UNDERWATER IMAGE ENHANCEMENT BY ATTENUATION INVERSION WITH QUATERNIONS

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ABSTRACT

In this paper, an underwater image enhancement method using quaternions is presented. This work aims to improve color rendition and contrast of the objects, as if the scene has been taken out of water. This method is based on light attenuation inversion after processing a color space contraction using quaternions. Applied to the white, the attenuation gives a hue vector caracterizing the water color. Using this reference axis, geometrical transformations into the color space are computed with quaternions. Pixels of water areas of processed images are moved to gray or colors with a low saturation whereas the objects remain fully colored. Thus, the contrast of the observed scene is significantly improved and the difference between the background and the rest of the image is increased, giving a first approach towards a pre-segmentation step.

***Index Terms*—** Underwater images, Images enhancement, Colorimetry, Quaternions.

1. INTRODUCTION

The data acquired under the sea often suffer of large defaults and have to be preprocessed before any analysis or understanding. Actually, underwater scenes are usually veiled by the light interaction with the medium: absorption and scattering of the light induce poor contrast, low luminosity and restricted visibility. An enhancement of image quality is then required by compensating attenuation effects and retrieving a better color balance between the elements of the image. Some enhancement methods already exist [1, 2, 3] and are based on attenuation phenomenon compensation. Quaternions are used in the presented method to perform a color dynamic compression governed by a given hue, by using color space geometrical transformation. An inversion of the attenuation is then computed to finalize the color rendition and contrast improvements. This paper is organized as followed. In section 2, light attenuation phenomenon is presented; in section 3, quaternion formalism is briefly described; in sections 4 ans 5 the proposed method using quaternion is described and discussed.

2. LIGHT ATTENUATION BY SEAWATER

2.1. Light attenuation

When passing through a medium composed of molecules and particles, the light interacts with the constituent matter of this medium. When the light reaches a particle, a part of its energy is absorbed and the remaining energy is scattered all around the particles. Thus, considering a given observation direction, some light is lost by scattering into other directions. The attenuation is caracterized by the spectral attenuation coefficient c_λ which depends on the wavelength. The quantity of light $L_\lambda(P)$ traveling through an optical path from a point P_0 (objects) to a point P (observer) without suffering the influence of attenuation is defined by the Beer-Lambert law [4], with d the length of the path between P and P_0 :

$$L_\lambda(P) = L_\lambda(P_0).e^{-c_\lambda d} \tag{1}$$

2.2. Water associated hue vector

In RGB color space, the white vector, representing a white light is given by $(1, 1, 1)$. We can apply the attenuation, by using the Beer-Lambert law, to each component of this vector. Underwater image correction aims to retrieve the initial value of a pixel tranformed by equation Eq. (1). Considering image correction as an inverse problem, solution is given by inversing Eq. (1) which requires spectral attenuation coefficient c_λ and distance d estimation. Solution is proposed to estimate these parameters in [1]. Given the estimated parameters c_λ with $\lambda \in R, G, B$ and d, the attenuated light vector is given by:

$$H = (e^{-c_R d}, e^{-c_G d}, e^{-c_B d}) \tag{2}$$

This vector H can be considered as the hue vector associated to the water color, which will be our reference axis to compute the operations later. Actually, it represents the color of the ambient light perceived by an observer after the attenuation by the water.

2.3. Natural waters color

While clear water mainly scatters blue light, waters containing more organic matter scatter more green and/or yellow light. Many measurements have been done, and a model linking chemical properties and attenuation has been established [5]. This model is used in the physical image enhancement method [1] to determine spectral attenuation coefficient c_λ directly from the concentration of chlorophyll-based pigments contained by the water.

In the presented method, the spectral attenuation coefficient and the distance have been determined using a previous unsupervised method of underwater images correction based on a physical inversion of light propagation [1]. Then, a space contraction and an attenuation inversion are performed as described in the following sections.

3. QUATERNIONS

3.1. Definitions

Quaternions (or hypercomplex numbers) are an extension of complex to four dimensions. Proposed by Hamilton in 1843. quaternions have been used with color space since several years. They can be considered as complex numbers with a real part and three imaginary parts. A quaternion $q \in \mathbb{H}$ is usually represented as, $q = w + xi + yj + zk$, where w, x, y and z are real and i, j and k are the complex operators which are following these properties:

$$i^2 = j^2 = k^2 = ijk = -1$$

and

$$ij = k, jk = i, ki = j, ji = -k, kj = -i, ik = -j$$

Given a quaternion q its conjugate is $\overline{q} = w - xi - yj - zk$ and its modulus is $|q| = \sqrt{w^2 + x^2 + y^2 + z^2}$. A *pure* quaternion is a quaternion with a zero real part and a *unit* quaternion has a unit modulus equal to 1. Pure quaternion space is usually denoted $\mathbb{P}$ and unit quaternion space is usually denoted by $\mathbb{S}$. A quaternion q can be splitted into a scalar part $S[q]$ and a vector part $V[q]$. And thus, $q = S[q] + V[q]$ where $V[q] = xi+yj+zk$. Note that the quaternionic product is anti-commutative.

If we consider an RGB space, each pixels of an image I of size $N \times M$ can be described by the following pure quaternion, with $n \in [1..N]$ and $m \in [1..M]$:

$$I(n, m) = r(n, m)i + g(n, m)j + b(n, m)k \qquad (3)$$

3.2. $\mathbb{R}^3$ transformations with quaternions

In this section, only pure quaternions representing three-dimensional vector of $\mathbb{R}^3$ are considered. The vector representation of pure quaternions induces an interesting property of the quaternionic product. The quaternion $q = q_1 q_2$ can be written as, with V_1 and V_2, the respective vector part of $q_1 \in \mathbb{P}$ and $q_2 \in \mathbb{P}$:

$$q = q_1 q_2 = -V_1.V_2 + V_1 \wedge V_2 \qquad (4)$$

Using this property, reflexion, projection, rejection and rotation have been expressed in quaternion space, using only quaternions additions and multiplications as described by Sangwine in [6].

All these operations allow to manipulate the colors associated vectors in a given colorimetric space, in this case RGB, as described here after.

4. COLOR SPACE CONTRACTION USING QUATERNIONS

The aim of the proposed method is to perform a separation of water areas of the image I from the objects areas by moving pixels close to the particular hue value to gray pixels or to pixels with a very low saturation (gray world). In the particular case of underwater image, the hue vector can be the one defined by Eq. (2) and representing perceived light after attenuation phenomenom. The effect of the space contraction on the hue axis is an enhancement of contrast and visibility of colored objects by separating them from bluish or greenish image background. Our purpose is to use the quaternionic projection relation using non-unit axis vectors. Thus, the projection relation becomes, with $\mu \notin \mathbb{S}$:

$$\hat{q} = \frac{1}{2}(q - \mu q \mu) = \Big[\underbrace{\frac{1}{2}(1 - |\mu|^2)q}_{v_1} + \underbrace{|q||\mu| cos(q, \mu)\mu}_{v_2} \Big] \qquad (5)$$

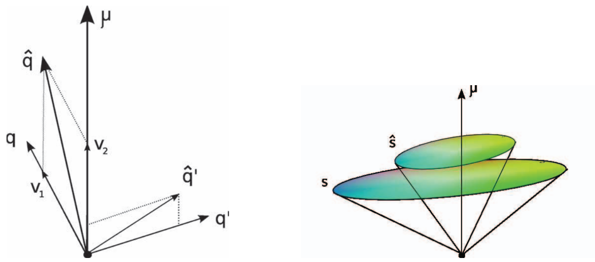
$\hat{q}$ is the sum of a part of q weighted by the norm of the water color axis, providing the transformation, and an energy part given by the projection of q on μ, corresponding to the luminance of q. The result of this transformation is a color contraction around axis μ as shown on the Fig. 1.(a) where v_1 and v_2 represent the two parts of $\hat{q}$.

After this transformation, vectors of the image are contracted towards the hue axis. Fig. 1.(b) represents the image vectors set S which is transformed to a new set $\hat{S}$ contracted on the hue axis. The second step of this method is to modify these vectors again, in RGB space to compensate attenuation effects on objects.

5. UNDERWATER IMAGE COLOR ENHANCEMENT

5.1. Attenutation inversion by normalization from hue vector

If we apply the transformation proposed in section 4 on the pixels of an underwater image I using a dedicated hue vector



(a) (b)

Fig. 1. Image domain contraction: (a) Shift of vectors towards axis μ (b) Space contraction by the quaternionic transformation.

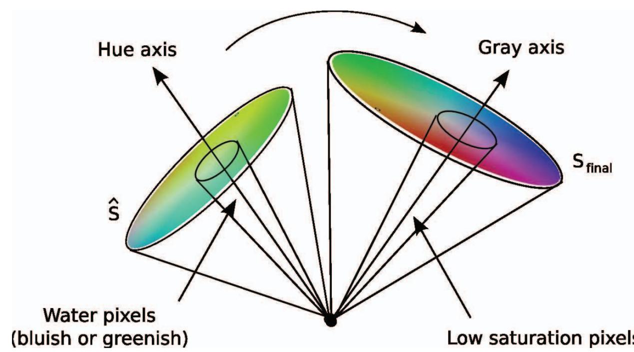


Fig. 2. Image normalization: water pixels turns to gray or low saturation pixels in the output image.

defined in [1], we are able to modify the image color enhancement and to compensate the light attenuation in water. The purpose of the processing is to move water pixels, close to the hue axis, near the gray axis, whereas preserving colors of the objects and modifying them to restore the color balance. Actually, after the space contraction computation, pixels close to the water color are moved towards the hue axis whereas the objects pixels remain distant from it. Finalization of the color enhancement is to provide a compensation of the light attenuation, to restore a good color balance. Note that this normalization of the $\hat{q}$ vectors coordinates, by the hue vector coordinates, here axis $\mu = (H_R, H_G, H_B)$, is exactly an attenuation equation inversion according to Eq. (2) applied to the considered pixel $\hat{q}$:

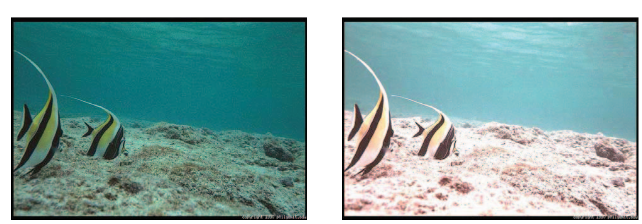
$$q_{final} = (\frac{\hat{q}_R}{H_R}, \frac{\hat{q}_G}{H_G}, \frac{\hat{q}_B}{H_B}) = (\hat{q}_R.e^{c_R d}, \hat{q}_G.e^{c_G d}, \hat{q}_B.e^{c_B d}) \tag{6}$$

Geometrically, this normalization performs a dilatation of the image vectors, providing a kind of rotation from hue axis μ to the gray axis (Fig. 2). Actually, when $\hat{q}$ is close to μ, q_{final} is almost colinear to the gray axis. Note that, if $\hat{q}$ is colinear to μ, then $\hat{q} = (\alpha.e^{-c_R x}, \alpha.e^{-c_G x}, \alpha.e^{-c_B x})$ and $q_{final} = (\alpha, \alpha, \alpha)$ which is a gray of level α. The water areas turn into the gray world whereas the objects which are usually associated to $\hat{q}$ vector furthest to μ remain colored. Thus, object contrats are significantly improved. Color vectors coordinates are adjusted proportionaly to the respective values of attenuation coefficient. When red coordinates are strongly increased, blue and green coordinates are slightly increased. Thus, the attenuation phenomenon is compensated and then the color balance restored (Fig. 3).

The efficiency of the proposed transformation deeply depends on the value of the μ vector. Methods of hue axis determination are discussed in the following section.

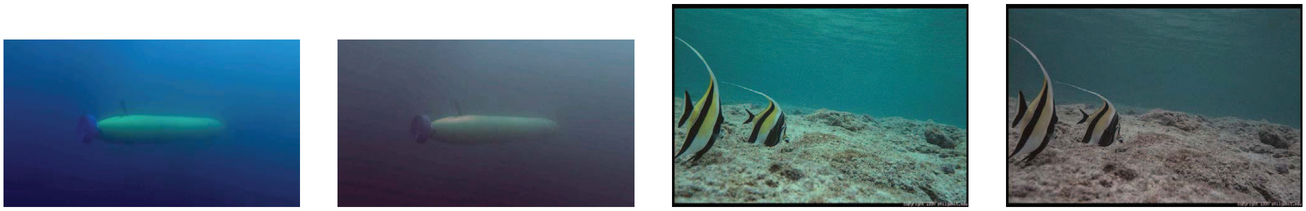
5.2. Hue axis determination

A first method to determine the hue axis is based on the estimation of the attenuation coefficient c_λ and distance d. Given this value, H can be computed using Eq. (2). These parameters can be estimated using the method proposed in [1]. However, this method requires computation time, and hue vector value are linked to an initial learning set. In order to be independent of any external estimated parameters, an alternative way is to determine hue vector only using the initial image I and a faster calculation using Principal Component Analysis (PCA). PCA calculation is used to determine a dominant axis which best describes the image. Actually, experimentation shows that the color vector (axis) calculated by using a PCA gives results not far from the one calculated with a physical-based image correction in term of color balancing. PCA thus extracts a dominant color of the image, hence, in most cases, the water color, and provides also good results in term of color enhancement by using the method described above. However, saturation of colors in output images is very high and need to be corrected in a post-processing step. The effect of driving water pixels towards gray world is also reduced because the axis is not as close as "physical" axis from the water color, as shown on the result images obtained on the Fig. 3 and the Fig. 5.



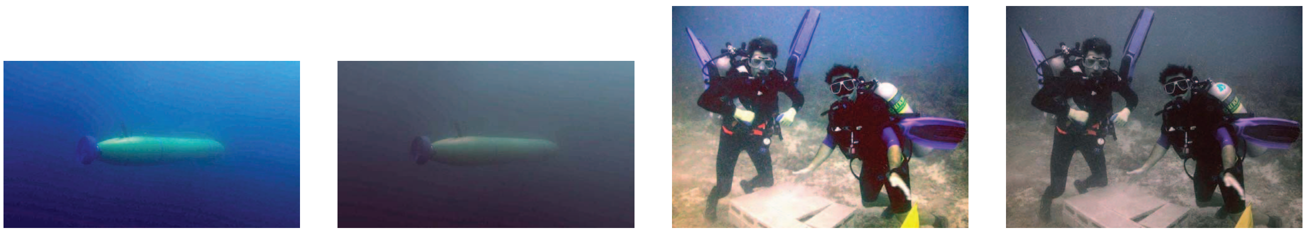
(a) (b)

Fig. 5. Example of image correction with PCA hue axis calculation. (a) Original image (b) Enhanced image with PCA axis



(a) (b) (c) (d)

Fig. 3. Quaternionic image correction. (a,c) Original image (b,d) Enhanced image



(a) (b) (c) (d)

Fig. 4. Comparison between the presented method and the physical-based method described in [1]. (a,c) Physical-based correction (b,d) Space contraction + normalization

5.3. Discussion on results

This method gives a new approach, based on vectors and color space manipulations, to compute a color enhancement on underwater images. Fig. 4 shows a comparison between the physical-based approach [1] and this method. Color balance is well restored by both the methods but the space compression provides a better separation between objects (foreground) and the water (background) and thus the contrast between them is improved. The attempt to define an axis directly from the image by PCA calculation gives promising results. Color restoration is still performed, as shown on Fig. 5, but the saturation decrease of the water pixels is not as good as the computation obtained with the physical axis. Further studies need to be conducted on this point, and a post-processing would probably be needed.

6. CONCLUSION

The method presented in this paper improves contrast and color dynamic on underwater images by turning water pixels to gray or low saturation colors whereas objects remain fully colored. Geometrical quaternionic transformation around a hue axis, representing the water color, has been used. Objects contrast are well enhanced and bluish aspect of images due to the light attenuation is removed. Physical attenuation parameters required to perform a direct attenuation inversion could be replaced by a simple dominant color calculation by PCA. On going work will be conducted on the determination of hue axis by PCA in order to get better and faster results.

7. REFERENCES

[1] F. Petit, A.-S. Capelle-Laizé, P. Blasi, and J.-C. Burie, "Underwater images enhancement by light propagation model reversion.," in *Conference on Colour in Graphics, Imaging, and Vision - CGIV 2008*, Terrassa, Barcelona - Spain, June 2008, Imaging Science and Technology (IS&T).

[2] J. Ahlen, *Colour correction of underwater images using spectral data*, Ph.D. thesis, University of Uppsala, 2005.

[3] L.A. Torres-Mendes and G. Dudek, "Colour correction of underwater for aquatic robot inspection," *Energy Minimization Methods in Computer Vision and Pattern Recognition, LNCS*, vol. 3757, pp. 60–73, 2005.

[4] H.R. Gordon, "Can the lambert-beer law be applied to the diffuse attenuation coefficient of ocean water?," *Limnology and Oceanography*, vol. 34, no. 8, pp. 1389–1409, 1989.

[5] K. Baker and R. Smith, "Bio-optical classification and model of natural waters," *Limnology and Oceanography*, vol. 27, no. 3, pp. 500–509, 1982.

[6] Sangwine S.J., "Mathematical approaches to linear vector filtering of color images," in *Conference on Colour in Graphics, Imaging, and Vision - CGIV 2002*, Poitiers - France, 2002, Imaging Science and Technology (IS&T).