Color Correction of Underwater Images Based on Estimation of Diffuse Attenuation Coefficients

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Abstract

The absorption of light as we descend under water cause production of bluish images. Objects are blue colored since shorter wavelengths are absorbed last in the water. In this paper we present a method for removing negative effects introduced by the optical properties of the water column. As a first step we estimate a diffuse attenuation coefficient for three wavelengths. The estimation is possible as we are using known reflectance values of a reference gray target that is present on all tested images. To calculate new intensity values we are using Beers Law. The depth parameter is derived from images that are taken at different depths approximately 50 cm from each other. Experimental results are shown using an image with a high variability of colors. The suggested method provides a quite effortless and economical way for color reconstruction in degraded underwater images.

Introduction

In underwater photography there are obstacles that make prediction of the outcome image difficult. Taking pictures is all about light, how it interacts with objects and how our eyes perceive it. Water absorbs lower energy wavelength first hence colors disappear in the following order as we descend underwater: red, orange, yellow, green, blue and indigo. Scattering of light in the sea is due to transparent biological organisms and particles that are large compared with the wavelength of light.[1] The magnitude of the scattering is, therefore, virtually independent of wavelength. The loss of color is based on the total distance the light travels, not just depth. The more water there is between the light source, and object and the camera, the fewer colors will remain. This optical nature of ocean water makes images blue-colored. For studies of submerged archaeological sites a proper color representation in the image is of a great importance. The problem arises whether anything can be done to remove the effects of light absorption in underwater environment.

The perception of color not only depends on the spectral characteristics of the light source and the human eye, but especially on those of the object itself. All objects absorb, transmit and reflect incident radiation to varying degrees depending on their chemical/molecular composition and the wavelength of the energy. Every land cover feature, such as open water, has a spectral signature. This spectral signature represents the character of the electromagnetic energy reflected from the land cover feature. In the case of open water, if there is very little turbidity, then there will be very little reflection in the near and mid-infrared ranges. Water absorbs light in this range. This sort of predictable characteristic is what defines a spectral signature, and thus allows the quantification of a wide range of land cover types. Taking images directly under the ocean surface increases the spatial resolution. In the underwater photography field there are two issues that should be brought into account. The first is to evaluate the effects of reflection of light at the surface and scattering that modify the radiant flux. The second is the interaction between this flux and ocean water.

The enhancement of “bluish” underwater images is considered as being a difficult task due to unknown proper color representation under the water. Here a color disappearance with depth will be shown. For that we need to estimate a downwelling absorption coefficient Kd. A digital camera in underwater housing was used to produce an underwater imagery. A neutral color, highly Lambertian reflecting surface called Spectralon [7] is used as a reference target.

Underwater Data Collection

There are a number of techniques for obtaining colored underwater images: still camera photography, remote sensing data collection, photogrammetric method which involves transfer of line work and point data using photogrammetric techniques such as a stereoplotter. For this study we choose to use a digital still camera, which is easy to use when investigating underwater sites or coral reefs. One of the drawbacks when using a digital camera is the often unpredictable spectral and photometric behavior of the CCD sensor in underwater conditions. Another drawback is that we have too few spectral channels to work with.

The digital imagery was collected outside of the Tampa Bay and in John Pennekamp resort in Florida. In Tampa Bay the sky conditions were fairly good for characterization and calibration. Air temp was 27-29^{o} C. Winds 5-8 m/s. Bottom conditions were observed as following: visibility 8 meters, thermo cline at ledge, lots of brown algae on bottom. During the dive pictures of encrusting coral and sponge on top of ledge and sand at foot of ledge were taken. The first image was taken at the top of the ledge at 16.5 meters. Thereafter the depth increased with approximately 50 cm and a new image was taken. This process continued until the bottom at 19 meters was reached and a series of sand pictures were taken. In John Pennekamp the process of collecting data was almost the same as in Tampa with one difference: images which contains mostly corals were collected with 1 meters intervals.

Image format is TIFF uncompressed with spatial resolution of 2048x1536 pixels. All automatic options of the camera were shut down. See Figure 1.

Figure 1. Spectralon at the sand bottom.

Calibrating the Digital Camera

Correct calibration of Digital Still Camera is crucial for the method that we will describe. Since water is a medium where light is behaving in quite an unpredictable manner we cannot use light balancing algorithms to correct the exposure. The light conditions are changing rapidly and constantly. Another point is that all setup operations are usually made before the actual dive. Finding underwater scenes and trying to hold the camera still is effort enough.

We need to calibrate the spectral responsivity of the camera. For that the measurement of the water absorption data is necessary. We are looking for an instrument or a technique that allows for:

- Calibration reading.
- Camera to view a near constant radiance field.
- Spectral and spatial uniformity.
- Showing the reflectance of various ocean bottoms at a low cost and insignificant effort.

This can be obtained using a special, reflective target. One such material that meets National Bureau of Standards specifications is known as "Spectralon".

Reflectance

When photons enter an absorbing medium, they are absorbed according to Beers Law:

$$I = I_0 e^{-kz} \tag{1}$$

where I is the observed intensity, Io is the original light intensity, k is an absorption coefficient and z is the distance traveled through the medium. The absorption coefficient is traditionally expressed in units of 1/cm (inverse cm) and z in cm. Equation 1 holds for a single wavelength.[2] At other wavelengths, the absorption coefficient is different, and the observed intensity varies. The absorption coefficient as a function of wavelength is a fundamental parameter describing the interaction of photons with a material.

Reflectance is considered as the ratio of the intensity of reflected radiant energy to that reflected from a defined reference standard. For the project a neutral color, highly lambertian reflecting surface called a Spectralon (Figure 2) is chosen as a reference standard. It is placed on a surface next to the target coral or other bottom type and imaged as part of the scene. This will together with the spectral data allow calibrating the spectral responsivity of the camera. The ratio after correcting for the Lambertian and reflectivity of the panel provides the remote-sensing reflectance.

Figure 2. 10% Spectralon.

Light Decrease with Water Depth

The severe absorption and scattering effects cause around 60% of all photographic errors.[6] Solar light supplies most of the illuminance to the ocean. That is why it is very important to be aware of the position of the sun. The lower the sun the more light will reflect from the surface. In fact, when the light strikes a surface at a 48-degree angle, all light will reflect. Water absorbs lower energy wavelength first. Three meters is the depth where almost all red light is gone for pictures taking purpose.

By careful examination of the images we can state that the same sand is slightly different in color depending on where in the image area it is situated. This is valid also for other bottom types such as brown algae and green algae. To evaluate the differences we need to calculate the reflectances of randomly selected pairs of bottom types. Since we did not measure the reflectances we can only estimate them. The calculation is made with the following assumptions:

1. All photographed bottoms have a Lambertian distribution of reflectances.
2. The Spectralon is taking in as much light as the surrounding environment.
3. The digital camera has stable sensitivity curves that are not shifted under different light conditions.

As we rely on assumption 2) and the definition of reflectance in chapter 1 each pixel on the image can be assigned its own value of reflectance. Grey targets reflectance is calculated as in Equation 2.

$$R = \frac{L_{out}}{L_{in}} \tag{2}$$

where L_{out} is the radiation striking the lens and L_{in} is the radiation incident on the object. It is a simplification that does not take into account additional factors such as incident and reflection angles. However now we are able to calculate the relative reflectance at any point in the image in each channel. Equation 3 does this.

$$R_r = \frac{I}{L_{in}} = \frac{I}{\frac{L_{out}}{R}} = \frac{I * R}{L_{out}} \tag{3}$$

where L_{in} is incident radiation (which is the same as on the Spectralon), I is the intensity of a pixel and L_{out} is intensity value of a Spectralon on the image.

The spectral signature of bottom pairs such as brown algae in Figure 3 is identical. This agrees with the initial hypothesis for the project, that is object reflectance in the underwater taken images will depend completely on Spectralons reflectance characteristics. However if the assumption 2) cannot be satisfied (i.e. the subject of investigation lies considerably deeper or shallower than the reflectance target) the relative reflectance is impossible to estimate. We need to introduce the depth parameter in the equation.

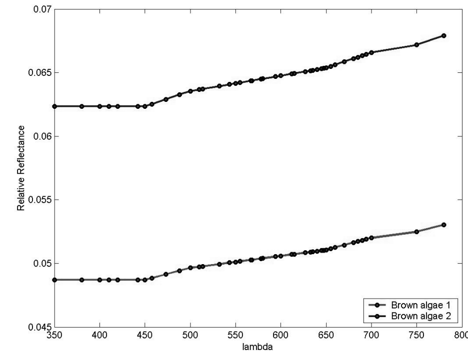

Figure 3. Reflectance of two brown algae areas in the same image.

Light striking the object is a function of wavelength. This means that for each wavelength we can calculate the rate at which it is absorbed by the water column. The absorption increases with depth. Images with the Spectralon are taken at a distance of 50 cm from each other, which give us a possibility to measure the differences in reflected light. In Equation 4 we calculate the absorption coefficient as a function of wavelength and depth.[3] For any appropriate wavelength the loss of light due to water depth is established.

$$K_d(z, \lambda) = -\left[\frac{1}{L_{in}(z, \lambda)}\right] * \left[\frac{\partial L_{in}}{\partial z}\right] \tag{4}$$

where z is the depth.

Color Loss

In the image of underwater scene the only dominant color is blue. However while diving we observe many colors including red. This phenomenon is explained by human vision having a different spectral sensitivity.[5] There is reason to assume that the process of adjusting the color of one object based on the reflectance of some established standard is quite effortless. To convert the camera output signals to device-independent data, several approaches were tested. Only one could be fully developed during this project. The method is based on the spectral model of the acquisition system and the gray reflectance target. By inverting the model, we can estimate the spectral reflectance of each pixel of the imaged surface.

In the application the acquired images are used to predict changes in color as changes in depth are presented. A first step is to perform a spectral characterization of the image acquisition system to establish the spectral model. Sensitivity curves of Red Green and Blue channels for the digital camera are studied in order to establish the appropriate wavelengths. These wavelengths are then interpolated to the known reflectance profile of a Spectralon. See Table 1.

Table 1. Hemispherical Reflectance of SRS-10-020-9274-A 2” Diameter.

Wavelength (nm)	8 deg /Hemispherical Reflectance
250	0.1140
300	0.1060
350	0.1030
400	0.1030
450	0.1030
500	0.1050
550	0.1060
600	0.1070
650	0.1080
700	0.1100
750	0.1110
800	0.1130
850	0.1150
900	0.1160

The second step is to calculate the ratio after correcting for Lambertian and reflectivity of panel to get the reflectance. The path effects to target and plaque are the same and cancel out. Series of vertical profiles of gray photos provides an estimation of downwelling irradiance to derive K_d (downward diffuse vertical attenuation coefficient) measures for three wavelengths.

As a next step we will insert K_d for Red, Green and Blue light into Equation 1 to estimate the loss of these particular colors in underwater images. To get the value of a pixel at depth z and z1 meters we need to use the equations below:

$$\begin{aligned} I(_z) &= I_0 e^{-k(z)z} \\ I(_{z1}) &= I_0 e^{-k(z1)z1} \end{aligned} \tag{6}$$

In both calculations we are referring to I_0, which is the incoming light at the surface. As we would like to visualize how much light is disappearing with depth we need to calculate the new intensity values for Red, Green and Blue channels in the image. Equation 7 shows how to estimate the new values for the image taken at z meters depth as if it was taken at z1 meters depth.

$$I(_{z1}) = \frac{I_z}{e^{-k(z)z}} e^{-k(z1)z1} = I_z e^{k(z)z - k(z1)z1} \tag{7}$$

Downwelling attenuation coefficients K are for the 3 wavelengths and these are varying with depth only. This is because we are limited to 3 given channels for Red, Green and Blue.

Result and Discussion

Applying the algorithm on the image that is corrupted due to water column apparent properties we get an improvement in colors. Experimental results showed that we do not need to bring up the image to the surface since Kd for 3 meters depth and at the surface are not significantly different. The method of reflectance estimation is found to work well on tested bottom types that have very different spectral properties.

Due to noise, measuring error and bottom reflectance properties, the Kd values obtained by experimental data do not increase strictly with depth, which is shown in Figures 4, 5 and 6.

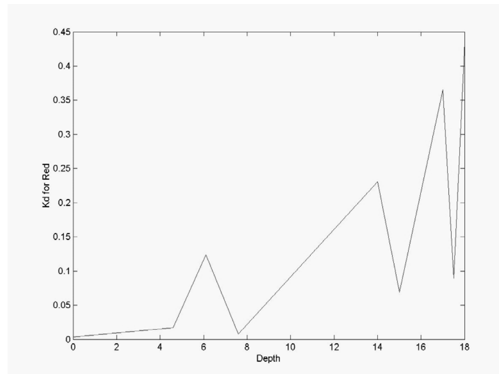

Figure 4. Kd for Red channel

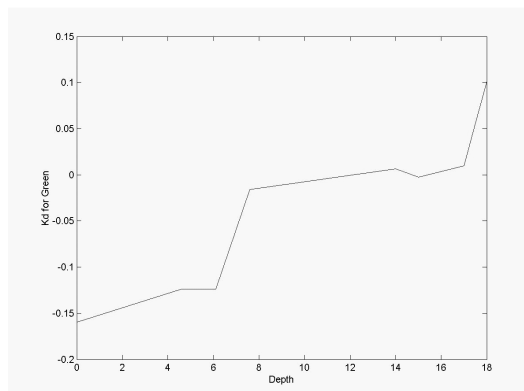

Figure 5. Kd for Green channel

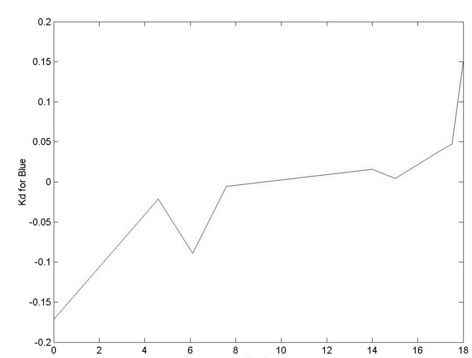

Figure 6. Kd for Blue channel

As could be expected the Kd curve for the Red channel is the most jagged since the lack of light makes Red the noisiest channel.

It was noticed that when we are using a series of images with strong bottom reflectances the resulting Kd values produce better results when used in the algorith m.

When applying this algorithm on a corrupted image a significant improvement in colors could be observed. The effects of the water column that make images bluish are diminished. See Figure 7.

The next step for the project is to determine in which manner bottom reflectance contributes to the errors in Kd-values.

a)

b)

Figure 7. a) Bluish image at 12 meters depth. b) Image corrected by bringing it up to 3 meters.

Acknowledgments

The authors would like to thank Kendall L. Carder for technical consulting, Robert Steward and David English for their help in collecting the images, David Sundgren and Marta Siborelius for many useful discussions and encouragement. The work was supported by the KK-foundation.

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Biography

Julia Åhlén received the B.Sc. degree in Computer Engineering from the University of Gävle (Sweden). She is currently with the Centre for Image Analysis at the Uppsala University (Sweden), where she started her PhD studies in 2001. The research studies topic involves colour correction of underwater multispectral images.