$Vol_{water} = Height_{cylinder} * \pi * radius^2_{cylinder} \quad (5)$$

For the kaolin solution, the test solutions are prepared with the following concentration of kaolin in water: 0, 10, 30, 100, 200, and 300 [mg/L]. The absorption coefficients for the 3 light sources are independently measured per concentration of the test solution to determine the wavelength-dependent attenuation coefficient for the various water depth.

4.2. *Results*

In Figure 7, Figure 8, and Figure 9 the result of the relationship between optical path and light intensity for Red, Green and Blue LED are shown respectively. we observe that the minimum coefficient of determination R^2 is 0.95, 0.98, and 0.97 for the Red, Green, and Blue light intensities. These high values validate the Beer-Lambert law which implies that for a distance $\boldsymbol{r}$ (Figure 1) from between the light source and the light sensor, we can obtain the coefficient of absorption which can be calculated from Eq. (4).

Having validated the high correlation between the optical path and light intensity in kaolin test solution, we conduct an experiment to determine the relationship between turbidity and the coefficient of absorption using the turbidity meter.

For this experiment, Kaolin test solution is incrementally dissolved in the water and data log of light reaching each light sensor is recorded. The concentrations of Kaolin are 0, 10, 100, 200, 300, and 400 mg/L.

The result of the data is plotted in Figure 10. The kaolin concentration at 0mg/L is pure tap water. The relationship is linear for the 3 light sources which validates Eq. (4) being that the absorbance coefficient has a proportional relationship to the concentration of kaolin with a strong coefficient of determination R^2 of 0.99 per light source.

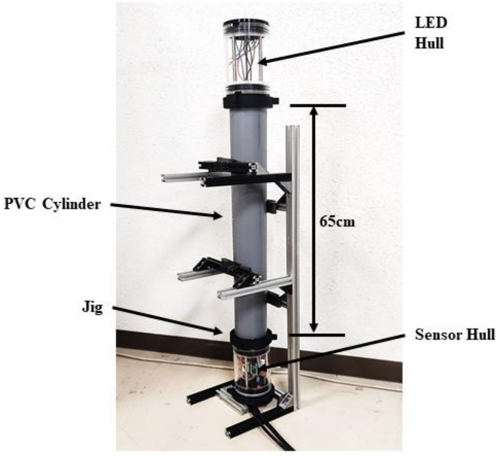

Fig. 6 Experimental Apparatus

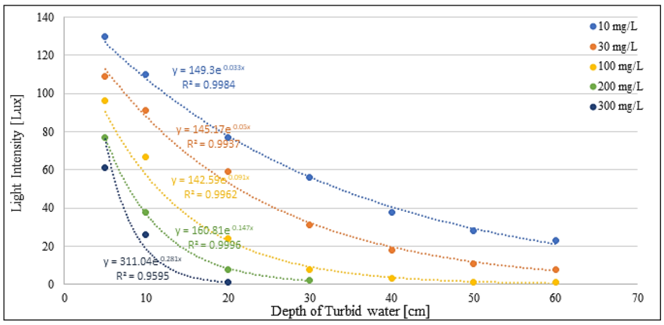

Fig. 7 Relationship between Red LED's optical path and light intensity in kaolin test solution

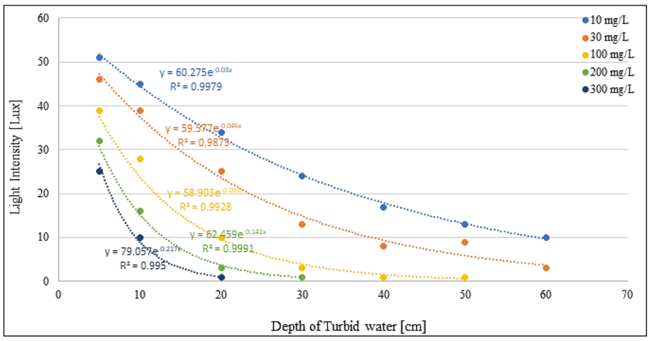

Fig. 8 Relationship between Green LED's optical path and light intensity in kaolin test solution

5. Conclusion

In this paper, we describe the design principle of a turbidity meter based on the transmitted light method and conducted experiments to verify the relationship between the optical path and light intensity in varying concentration of kaolin standard solution. We also validated the Beer-Lambert law by experimenting with the turbidity meter and found a strong correlation between coefficient of absorption and concentration of kaolin.

In the future task, image data will be concurrently collected with turbidity data to provide the attenuation coefficient parameter in Eq. (1) for image restoration. As a final step, we will mount the turbidity meter on an AUV (Tuna Sand2) for data collection in different underwater conditions.

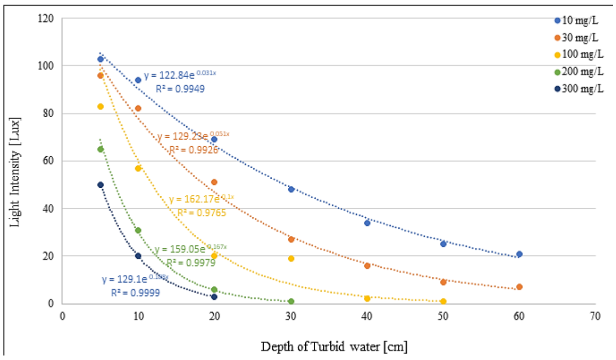

Fig. 9 Relationship between Blue LED's optical path and light intensity in kaolin test solution

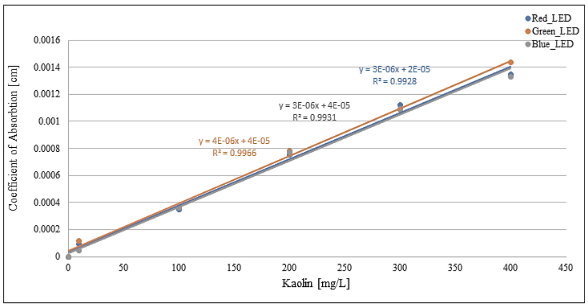

Fig. 10 Relationship between coefficient of light absorption and Kaolin based turbidity

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References

1. H. Blasinski and J. Farrell, "A three parameter underwater image formation model," *IS T Int. Symp. Electron. Imaging Sci. Technol.*, pp. 1–8, 2016, doi: 10.2352/ISSN.2470-1173.2016.18.DPMI-252
2. K. A. Skinner, J. Zhang, E. A. Olson, and M. Johnson-Roberson, "UWStereoNet: Unsupervised learning for depth estimation and color correction of underwater stereo imagery," *Proc. - IEEE Int. Conf. Robot. Autom.*, vol. 2019-May, pp. 7947–7954, 2019, doi: 10.1109/ICRA.2019.8794272.
3. J. Y. Chiang and Y. C. Chen, "Underwater image enhancement by wavelength compensation and dehazing," *IEEE Trans. Image Process.*, vol. 21, no. 4, pp. 1756–1769, 2012, doi: 10.1109/TIP.2011.2179666.
4. D. Berman, T. Treibitz, and S. Avidan, "Diving into haze-lines: Color restoration of underwater images," *Br. Mach. Vis. Conf. 2017, BMVC 2017*, pp. 1–12, 2017.
5. https://global.ihs.com/standards.cfm?publisher=JSA

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