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

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Outline

1. Introduction.
2. Enhancement by Alpha-rooting by Two-side 2-D Quaternion Discrete Fourier Transform.
3. Enhancement by Transforming the color-image to 2-D grayscale image, and performing Alpha-rooting method by 2-D DFT.
5. Pre-processing method by Multi-scale Retinex Algorithm (MSR) and color-correction Method.
6. Enhancement Results.
7. Summary.
8. References.
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

- Courtesy: 1. Vanessa Pateman, Color Correction for Underwater Photography
  2. Oceanservice.NOAA.gov
A few Raw-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

\[ |F_{p,s}| \rightarrow |F_{p,s}|^\alpha, \ 0 < \alpha < 1 \]

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

\[ F_{p,s} = \sum_{n=0}^{N-1} \sum_{m=0}^{M-1} W_{jn} f_{n,m} W_{km}^{ms} \]

\[ f_{n,m} = \frac{1}{NM} \sum_{p=0}^{N-1} \sum_{s=0}^{M-1} W_{jn}^{-np} F_{p,s} W_{km}^{-ms} \]

\[ W_{jn}^t = \exp \left( -\frac{j2\pi t}{N} \right) = \cos \left( \frac{2\pi t}{N} \right) - jsin \left( \frac{2\pi t}{N} \right), \]
\[ t = 0,1, ..., (N - 1), \]

\[ W_{km}^t = \exp \left( -\frac{k2\pi t}{M} \right) = \cos \left( \frac{2\pi t}{M} \right) - k\sin \left( \frac{2\pi t}{M} \right), \]
\[ t = 0,1, ..., (M - 1). \]
Two-sided 2-D Quaternion Discrete Fourier Transform

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

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

\[ W_j^t = \exp \left( -j \frac{2\pi t}{N} \right) = \cos \left( \frac{2\pi t}{N} \right) - j\sin \left( \frac{2\pi t}{N} \right), \quad t = 0, 1, ..., (N - 1), \]

\[ W_k^t = \exp \left( -k \frac{2\pi t}{M} \right) = \cos \left( \frac{2\pi t}{M} \right) - k\sin \left( \frac{2\pi t}{M} \right), \quad t = 0, 1, ..., (M - 1). \]
Two-side 2-D QDFT

• $F = [\cos(\varphi) - j\sin(\varphi)]q[\cos(\varphi) - k\sin(\varphi)]$

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

• $F = e(CGrayC + SGreenC + CBlueS + SRedS) + i(CRedC - SBlueC - CGreenS + SGrayS) + j(CGreenC - SGrayC + CRedS - SBlueS) + k(CBlueC + SRedC - CGrayS - SGreenS)$
Two-side 2-D QDFT

\[ F = \{\cos(\varphi) - j\sin(\varphi)\}q\{\cos(\varphi) - k\sin(\varphi)\} \]

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

\[ F = e(CGrayC + SMagentaC + CYellowS + SCyanS) + i(CCyanC - SYellowC - CMagentaS + SGrayS) + j(CMagentaC - SGrayC + CCyanS - SYellowS) + k(CYellowC + SCyanC - CGrayS - SMagentaS) \]
Enhancement by Transformation Model

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

Transformation Model $2 \times 2$, $2 \times 3$, row, and column.
**Transformation of 3 or 4 Channel color-image to 2-D grayscale image**

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## 2×2 Transformation Model

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Alpha-Rooting by 2-D DFT

\[ |F_{p,s}| \rightarrow |F_{p,s}|^\alpha, \ 0 < \alpha < 1 \]
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)

\[ f \rightarrow \hat{f} \]

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

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

\[ \text{Color-image } f_{n,m} \rightarrow \text{2D-QDFT } F_{p,s} \rightarrow \hat{F}_{p,s} = |F_{p,s}|^{\alpha - 1} F_{p,s} \rightarrow \text{Inverse QDFT } \hat{f}_{n,m} \]
Retinex Algorithm

\[ f(n, m) = r(n, m) \cdot l(n, m); \]
\[ n = 0, 1, ..., N - 1, m = 0, 1, ..., M - 1 \]

\[ \log[r(n, m)] = \log[f(n, m)] - \log[l(n, m)] \]
Multi-scale Retinex Algorithm

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

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

\[ n = 0, 1, ..., N; m = 0, 1, ..., M; \]

\[ A = \left( \sum_{n=0}^{N-1} e^{-\left(\frac{(n-n_0)^2}{2\sigma_1^2}\right)} \right)^{-1} \left( \sum_{m=0}^{M-1} e^{-\left(\frac{(m-m_0)^2}{2\sigma_2^2}\right)} \right)^{-1} \]
Multi-scale Retinex Algorithm (MSR)
Gaussian Beam - *TEM Mode*

\[ \theta = \frac{\lambda}{\pi \omega_0} \]
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

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

**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

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

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

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

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].
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

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<th>Original Images</th>
<th>Original Image</th>
<th>Color-correct by Multiscale Retinex</th>
<th>Alpha-rooting by 2-D QDFT</th>
<th>Alpha-rooting method on transformed 2-D grayscale image model</th>
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<td>20.3362 (alpha = 0.73)</td>
<td>20.9267 (alpha = 0.8)</td>
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<td>27.9550</td>
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<td>17.7172</td>
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<td>12.1283 (alpha = 0.9)</td>
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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


Thank You
Questions?

Please