Enhancement of Underwater Color Images by Two-side 2-D Quaternion Discrete Fourier Transform

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Outline

1. Introduction.
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3. Enhancement by Transforming the color-image to 2-D grayscale image, and performing Alpha-rooting method by 2-D DFT.
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Underwater Images

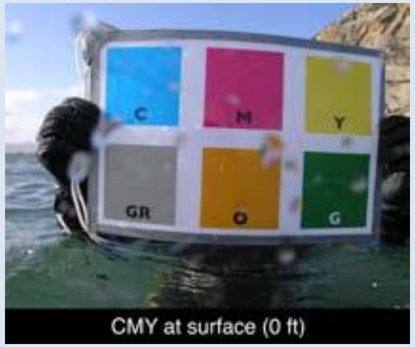
Enhancement of Underwater Images

1. High Wavelengths regions of light gets absorbed by water as depth increases.

2. Poor-lighting Conditions.

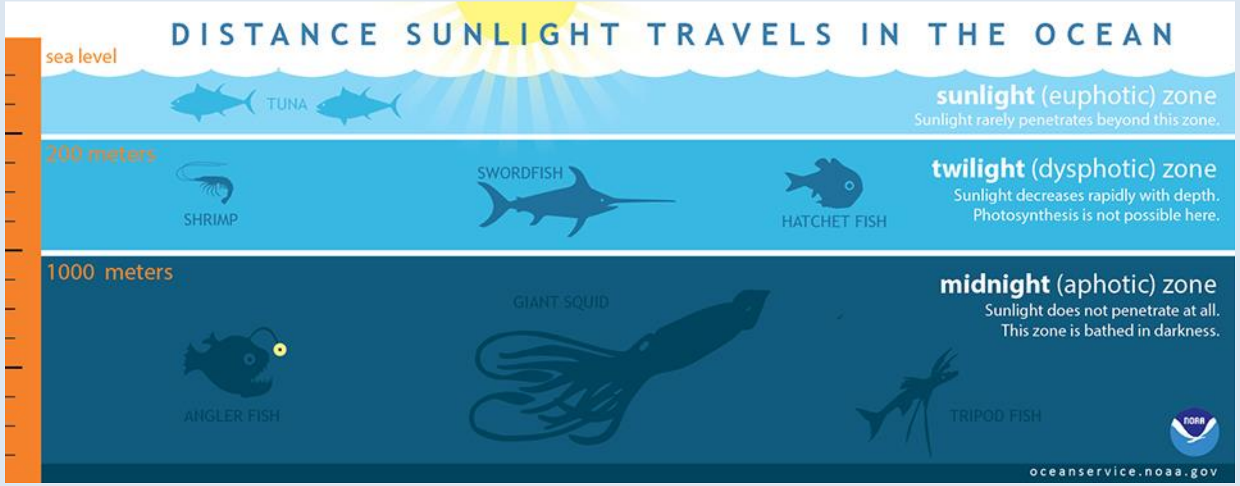
3. Enhance the quality of Images.

Raw Underwater Images


CMY at surface (0 ft)


CMY at 5 ft


CMY at 10 ft



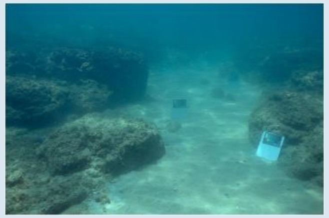
- Courtesy: 1. Vanessa Pateman, Color Correction for Underwater Photography

  2. Oceanservice.NOAA.gov

A few Raw-Underwater Images








- Courtesy: 1. *Courtesy: Photo from [1] & [2]*

[1] D. Berman, T. Treibitz, S. Avidan, "Diving into Haze-Lines: Color Restoration of Underwater Images", BMVC 2017.

[2] C.-Yi Li, Ji-C. Guo, R.-M. Cong, Y.-W. Pang, B. Wang, "Underwater Image Enhancement by Dehazing With Minimum Information Loss and Histogram," IEEE Transactions On Image Processing, Vol. 25, No. 12, December 2016.



Enhancement of Underwater Images

Enhancement of Underwater Images

1. High Wavelengths regions of light gets absorbed by water as depth increases. – Color Corrections

2. Poor-lighting Conditions. – Multi-scale Retinex Algorithm (MSR)

3. Enhance the quality of Images. – i. Quaternion Approach.
ii. Transformation Model Approach.

Quaternion Approach of Enhancement

Color Images can be represented as a Quaternion Number.

- Quaternion Numbers are four-dimensional Hyper-complex numbers.

$$q = a + ib + jc + kd$$

$$q_{n,m} = ir_{n,m} + jg_{n,m} + kb_{n,m}$$

$$a_{n,m} = 0$$

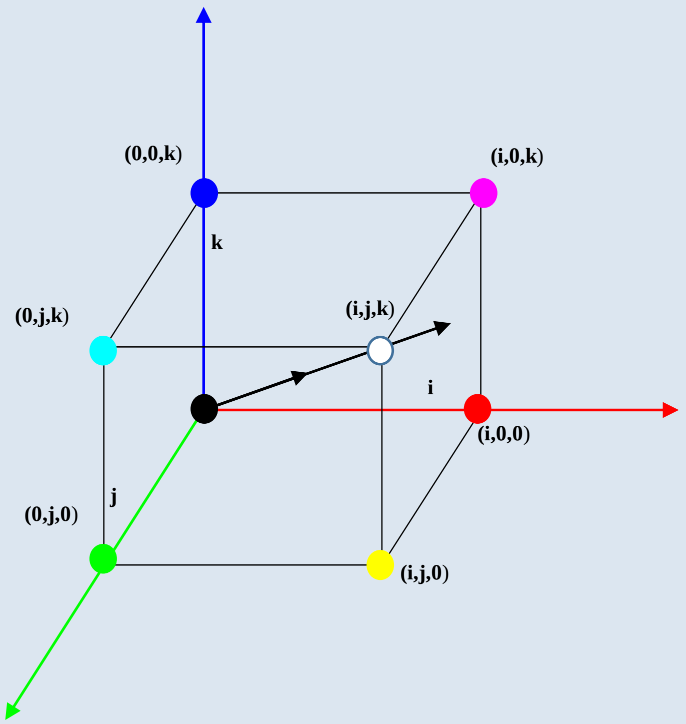
$$q_{n,m} = a_{n,m} + ir_{n,m} + jg_{n,m} + kb_{n,m}$$

$$a_{n,m} = \frac{1}{3}(r_{n,m} + g_{n,m} + b_{n,m})$$

$$a_{n,m} = 0.3r_{n,m} + 0.58g_{n,m} + 0.12b_{n,m}$$



Color-vector in Quaternion Color-Cube



Alpha-Rooting by 2-D QDFT

$$|F_{p,s}| \to |F_{p,s}|^{\alpha} \;, 0 < \alpha < 1$$

$$|F_{p,s}| = \sqrt{|F_{e_{p,s}}|^2 + |F_{i_{p,s}}|^2 + |F_{j_{p,s}}|^2 + |F_{k_{p,s}}|^2}$$



2-D Quaternion Discrete Fourier Transform

LEFT-SIDED

$$F_{p,s} = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} W_j^{np} W_k^{ms} f_{n,m}$$

$$f_{n,m} = \frac{1}{NM}\left[\sum_{p=0}^{N-1} \sum_{s=0}^{M-1} W_j^{-np} W_k^{-ms} F_{p,s}\right]$$

RIGHT-SIDED

$$F_{p,s} = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} f_{n,m} W_j^{np} W_k^{ms}$$

$$f_{n,m} = \frac{1}{NM}\left[\sum_{p=0}^{N-1} \sum_{s=0}^{M-1} F_{p,s} W_j^{-np} W_k^{-ms}\right]$$

TWO-SIDED

$$F_{p,s} = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} W_j^{np} f_{n,m} W_k^{ms}$$

$$f_{n,m} = \frac{1}{NM}\left[\sum_{p=0}^{N-1} \sum_{s=0}^{M-1} W_j^{-np} F_{p,s} W_k^{-ms}\right]$$

Two-sided 2-D Quaternion Discrete Fourier Transform

$$F_{p,s} = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} W_j^{np} f_{n,m} W_k^{ms}$$

$$f_{n,m} = \frac{1}{NM} \sum_{p=0}^{N-1} \sum_{s=0}^{M-1} W_j^{-np} F_{p,s} W_k^{-ms}$$

$$W_j^t = \exp\left(-\frac{j2\pi t}{N}\right) = \cos\left(\frac{2\pi t}{N}\right) - j\sin\left(\frac{2\pi t}{N}\right),$$
$$t = 0,1,\dots,(N-1),$$
$$W_k^t = \exp\left(-\frac{k2\pi t}{M}\right) = \cos\left(\frac{2\pi t}{M}\right) - k\sin\left(\frac{2\pi t}{M}\right),$$
$$t = 0,1,\dots,(M-1).$$




Two-sided 2-D Quaternion Discrete Fourier Transform

$$F_{p,s} = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} \left\{ \left[\exp\left(-j \frac{2\pi}{N} np \right) \right] f_{n,m} \left[\exp\left(-k \frac{2\pi}{M} ms \right) \right] \right\}$$

$$f_{n,m} = \frac{1}{NM} \sum_{p=0}^{N-1} \sum_{s=0}^{M-1} \left\{ \left[\exp\left(j \frac{2\pi}{N} np \right) \right] F_{p,s} \left[\exp\left(k \frac{2\pi}{M} ms \right) \right] \right\}$$

$$W_j^t = \exp\left(-\frac{j2\pi t}{N} \right) = \cos\left(\frac{2\pi t}{N} \right) - \mathrm{j}\sin\left(\frac{2\pi t}{N} \right),$$
$$t = 0,1, \dots, (N-1),$$
$$W_k^t = \exp\left(-\frac{k2\pi t}{M} \right) = \cos\left(\frac{2\pi t}{M} \right) - k\sin\left(\frac{2\pi t}{M} \right),$$
$$t = 0,1, \dots, (M-1).$$



Two-side 2-D QDFT

- $F = [COS(\varphi) - jSIN(\varphi)]q[COS(\varphi) - kSIN(\varphi)]$
- $F = e(CEC + SJC + CKS + SIS) + i(CIC - SKC - CJS + SES) + j(CJC - SEC + CIS - SKS) + k(CKC + SIC - CES - SJS)$
- $F = e(CGrayC + SGreenC + CBlueS + SRedS) + i(CRedC - SBlueC - CGreenS + SGrayS) + j(CGreenC - SGrayC + CRedS - SBlueS) + k(CBlueC + SRedC - CGrayS - SGreenS)$

Two-side 2-D QDFT

- $F = [COS(\varphi) - jSIN(\varphi)]q[COS(\varphi) - kSIN(\varphi)]$

- $F = e(CEC + SJC + CKS + SIS) + i(CIC - SKC - CJS + SES) + j(CJC - SEC + CIS - SKS) + k(CKC + SIC - CES - SJS)$

- $F = e(CGrayC + SMagentaC + CYellowS + SCyanS) + i(CCyanC - SYellowC - CMagentaS + SGrayS) + j(CMagentaC - SGrayC + CCyanS - SYellowS) + k(CYellowC + SCyanC - CGrayS - SMagentaS)$



Enhancement by Transformation Model

Color-image is transformed to 2-D grayscale image.

Transformation Model 2×2 , 2×3 , row, and column.



Transformation of 3 or 4 Channel color-image to 2-D grayscale image

I(0,0)	R(0,0)	I(0,1)	R(0,1)	I(0,2)	R(0,2)	…
G(0,0)	B(0,0)	G(0,1)	B(0,1)	G(0,2)	B(0,2)	…
I(1,0)	R(1,0)	I(1,1)	R(1,1)	I(1,2)	R(1,2)	…
G(1,0)	B(1,0)	G(1,1)	B(1,1)	G(1,2)	B(1,2)	…
I(2,0)	R(2,0)	I(2,1)	R(2,1)	I(2,2)	R(2,2)	…
G(2,0)	B(2,0)	G(2,1)	B(2,1)	G(2,2)	B(2,2)	…
…	…	…	…	…	…	…

I(0,0)	I(0,1)	I(0,2)	…
R(0,0)	R(0,1)	R(0,2)	…
G(0,0)	G(0,1)	G(0,2)	…
B(0,0)	B(0,1)	B(0,2)	…
I(1,0)	I(1,1)	I(1,2)	…
R(1,0)	R(1,1)	R(1,2)	…
G(1,0)	G(1,1)	G(1,2)	…
B(1,0)	B(1,1)	B(1,2)	…
…	…	…	…

R(0,0)	G(0,0)	B(0,1)	R(0,2)	G(0,2)	B(0,3)	R(0,4)	G(0,4)	B(0,5)	…
B(0,0)	R(0,1)	G(0,1)	B(0,2)	R(0,3)	G(0,3)	B(0,4)	R(0,5)	G(0,5)	…
R(1,0)	G(1,0)	B(1,1)	R(1,2)	G(1,2)	B(1,3)	R(1,4)	G(1,4)	B(1,5)	…
B(1,0)	R(1,1)	G(1,1)	B(1,2)	R(1,3)	G(1,3)	B(1,4)	R(1,5)	G(1,5)	…
R(2,0)	G(2,0)	B(2,1)	R(2,2)	G(2,2)	B(2,3)	R(2,4)	G(2,4)	B(2,5)	…
B(2,0)	R(2,1)	G(2,1)	B(2,2)	R(2,3)	G(2,3)	B(2,4)	R(2,5)	G(2,5)	…
…	…	…	…	…	…	…	…	…	…

I(0,0)	R(0,0)	G(0,0)	B(0,0)	I(0,1)	R(0,1)	G(0,1)	B(0,1)	…
I(1,0)	R(1,0)	G(1,0)	B(1,0)	I(1,1)	R(1,1)	G(1,1)	B(1,1)	…
I(2,0)	R(2,0)	G(2,0)	B(2,0)	I(2,1)	R(2,1)	G(2,1)	B(2,1)	…
…	…	…	…	…	…	…	…	…

2×2 Transformation Model

I(0,0)	R(0,0)	I(0,1)	R(0,1)	I(0,2)	R(0,2)	…
G(0,0)	B(0,0)	G(0,1)	B(0,1)	G(0,2)	B(0,2)	…
I(1,0)	R(1,0)	I(1,1)	R(1,1)	I(1,2)	R(1,2)	…
G(1,0)	B(1,0)	G(1,1)	B(1,1)	G(1,2)	B(1,2)	…
I(2,0)	R(2,0)	I(2,1)	R(2,1)	I(2,2)	R(2,2)	…
G(2,0)	B(2,0)	G(2,1)	B(2,1)	G(2,2)	B(2,2)	…
…	…	…	…	…	…	…

Alpha-Rooting by 2-D DFT

$$\left|F_{p,s}\right| \rightarrow \left|F_{p,s}\right|^{\alpha}\ ,\ 0<\alpha<1$$

Measure of Visual Perception/Contrast Perception

- Weber’s Law

The Change in Stimulus that can be perceived is proportional to Initial Stimuli

- Fechner’s Law

Perception and Stimulus are related **logarithmically**.

For example:

Visually perceived Intensity is proportional to the logarithm of the actual Intensity



Enhancement Measure Estimation (EME)

$$f \to \hat{f}$$

Quantitative measure

$$EME(\hat{f}) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} 20\, log_{10} \left[\frac{\max_{k,l}(\hat{f})}{\min_{k,l}(\hat{f})} \right]$$



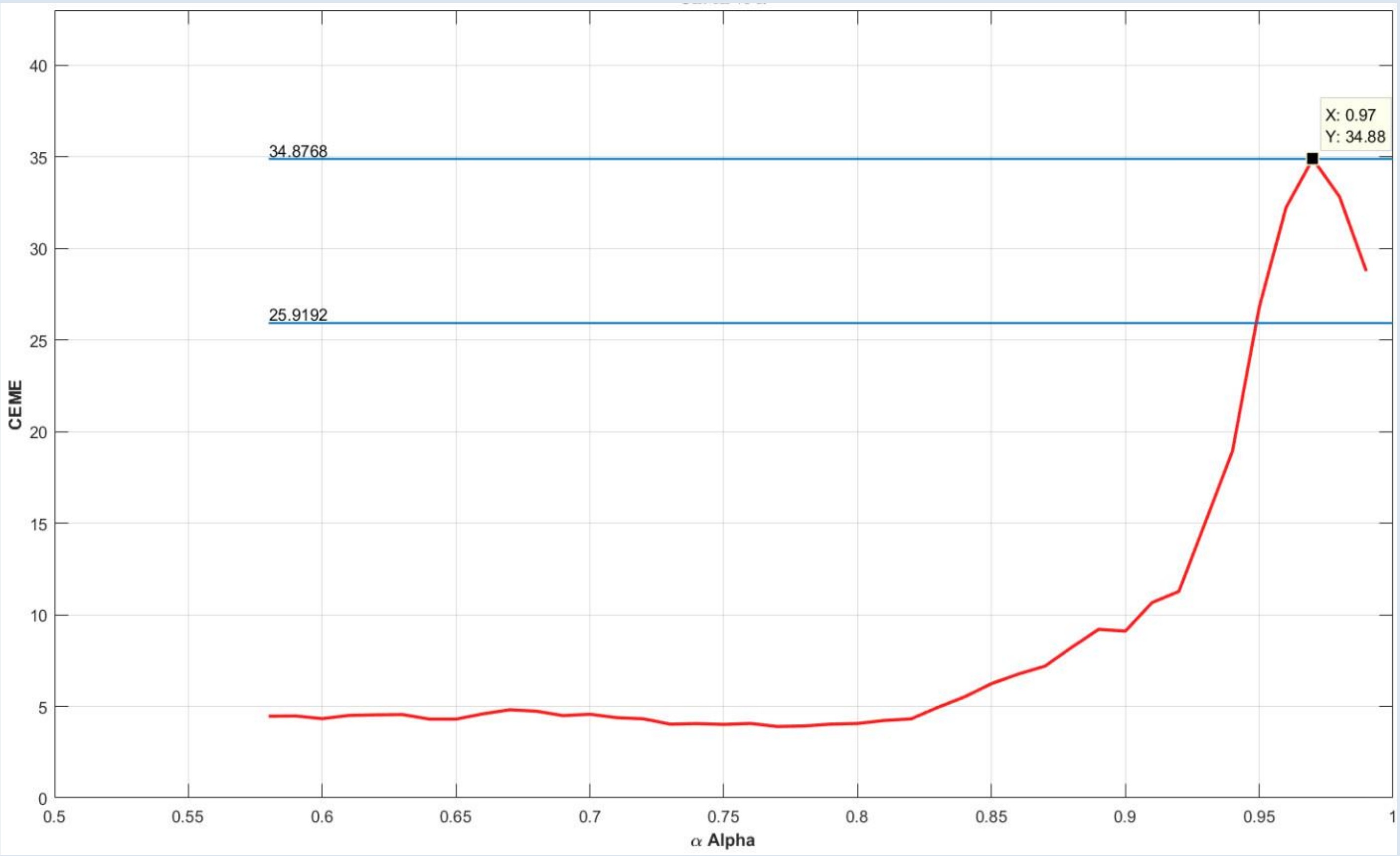
Color Enhancement Measure Estimation (CEME)

Quantitative measure

$$CEME(\hat{f}) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} 20log_{10} \left[\frac{max_{k,l}\{\hat{f}_R, \hat{f}_G, \hat{f}_B\}}{min_{k,l}\{\hat{f}_R, \hat{f}_G, \hat{f}_B\}} \right]$$

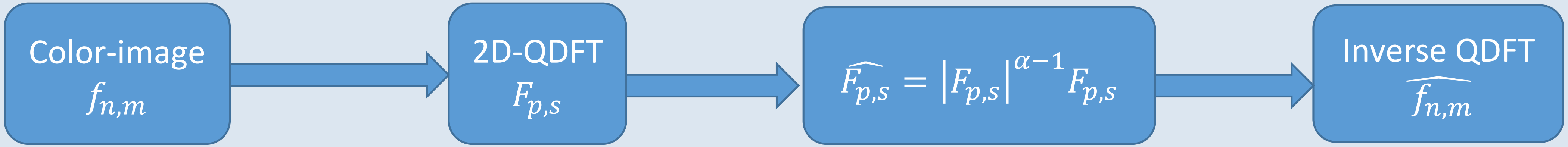


CEME



40
35
30
25
20
15
10
5
0
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
CEME
α Alpha
34.8768
25.9192
X: 0.97
Y: 34.88

Alpha-Rooting



Retinex Algorithm

$$f(n,m) = r(n,m).\, l(n,m);$$

$$n = 0,1,\ldots,N-1,\ m = 0,1,\ldots,M-1$$

$$\log[r(n,m)] = \log[f(n,m)] - \log[l(n,m)]$$



Multi-scale Retinex Algorithm

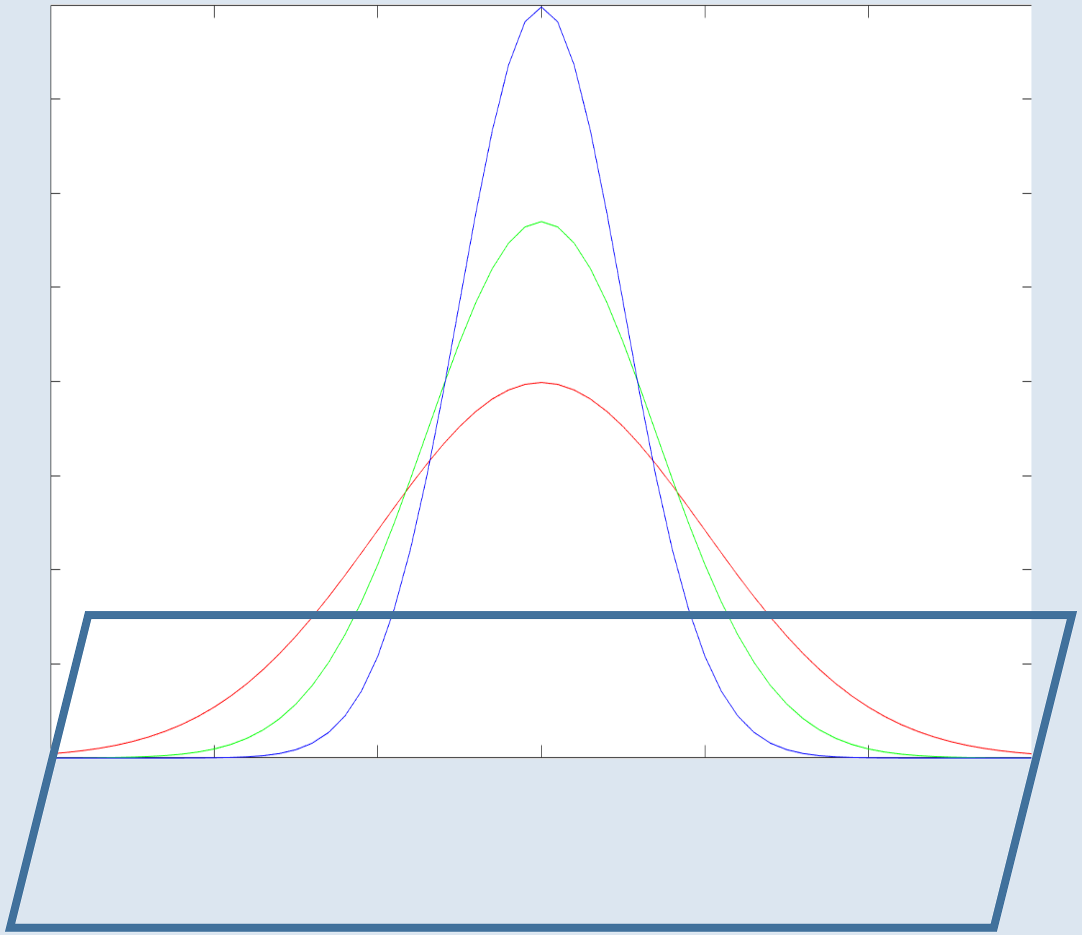
$$X_K(n,m) = \log\left(f_{K_{n,m}}\right) - \sum_{k=1}^{l} w_k \log\left(\left[\left(y_{\sigma_k} * f_K\right)_{n,m}\right]\right)$$

$$y_{\sigma_1,\sigma_2}(n,m) = A.e^{-\left[\frac{(n-n_0)^2}{2\sigma_1^2}+\frac{(m-m_0)^2}{2\sigma_2^2}\right]};$$

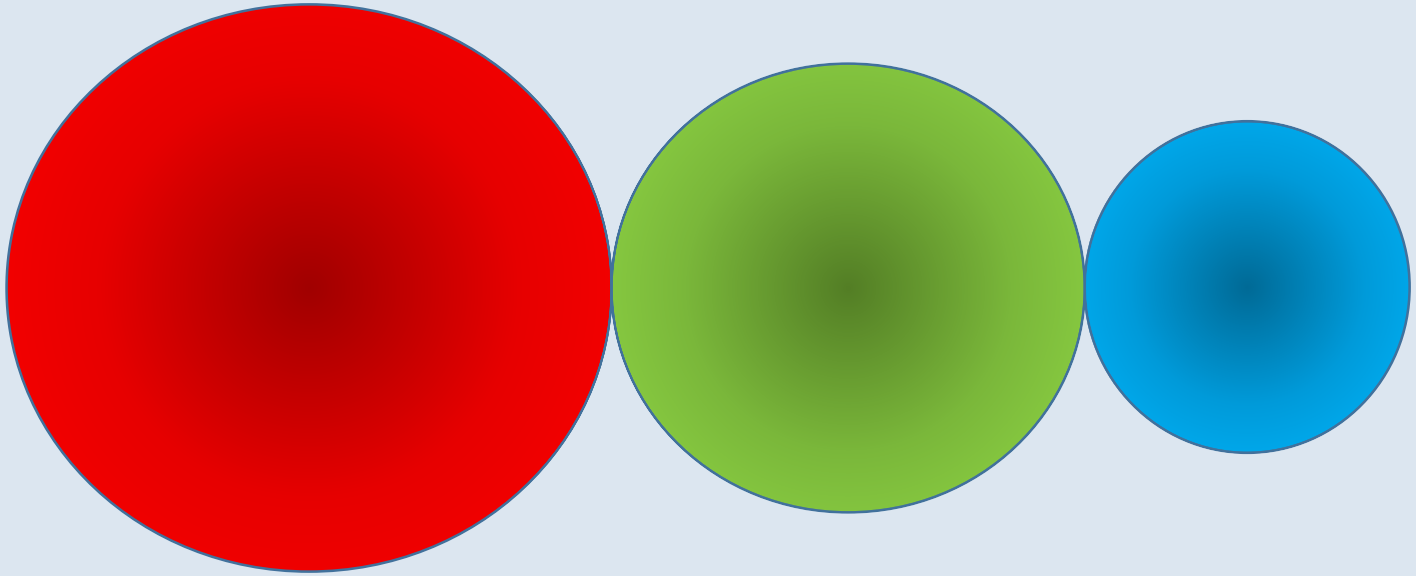
$$n = 0,1,\dots,N; m = 0,1,\dots,M;$$

$$A = \left(\sum_{n=0}^{N-1} e^{-\frac{(n-n_0)^2}{2\sigma_1^2}}\right)^{-1}\left(\sum_{m=0}^{M-1} e^{-\frac{(m-m_0)^2}{2\sigma_2^2}}\right)^{-1}$$

Multi-scale Retinex Algorithm (MSR)



Gaussian Beam - $TEM\ Mode$



$$\boldsymbol{\theta} = \frac{\lambda}{\boldsymbol{\pi\omega_0}}$$

MSR with Color-correction

Color-correction function is expressed as

$$C_K(n,m) = B + \beta\left[\log(f_K)_{n,m} - \log(f_{gray})_{n,m}\right]; B = 125\log(\alpha);\ \alpha = 125$$

where $f_{gray} = \frac{(R+G+B)}{3}$.

The MSR with color correction is expressed as

$$\hat{X}_K(n,m) = C_K(n,m).X_K(n,m)$$



Enhancement Results

Original Image | **MSR + Color-correction** | **2-D QDFT Method** | **Transformation Model Method**

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

***Figure 1**: (a) Original Image "fish.jpg"; (b) color-correction of image in (a) by multiscale retinex; (c) Alpha-rooting by two-side 2-D QDFT with alpha = 0.73; (d) the alpha-rooting with alpha = 0.8 on transformed 2-D grayscale image and then converting back to color image. *Courtesy: Photo from [10].*

Enhancement Results

Original Image | MSR + Color-correction | 2-D QDFT Method | Transformation Model Method

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

***Figure 2**: (a) Original Image "sculpture.jpg;" (b) color-correction of image in (a) by multiscale retinex; (c) the alpha-rooting by two-side 2-D QDFT with alpha = 0.83; (d) the alpha-rooting with alpha = 0.85 on transformed 2-D grayscale image and then converting back to color image. *Courtesy: Photo from [10].*

Enhancement Results

Original Image

(a)

MSR + Color-correction

(b)

2-D QDFT Method

(c)

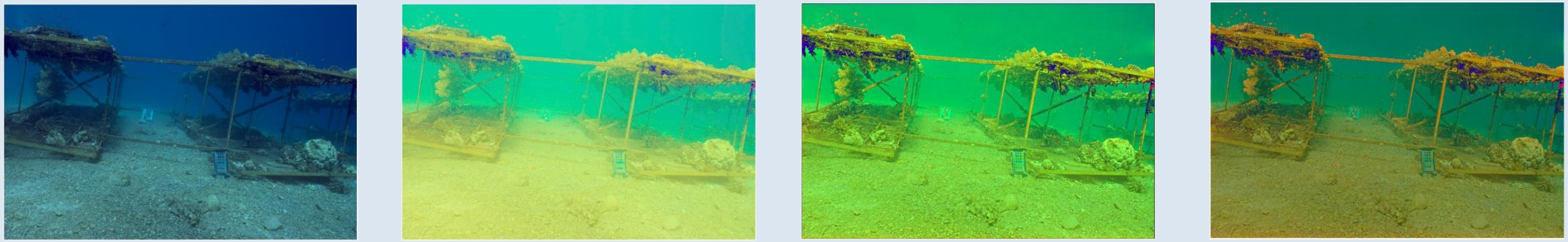
Transformation Model Method

(d)

Figure 3: *(a) Original Image “planktons.jpg”; (b) Color-correction of image in (a) by multiscale retinex; (c) Alpha-rooting by two-side 2-D QDFT with alpha = 0.92; (d) Alpha-rooting with alpha = 0.93 on transformed 2-D grayscale image and then converting back to color image. *Courtesy: Photo from [10].*

Enhancement Results

Original Image | **MSR + Color-correction** | **2-D QDFT Method** | **Transformation Model Method**



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

Figure 4*: (a) Original Image "tent.jpg;" (b) Color-correction of image in (a) by multiscale retinex; (c) Alpha-rooting by two-side 2-D QDFT with alpha = 0.86; (d) Alpha-rooting with alpha = 0.87 on transformed 2-D grayscale image and then converting back to color image. *Courtesy: Photo from [10].*

Enhancement Results

Original Image

(a)

MSR + Color-correction

(b)

2-D QDFT Method

(c)

Transformation Model Method

(d)

Figure 5: *(a) Original Image "ship_wreck.jpg;" (b) Color-correction of image in (a) by multiscale retinex; (c) Alpha-rooting by two-side 2-D QDFT with alpha = 0.93; (d) Alpha-rooting with alpha = 0.94 on transformed 2-D grayscale image and then converting back to color image. *Courtesy: Photo from [10].*

Enhancement Results

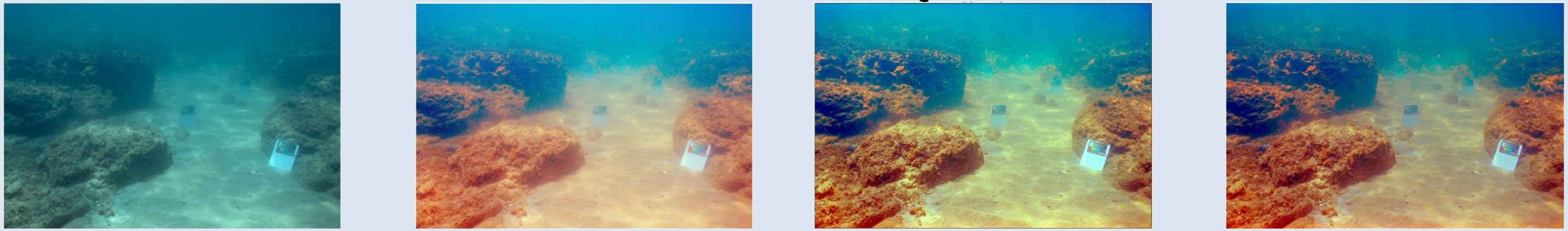
Original Image | **MSR + Color-correction** | **2-D QDFT Method** | **Transformation Model Method**

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

Figure 6: (a) Original Image "corals.jpg;" (b) Color-correction of image in (a) by multiscale retinex; (c) Alpha-rooting by two-side 2-D QDFT with alpha = 0.87; (d) Alpha-rooting with alpha = 0.88 on transformed 2-D grayscale image and then converting back to color image. *Courtesy: Photo from [10].*

Enhancement Results

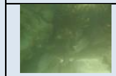
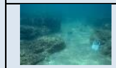
Original Image | MSR + Color-correction | 2-D QDFT Method | Transformation Model Method



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

Figure 7: *(a) Original Image "rocks.jpg"*; (b) Color-correction of image in (a) by multiscale retinex; (c) Alpha-rooting by two-side 2-D QDFT with alpha = 0.9; (d) Alpha-rooting with alpha = 0.9 on transformed 2-D grayscale image and then converting back to color image. *Courtesy: Photo from [9].*

CEME Values

Original Images	Original Image	Color-correction by Multiscale Retinex	Alpha-rooting by 2-D QDFT	Alpha-rooting method on transformed 2-D grayscale image model
	CEME			
	18.0237	6.1704	20.3362 (alpha = 0.73)	20.9267 (alpha = 0.8)
	27.9550	9.4850	17.5209 (alpha = 0.83)	17.4997 (alpha = 0.85)
	11.6103	15.8916	23.3601 (alpha = 0.92)	23.1925 (alpha = 0.93)
	21.9634	12.9805	19.3646 (alpha = 0.86)	16.7009 (alpha = 0.87)
	37.0770	13.4596	17.7915 (alpha = 0.93)	17.7398 (alpha = 0.94)
	22.4217	7.9381	11.7513 (alpha = 0.87)	10.9437 (alpha = 0.88)
	17.7172	10.6056	12.1283 (alpha = 0.9)	12.3562 (alpha = 0.9)

Summary

A new Enhancement Method is proposed for enhancing the quality of Underwater Color images, Enhancement by Two-side 2-D Quaternion Discrete Fourier Transform.

The enhanced image are giving good enhancement results, with reference to the metric, Color Enhancement Measure Estimation (CEME). CEME values are high for enhanced images.

The proposed image is compared with another enhancement method by transforming the color-image to 2-D grayscale image and then performing the Alpha-rooting method by 2-D DFT.

Pre-processing of the underwater images are done by Multiscale Retinex (MSR) and color-correction.



A few Selected References

[1] A.M. Grigoryan, S.S. Agaian, Practical Quaternion and Octonion Imaging With MATLAB, SPIE PRESS, 2018.

[2] A. M. Grigoryan, S.S. Agaian, “Quaternion Fourier transform based medical image enhancement centered on Cellular Phone technology”, SPIE Proceedings 2016.

[3] A.M. Grigoryan and S.S. Agaian, "Retooling of color imaging in the quaternion algebra," Applied Mathematics and Sciences: An International Journal, vol. 1, no. 3, pp. 23-39, December 2014

[4] A.M. Grigoryan, J. Jenkinson and S.S. Agaian, “Quaternion Fourier transform based alpha-rooting method for color image measurement and enhancement,” SIGPRO-D-14-01083R1, Signal Processing, vol. 109, pp. 269-289, April 2015, (doi: 10.1016/j.sigpro.2014.11.019).

[5] F.T. Arslan and A.M. Grigoryan, (2006) “Fast splitting alpha-rooting method of image enhancement: Tensor representation,” IEEE Trans. on Image Processing, vol. 15, no. 11, pp. 3375-3384.

[6] T.A. Ell, N. Bihan and S.J. Sangwine, “Quaternion Fourier transforms for signal and image processing,” Wiley NJ and ISTE UK, 2014 s

[7] Vanessa Pateman, Color Correction for Underwater Photography.

[8] D. Berman, T. Treibitz, S. Avidan, “Diving into Haze-Lines: Color Restoration of Underwater Images”, BMVC 2017.

[9] C.-Yi Li, Ji-C. Guo, R.-M. Cong, Y.-W. Pang, B. Wang, “Underwater Image Enhancement by Dehazing With Minimum Information Loss and Histogram,” IEEE Transactions On Image Processing, Vol. 25, No. 12, December 2016.

Thank You

Questions ?

Please